



Sturdevant's
Art and Science of
OPERATIVE DENTISTRY

Sixth Edition

Harald O. Heymann
Edward J. Swift, Jr.
André V. Ritter

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*This book is dedicated to the continued advancement of operative dentistry.
While working on the new edition, the primary goal of the editors and
contributors was to provide a book that is a reliable and trustworthy resource for our students,
as well as our teaching and practicing colleagues.*

*In addition, we dedicate the sixth edition to the editors and
contributors who have come before us.
Much of their work can still be found in this edition.*

*Finally, we dedicate this book to Dr. Clifford Sturdevant, who was a true leader in dental education,
and a driving force for the first three editions of this book.*

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Foreword

Not long ago I picked up and read Charles Pappas' lively 1983 account of "The Life and Times of G.V. Black."* I rapidly marveled at the scintillating accomplishments of a man whose only dental training comprised a few weeks as an apprentice to a Mount Sterling, Illinois, dentist. Often referred to as the father of Operative Dentistry, Greene Vardiman Black was born in 1836, and opened his first dental practice in 1857, in Winchester, Illinois. Coincident with starting his practice, G.V. Black imposed on himself a rigorous self-education routine, focused primarily on the basic sciences that were emerging and/or developing so impressively during most of the 1800s. Utilizing a few precious hours each evening, after his children had been sent to bed, Black began intensive studies of chemistry, microbiology, and pathology. At that time most of the books and scientific essays available to Black were authored by Europeans, some writing in English, but many in Latin, German, and French. Consequently, Black studied these foreign languages until he was sufficiently proficient to absorb the science he needed in order to advance in his chosen professional and early academic life.

Beginning in the mid-1860s, Black began to apply what he drew from his basic science studies, and started to publish increasingly learned articles about various facets of Dentistry. With his dental experience growing, and his academic capabilities ever more obvious, Black was invited in 1866 to become a founding trustee of the Missouri Dental College, where he subsequently taught from 1870 to 1881. In 1877 Black was awarded an honorary DDS by the Missouri Dental College, and in 1884 he received an honorary MD degree from the Chicago Medical College (later to become Northwestern University Medical School). In 1883 Black had begun to teach at the Chicago College of Dental Surgery as Professor of Dental Pathology and Bacteriology. In 1897, G.V. Black became Dean and Professor of Operative Dentistry, Dental Pathology and Bacteriology at the Northwestern University Dental School, a position he held for 17 years. Black died on August 31, 1915.

Black himself published six books, of which his magnum opus was *Operative Dentistry: Volumes I and II* (1908). Quickly receiving wide acclaim, that work was revised and republished seven times over the period of a half-century. What would G. V. Black say if today he were handed, and asked for comments on, the sixth edition of *Sturdevant's Art and Science of Operative Dentistry*? My guess is that Black would, first of all, express quiet satisfaction that as a science Operative Dentistry has made so much progress that some of the key, enduring principles he enunciated were no longer relevant, having been overtaken by modern science and technology. An example would be Black's famous principle of extension for prevention, a dictum no longer followed because of the improvements in

oral hygiene, fluoride therapy, remineralization formulations, and fissure sealants, that together have greatly reduced the incidence and severity of recurrent caries.

I think that Black would also be pleased that the authors collaborating on *Sturdevant's* sixth edition have retained the impressively comprehensive nature of this textbook. With his own background in microbiology and pathology, Black would have seen as very relevant the extensive coverage devoted to anatomy, histology, physiology, microbiology and cariology within the Operative Dentistry framework. For example, and as is more apparent than ever, modern cariology has become a fast moving field with changing ideas on etiology, detection, measurement, risk assessment, prevention, and treatment of caries. *Sturdevant's* editors and co-authors fully immerse themselves in such topics, and skillfully blend and present the established understandings with the new, emerging scientific developments.

Black was also a student of chemistry and materials science. He carefully studied the chemistry of dental cements, and he shared his findings via many scientific publications. Black conducted numerous studies on amalgams, their composition and properties. These experiments were also written up and published. Because of the central place amalgams held in dental practice a century ago, I think Black would be astounded by the enormous role adhesive resins and various composite restorative materials play today in contemporary Operative Dentistry. The transition from amalgam to non-metallic restorations is far from complete, yet the adhesive dentistry revolution has been accompanied by modifications of G. V. Black's venerable six principles of cavity preparation, as originally codified in 1908. Black would surely think of this as a definitive and welcome sign of dentistry's scientific progress, a goal for which he always advocated.

Black would likely be impressed by the functional and greatly improved esthetic results achievable with the modern composite restorative materials. Yet it is probably safe to assume that Black the scientist would urge even more research to develop still better dental materials with which to treat patients, and thereby improve the public's health. That is the type of challenge the sixth edition of *Sturdevant's Operative Dentistry* has embraced, and represents the type of vision and spirit that guided the major revisions contained within this book.

G.V. Black was a consummate operative dentist, a life-long scientist, and a widely respected teacher. He was aware of the importance of scientific papers and well-illustrated textbooks as critical learning materials for the dental student, and the conscientious practitioner alike. Black would likely, therefore, appreciate and applaud the well organized structure and the up-to-date content of *Sturdevant's* sixth edition. (The first edition appeared in 1968.) It is also likely that after a stellar academic career, G.V. Black would lightly tug on his beard and smile in admiration as his eyes fell on the electronic

*Pappas, C.N. *The Life and Times of G.V. Black*. Quintessence Publishing Co., Chicago, 1983.

renderings and colorful digital images that grace *Sturdevant's* sixth edition. Furthermore, the always inquisitive Professor Black would surely want to access the website that accompanies this book, and view for himself the supplemental book chapters, videos, and weblinks that round out a truly comprehensive Operative Dentistry learning system. For the dental students who may immerse themselves in this book, and for practitioners who will wish to use it as the standard reference to the subject, the skillful employment of digital tools and technology

will be welcome, and will make this superb master work more comprehensive, more accessible, and surely more valued.

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Preface

Sturdevant's Art and Science of Operative Dentistry is considered to be the most comprehensive operative dentistry text on the market. Drawing from both theory and practice, and supported by extensive clinical and laboratory research, it presents a clearly detailed, heavily illustrated step-by-step approach to conservative restorative and preventive dentistry. Based upon the principle that dental caries is a disease, the book provides both a thorough understanding of caries and an authoritative approach to its treatment and prevention. Throughout the book, emphasis is placed on the importance of treating the underlying causes of the patient problem(s), not just restoring the damage that has occurred. It is organized in a sequential format; the early chapters present the necessary general information while the later chapters are specifically related to the practice of operative dentistry, including conservative esthetic procedures.

The sixth edition of *Sturdevant's Art and Science of Operative Dentistry* has been **significantly revised** in order to streamline the text and improve readability. The order of chapters has been reorganized, redundant and outdated information has been deleted, and several chapters have been moved to the new companion website. In addition, the book is now in **full color**. The line art for the book has been completely redrawn in full color to better show techniques and detail, and new, full color photos have been added where appropriate. Conservative esthetic procedures, which are covered at length, especially benefit from the addition of color.

The sixth edition is much more than just a printed book, however. The new **companion website** features the entire text online, plus six chapters that are exclusively online. In addition, videos demonstrate key procedures addressed in the text. See the inside front cover for a complete listing of the chapters and videos available.

New to this Edition

- Streamlined for improved readability
- Full color
- Companion website

Chapter Synopses

CHAPTER 1: CLINICAL SIGNIFICANCE OF DENTAL ANATOMY, HISTOLOGY, PHYSIOLOGY, AND OCCLUSION

This chapter provides a thorough understanding of the histology, physiology, and occlusal interactions of the dentition and supporting tissues.

CHAPTER 2: DENTAL CARIES: ETIOLOGY, CLINICAL CHARACTERISTICS, RISK ASSESSMENT, AND MANAGEMENT

This chapter presents basic definitions and information on: dental caries, clinical characteristics of the caries lesions, caries risk assessment, and caries management in the medical model, all in the context of clinical operative dentistry.

CHAPTER 3: PATIENT ASSESSMENT, EXAMINATION AND DIAGNOSIS, AND TREATMENT PLANNING

This chapter provides an overview of the process through which a clinician completes a patient assessment, clinical examination, diagnosis, and treatment plan to operative dentistry procedures.

CHAPTER 4: FUNDAMENTAL CONCEPTS OF ENAMEL AND DENTIN ADHESION

The chapter presents the basic concepts of adhesion, along with detailed descriptions of the factors affecting enamel and dentin adhesion, and the different approaches for resin bonding to tooth structure.

CHAPTER 5: FUNDAMENTALS OF TOOTH PREPARATION AND PULP PROTECTION

This chapter emphasizes procedural organization for tooth preparation and associated nomenclature, including the historical classification of carious lesions.

CHAPTER 6: INSTRUMENTS AND EQUIPMENT FOR TOOTH PREPARATION

This chapter reviews hand instruments for cutting, powered cutting equipment, and rotary cutting instruments. It also looks at cutting mechanisms, as well as the hazards of cutting instruments, and the precautions that should be taken when using them.

CHAPTER 7: PRELIMINARY CONSIDERATIONS FOR OPERATIVE DENTISTRY

This chapter addresses routine, chairside, pre-operative procedures (before actual tooth preparation). Primarily, these procedures include patient and operator positions and isolation of the operating field.

CHAPTER 8: INTRODUCTION TO COMPOSITE RESTORATIONS

This chapter provides a general introduction to composite restorations (the predominant direct esthetic restorative material), and describes the properties and clinical uses of composite materials. There is also information about various types of composites, including macrofill, microfill, hybrid, nanofill, nanohybrid, flowable, and packable types as well as other direct tooth-colored restorative materials such as glass ionomers and resin-modified glass ionomers. A brief historical perspective of other tooth-colored materials that may still be encountered clinically is provided.

CHAPTER 9: CLASS III, IV, AND V DIRECT COMPOSITE AND GLASS IONOMER RESTORATIONS

This chapter presents the specific rationales and techniques for use of direct composite resin in Class III, IV, and V direct composite restorations. It also presents information about any differences in these classes of restorations when a glass ionomer material is used for the restoration.

CHAPTER 10: CLASS I, II, AND VI DIRECT COMPOSITE RESTORATIONS AND OTHER TOOTH-COLORED RESTORATIONS

This chapter presents techniques for restoring the occlusal (including the occlusal thirds of facial and lingual surfaces) and proximal surfaces of posterior teeth with direct composite resin and other directly placed tooth-colored materials. The least invasive treatments are presented first, followed by progressively more involved methods of treatment. Consequently, first the rationale and technique for pit-and-fissure sealants, preventive resin or conservative composite restorations, and Class VI composite restorations are presented. Next, Class I and II composite restorations are presented, followed by composite foundations.

CHAPTER 11: INDIRECT TOOTH-COLORED RESTORATIONS

This chapter reviews the indications, contraindications, advantages, disadvantages, and clinical techniques for Class I and II indirect tooth-colored restorations, restorations which are made on a replica of the prepared tooth in a dental laboratory or by using computer-aided design/computer-assisted manufacturing (CAD/CAM) either at chairside or in the dental laboratory.

CHAPTER 12: ADDITIONAL CONSERVATIVE ESTHETIC PROCEDURES

This chapter presents conservative esthetic procedures in the context of their clinical applications. Fundamental principles in conservative esthetic dentistry are reviewed in detail. A complete review of esthetic procedures is included, ranging from conservative treatments, such as vital bleaching, to more extensive procedures involving etched porcelain veneers. Detailed step-by-step procedures are systematically presented, and exquisitely illustrated.

CHAPTER 13: INTRODUCTION TO AMALGAM RESTORATIONS

This chapter presents the fundamental concepts of amalgam restoration, including the types of amalgam restorations, properties, clinical procedures, controversial issues, and safety.

CHAPTER 14: CLASS I, II, AND VI AMALGAM RESTORATIONS

This chapter presents the techniques and procedures for Class I, II, and VI amalgam restorations. Class I restorations restore defects on the occlusal surface of posterior teeth, the occlusal two thirds of the facial and lingual surface of molars, and the lingual surfaces of maxillary anterior teeth. Class II restorations restore defects that affect one or both of the proximal surfaces of the posterior teeth. Class VI restorations restore rare defects affecting the cusp tips of posterior teeth or the incisal edges of anterior teeth.

CHAPTER 15: CLASS III AND V AMALGAM RESTORATIONS

This chapter presents information about Class III and V amalgam restorations. Class III restorations are indicated for defects located on the proximal surface of anterior teeth that do not affect the incisal edge. Part of the facial or the lingual surfaces also may be involved in Class III restorations. Class V restorations are indicated to restore defects on the facial or lingual cervical third of any tooth.

CHAPTER 16: COMPLEX AMALGAM RESTORATIONS

This chapter describes the use of dental amalgam for complex direct posterior restorations. Complex posterior restorations are used to replace missing tooth structure of teeth that have fractured or are severely involved with caries or existing restorative material. These restorations usually involve the replacement of one or more missing cusps and require additional means of retention.

CHAPTER 17: CLASS II CAST METAL RESTORATIONS

This chapter provides thorough coverage of the entire cast metal restoration procedure, with information on impression, temporary and working model procedures.

Acknowledgments

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- Our spouses and families for the continual love, understanding, and support during this revision.
- The UNC Operative Dentistry staff, adjunct faculty, and graduate students whose support of the authors and editors helped make the book possible.
- John Dolan, Courtney Sprehe, Kari Terwelp, Sara Alsup, and Jaime Pendill at Elsevier for the support, encouragement, and expertise during the revision process. Their guidance and ideas have helped us to provide a more streamlined, readable book.

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Clinical Significance of Dental Anatomy, Histology, Physiology, and Occlusion

Lee W. Boushell, John R. Sturdevant

A thorough understanding of the histology, physiology, and occlusal interactions of the dentition and supporting tissues is essential for the restorative dentist. Knowledge of the structures of teeth (enamel, dentin, cementum, and pulp) and their relationships to each other and to the supporting structures is necessary, especially when treating dental caries. The protective function of the tooth form is revealed by its impact on masticatory muscle activity, the supporting tissues (osseous and mucosal), and the pulp. Proper tooth form contributes to healthy supporting tissues. The form of a tooth and its contour and contact relationships with adjacent and opposing teeth are major determinants of muscle function in mastication, esthetics, speech, and protection. The relationships of form to function are especially noteworthy when considering the shape of the dental arch, proximal contacts, occlusal contacts, and mandibular movement.

Teeth and Supporting Tissues

Dentitions

Humans have primary and permanent dentitions. The primary dentition consists of 10 maxillary and 10 mandibular teeth. Primary teeth exfoliate and are replaced by the permanent dentition, which consists of 16 maxillary and 16 mandibular teeth.

Classes of Human Teeth: Form and Function

Human teeth are divided into classes on the basis of form and function. The primary and permanent dentitions include the incisor, canine, and molar classes. The fourth class, the premolar, is found only in the permanent dentition (Fig. 1-1). Tooth form predicts the function of teeth; class traits are the characteristics that place teeth into functional categories.

Because the diet of humans consists of animal and plant foods, the human dentition is called *omnivorous*.

Incisors

The incisors are located near the entrance of the oral cavity and function as cutting or shearing instruments for food (see Fig. 1-1). From a proximal view, the crowns of these teeth have a relatively triangular shape, with a narrow incisal surface and a broad cervical base. During mastication, incisors are used to shear (cut through) food. Incisors are essential for the proper esthetics of the smile, facial soft tissue contours (e.g., lip support), and speech (phonetics).

Canines

Canines possess the longest roots of all teeth and are located at the corners of the dental arch. They function in the seizing, piercing, tearing, and cutting of food. From a proximal view, the crown also has a triangular shape, with a thick incisal ridge. The anatomic form of the crown and the length of the root make these teeth strong, stable abutment teeth for a fixed or removable prosthesis. Canines not only serve as important guides in occlusion because of their anchorage and position in the dental arches but also play a crucial role (along with the incisors) in the esthetics of the smile and lip support (see Fig. 1-1).

Premolars

Premolars serve a dual role: (1) they are similar to canines in the tearing of food, and (2) they are similar to molars in the grinding of food. Although the first premolars are angular, with their facial cusps resembling the canines, the lingual cusps of the maxillary premolars. The occlusal surfaces present a series of curves in the form of concavities and convexities

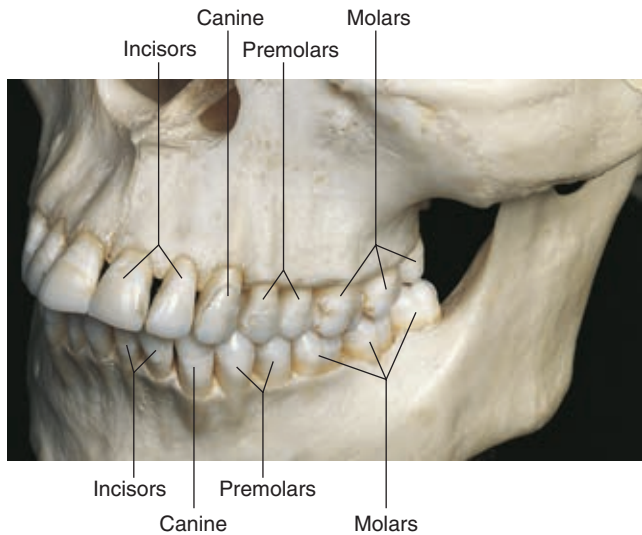


Fig. 1-1 Maxillary and mandibular teeth in maximum intercuspal position. The classes of teeth are incisors, canines, premolars, and molars. Cusps of mandibular teeth are one-half cusp anterior of corresponding cusps of teeth in the maxillary arch. (From Logan BM, Reynolds P, Hutchings RT: McMinn's color atlas of head and neck anatomy, ed 4, Edinburgh, Mosby, 2010.)

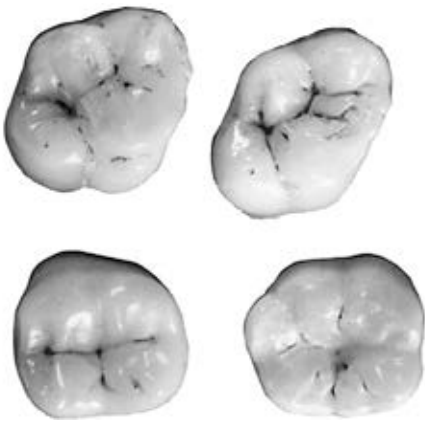


Fig. 1-2 Occlusal surfaces of maxillary and mandibular first and second molars after several years of use, showing rounded curved surfaces and minimal wear.

that should be maintained throughout life for correct occlusal contacts and function. Although less visible than incisors and canines, premolars still can play an important role in esthetics.

Molars

Molars are large, multi-cusped, strongly anchored teeth located nearest the temporomandibular joint (TMJ), which serves as the fulcrum during function. These teeth have a major role in the crushing, grinding, and chewing of food to the smallest dimensions suitable for swallowing. They are well suited for this task because they have broad occlusal surfaces and multi-rooted anchorage (Fig. 1-2 and 1-3). Premolars and molars are important in maintaining the vertical dimension of the face (see Fig. 1-1).

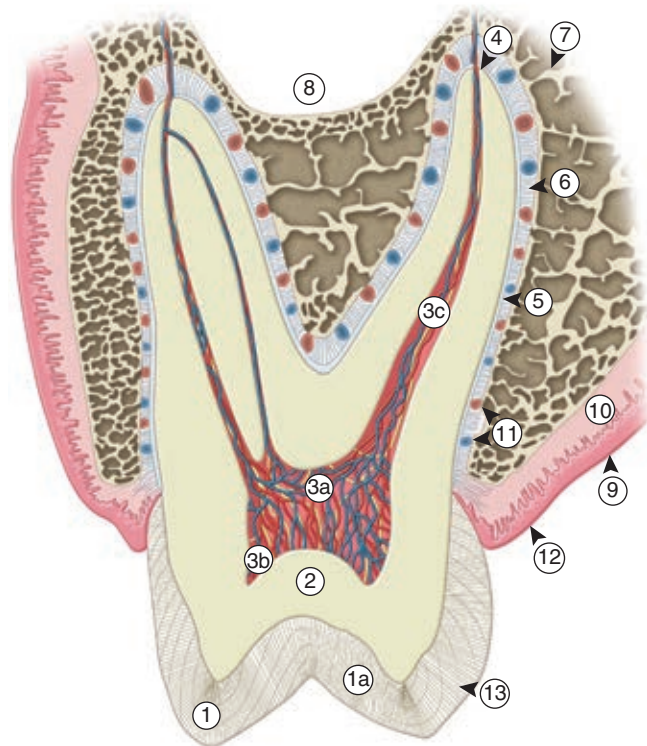


Fig. 1-3 Cross-section of the maxillary molar and its supporting structures. 1, enamel; 1a, gnarled enamel; 2, dentin; 3a, pulp chamber; 3b, pulp horn; 3c, pulp canal; 4, apical foramen; 5, cementum; 6, periodontal fibers in periodontal ligament; 7, alveolar bone; 8, maxillary sinus; 9, mucosa; 10, submucosa; 11, blood vessels; 12, gingiva; 13, striae of Retzius.

Structures of Teeth

Teeth are composed of enamel, the pulp–dentin complex, and cementum (see Fig. 1-3). Each of these structures is discussed individually.

Enamel

Enamel formation, *amelogenesis*, is accomplished by cells called *ameloblasts*. These cells originate from the embryonic germ layer known as *ectoderm*. Enamel covers the anatomic crown of the tooth and varies in thickness in different areas (see Fig. 1-3). It is thicker at the incisal and occlusal areas of a tooth and becomes progressively thinner until it terminates at the cemento–enamel junction (CEJ). The thickness also varies from one class of tooth to another, averaging 2 mm at the incisal ridges of incisors, 2.3 to 2.5 mm at the cusps of premolars, and 2.5 to 3 mm at the cusps of molars. The cusps of posterior teeth begin as separate ossification centers, which form lobes that coalesce. Enamel usually decreases in thickness toward the junction of these developmental features and can approach zero where the junction is fissured (noncoalesced).

Chemically, enamel is a highly mineralized crystalline structure. Hydroxyapatite, in the form of a crystalline lattice, is the largest mineral constituent (90%–92% by volume). Other minerals and trace elements are present in smaller amounts. The remaining constituents of tooth enamel include organic matrix proteins (1%–2%) and water (4%–12%) volume.

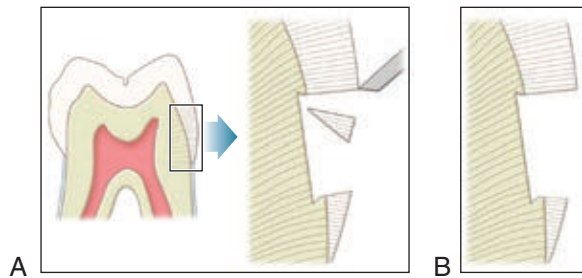


Fig. 1-4 **A**, Enamel rods unsupported by dentin are fractured away readily by pressure from hand instrument. **B**, Cervical preparation showing enamel rods supported by dentin.

Structurally, enamel is composed of millions of enamel rods or prisms, which are the largest structural components, rod sheaths, and a cementing inter-rod substance in some areas. The inter-rod substance, or sheath, may be the increased spacing between crystallites oriented differently to where the “tail” portion of one rod meets the “head” portion of another. This spacing apparently is partially organic material. The rods vary in number from approximately 5 million for a mandibular incisor to about 12 million for a maxillary molar. The rods are densely packed and intertwined in a wavy course, and each extends from the DEJ to the external surface of the tooth. In general, the rods are aligned perpendicularly to the DEJ and the tooth surface in the primary and permanent dentitions except in the cervical region of permanent teeth, where they are oriented outward in a slightly apical direction. In the primary dentition, the enamel rods in the cervical and central parts of the crown are nearly perpendicular to the long axis of the tooth and are similar in their direction to permanent teeth in the occlusal two thirds of the crown. Enamel rod diameter near the dentinal borders is about 4 μm and about 8 μm near the surface. This difference accommodates the larger outer surface of the enamel crown compared with the dentinal surface at the DEJ.

Enamel is the hardest substance of the human body. Hardness can vary over the external tooth surface according to the location; also, it decreases inwardly, with hardness lowest at the DEJ. The density of enamel also decreases from the surface to the DEJ. Enamel is a rigid structure that is both strong and brittle (high elastic modulus, high compressive strength, and low tensile strength) and requires a dentin support to withstand masticatory forces. Dentin is a more flexible substance that is strong and resilient (low elastic modulus, high compressive strength, and high tensile strength), which essentially increases the fracture toughness of the more superficial enamel. Enamel rods that lack dentin support because of caries or improper preparation design are easily fractured away from neighboring rods. For optimal strength in tooth preparation, all enamel rods should be supported by dentin (Fig. 1-4).

Human enamel is composed of rods that, in transverse section, have a rounded head or body section and a tail section, forming a repetitive series of interlocking prisms. The rounded head portion of each prism (5 μm wide) lies between the narrow tail portions (5 μm long) of two adjacent prisms (Fig. 1-5). Generally, the rounded head portion is oriented in the incisal or occlusal direction; the tail section is oriented cervically.

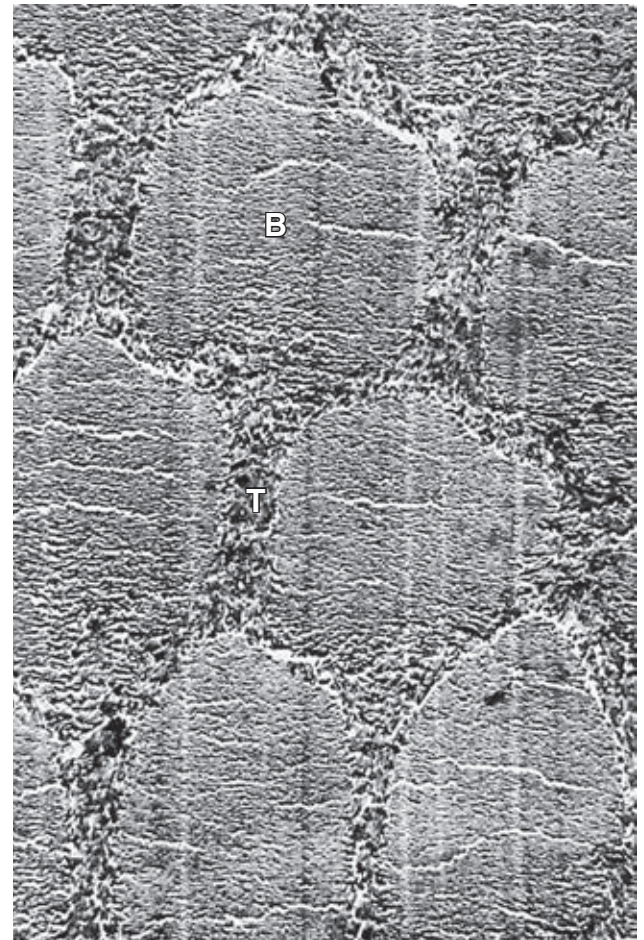


Fig. 1-5 Electron micrograph of cross-section of rods in mature human enamel. Crystal orientation is different in “bodies” (B) than in “tails” (T). Approximate level of magnification 5000 \times . (From Meckel AH, Griebstein WJ, Neal RJ: Structure of mature human dental enamel as observed by electron microscopy, Arch Oral Biol 10(5):775–783, 1965.)

The structural components of the enamel prism are millions of small, elongated apatite crystallites that vary in size and shape. The crystallites are tightly packed in a distinct pattern of orientation that gives strength and structural identity to the enamel prisms. The long axis of the apatite crystallites within the central region of the head (body) is aligned almost parallel to the rod long axis, and the crystallites incline with increasing angles (65 degrees) to the prism axis in the tail region. The susceptibility of these crystallites to acid, from either an etching procedure or caries, may be correlated with their orientation. Although the dissolution process occurs more in the head regions of the rod, the tail regions and the periphery of the head regions are relatively resistant to acid attack. The crystallites are irregular in shape, with an average length of 160 nm and an average width of 20 to 40 nm. Each apatite crystallite is composed of thousands of unit cells that have a highly ordered arrangement of atoms. A crystallite may be 300 unit cells long, 40 cells wide, and 20 cells thick in a hexagonal configuration (Fig. 1-6). An organic matrix or prism sheath also surrounds individual crystals and appears to be an organically rich interspace rather than a structural entity.

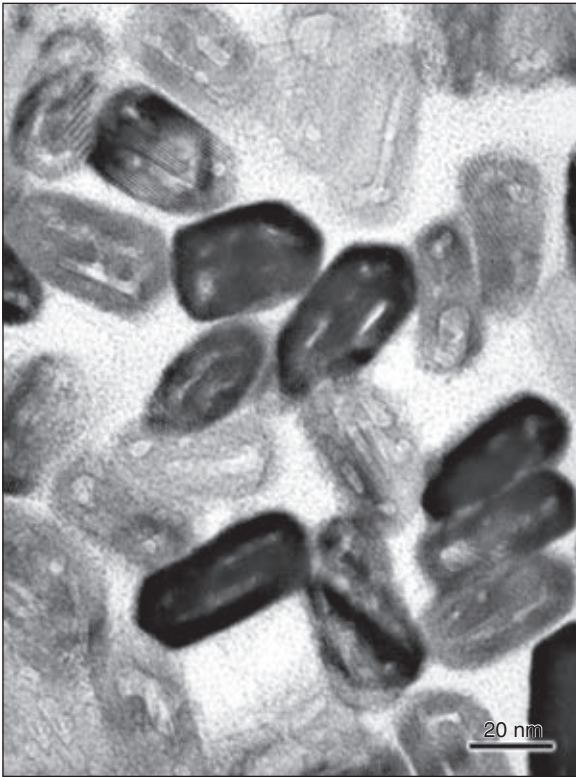


Fig. 1-6 Electron micrograph of mature, hexagon-shaped enamel crystallites. (From Nanci A: Ten Cate's oral histology: development, structure, and function, ed 7, St Louis, 2008, Mosby.)

Enamel rods follow a wavy, spiraling course, producing an alternating arrangement for each group or layer of rods as they change direction in progressing from the dentin toward the enamel surface, where they end a few micrometers short of the tooth surface. Enamel rods rarely run a straight radial course, as there is an alternating clockwise and counterclockwise deviation of the rods from the radial course at all levels of the crown. They initially follow a curving path through one third of the enamel next to the DEJ. After that, the rods usually follow a more direct path through the remaining two thirds of the enamel to the enamel surface. Groups of enamel rods may entwine with adjacent groups of rods, and they follow a curving irregular path toward the tooth surface. These constitute gnarled enamel, which occurs near the cervical regions and the incisal and occlusal areas (Fig. 1-7). Gnarled enamel is not subject to fracture as much as is regular enamel. This type of enamel formation does not yield readily to the pressure of bladed, hand-cutting instruments in tooth preparation.

The changes in direction of enamel prisms that minimize fracture in the axial direction produce an optical appearance called *Hunter-Schreger bands* (Fig. 1-8). These bands appear to be composed of alternate light and dark zones of varying widths that have slightly different permeability and organic content. These bands are found in different areas of each class of teeth. Because the enamel rod orientation varies in each tooth, Hunter-Schreger bands also have a variation in the number present in each tooth. In anterior teeth, they are located near the incisal surfaces. They increase in numbers and areas of teeth, from canines to premolars. In molars, the bands

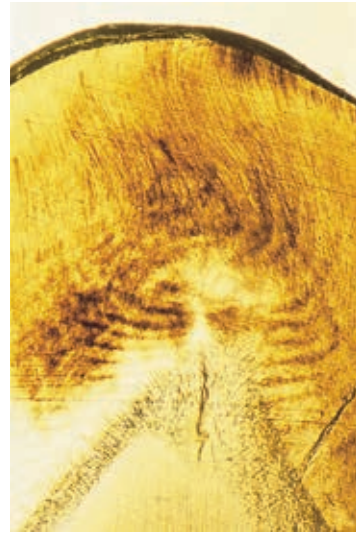


Fig. 1-7 Gnarled enamel. (From Berkovitz BKB, Holland GR, Moxham BJ: Oral anatomy, histology and embryology, ed 4, Edinburgh, 2009, Mosby.)

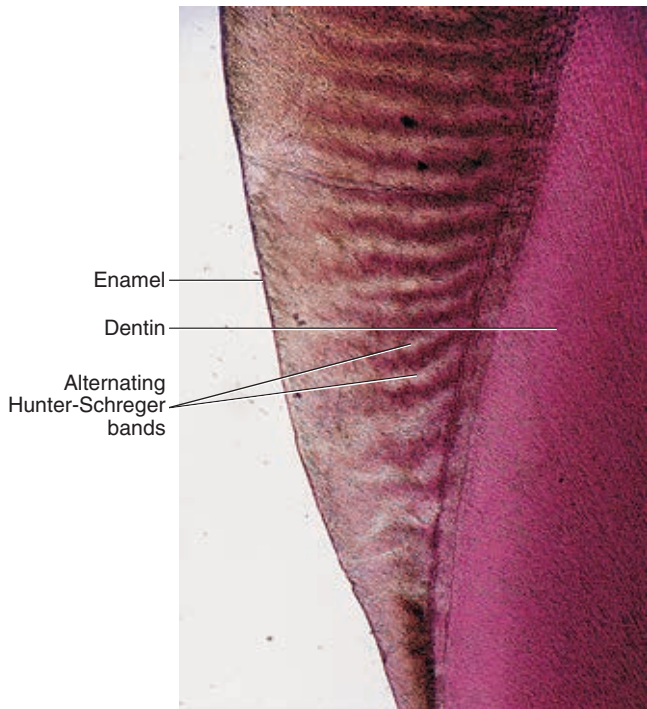


Fig. 1-8 Photomicrograph of enamel photographed by reflected light of Hunter-Schreger bands. (From Avery JK and Chiego DJ: Essentials of oral histology and embryology: A clinical approach, ed 3, St Louis, 2006, Mosby.)

occur from near the cervical region to the cusp tips. The orientation of the enamel rod heads and tails and the gnarling of enamel rods provide strength by resisting, distributing, and dissipating impact forces.

Enamel tufts are hypomineralized structures of the enamel rods and the inter-rod substance that project between adjacent groups of enamel rods from the DEJ (Fig. 1-9). These projections arise in dentin, extend into enamel in the direction of the long axis of the crown, and may play a role in the spread of dental caries. Enamel lamellae are thin, leaf-like faults

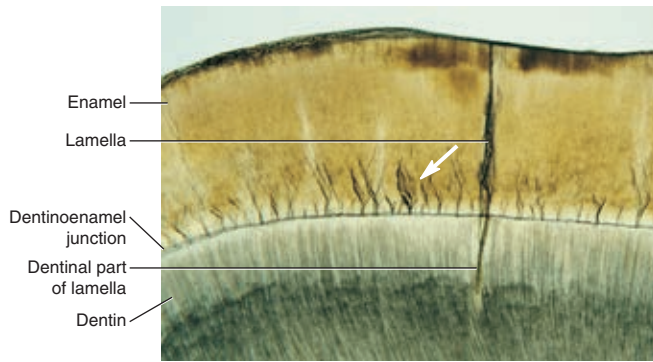


Fig. 1-9 Microscopic view through lamella that goes from enamel surface into dentin. Note the enamel tufts (arrow). (From Bath Balogh M, Fehrenbach MJ: Illustrated dental embryology, histology, and anatomy, ed 3, Saunders, 2011, St Louis. Courtesy James McIntosh, PhD, Assistant Professor Emeritus, Department of Biomedical Sciences, Baylor College of Dentistry, Dallas, TX.)

between enamel rod groups that extend from the enamel surface toward the DEJ, sometimes extending into dentin (see Fig. 1-9). They contain mostly organic material, which is a weak area predisposing a tooth to the entry of bacteria and dental caries. Enamel rods are formed linearly by successive apposition of enamel in discrete increments. The resulting variations in structure and mineralization are called *incremental striae of Retzius* and can be considered growth rings (see Fig. 1-3). In horizontal sections of a tooth, the striae of Retzius appear as concentric circles. In vertical sections, the lines traverse the cuspal and incisal areas in a symmetric arc pattern, descending obliquely to the cervical region and terminating at the DEJ. When these circles are incomplete at the enamel surface, a series of alternating grooves, called *imbrication lines of Pickerill*, are formed. The elevations between the grooves are called *perikymata*; these are continuous around a tooth and usually lie parallel to the CEJ and each other.

A structureless outer layer of enamel about 30 μm thick is found most commonly toward the cervical area and less often on cusp tips. No prism outlines are visible, and all of the apatite crystals are parallel to one another and perpendicular to the striae of Retzius. This layer, referred to as *prismless enamel*, may be more heavily mineralized. Microscopically, the enamel surface initially has circular depressions indicating where the enamel rods end. These concavities vary in depth and shape, and they may contribute to the adherence of plaque material, with a resultant caries attack, especially in young individuals. The dimpled surface anatomy of the enamel, however, gradually wears smooth with age.

The interface of enamel and dentin (dentinoenamel junction, or DEJ) is scalloped or wavy in outline, with the crest of the waves penetrating toward enamel (Fig. 1-10). The rounded projections of enamel fit into the shallow depressions of dentin. This interdigitation may contribute to the firm attachment between dentin and enamel. The DEJ is also a hypermineralized zone approximately 30 μm thick.

The occlusal surfaces of premolars and molars have grooves and fossae that form at the junction of the developmental lobes of enamel. These allow movement of food to the facial and lingual surfaces during mastication. A functional cusp that opposes a groove (fossa) occludes on enamel and inclines on each side of the groove and not in the depth of the groove.

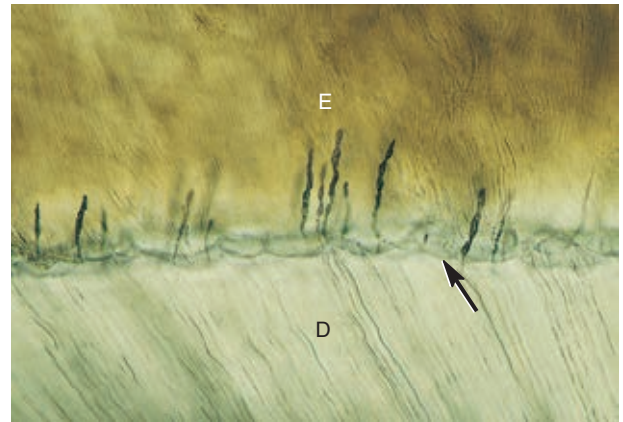


Fig. 1-10 Microscopic view of scalloped dentinoenamel junction (DEJ) (arrow). E, enamel; D, dentin. (From Bath Balogh M, Fehrenbach MJ: Illustrated dental embryology, histology, and anatomy, ed 3, Saunders, 2011, St Louis. Courtesy James McIntosh, PhD, Assistant Professor Emeritus, Department of Biomedical Sciences, Baylor College of Dentistry, Dallas, TX.)



Fig. 1-11 Fissure (f) at junction of lobes allows accumulation of food and bacteria predisposing the tooth to dental caries (c). Enamel (e); dentin (d).

This arrangement leaves a V-shaped escape path between the cusp and its opposing groove for the movement of food during chewing. Failure of the enamel of the developmental lobes to coalesce results in a deep invagination of the enamel surface and is termed *fissure*. Non-coalesced enamel at the deepest point of a fossa is termed *pit*. These fissures and pits act as food and bacterial traps that predispose the tooth to dental caries (Fig. 1-11).

Once damaged, enamel is incapable of repairing itself because the ameloblast cell degenerates after the formation of the enamel rod. The final act of the ameloblast is secretion of a membrane covering the end of the enamel rod. This layer is referred to as *Nasmyth's membrane*, or *primary enamel cuticle*. This membrane covers the newly erupted tooth and is worn away by mastication and cleaning. The membrane is replaced by an organic deposit called the *pellicle*, which is a precipitate of salivary proteins. Microorganisms may attach to the pellicle to form bacterial plaque, which, if acidogenic in nature, can be a potential precursor to dental disease.

Although enamel is a hard, dense structure, it is permeable to certain ions and molecules. The route of passage may be

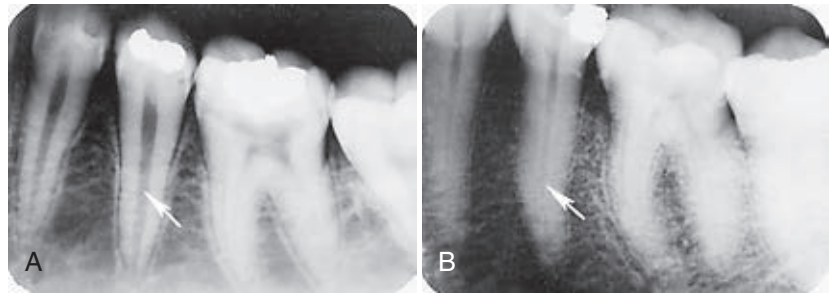


Fig. 1-12 Pulp cavity size. **A**, Premolar radiograph of young person. **B**, Premolar radiograph of older person. Note the difference in the size of the pulp cavity (arrows).

through structural units that are hypomineralized and rich in organic content, such as rod sheaths, enamel cracks, and other defects. Water plays an important role as a transporting medium through small intercrystalline spaces. Enamel permeability decreases with age because of changes in the enamel matrix, a decrease referred to as *enamel maturation*.

Enamel is soluble when exposed to an acid medium, but the dissolution is not uniform. Solubility of enamel increases from the enamel surface to the DEJ. When fluoride ions are present during enamel formation or are topically applied to the enamel surface, the solubility of surface enamel is decreased. Fluoride concentration decreases toward the DEJ. Fluoride can affect the chemical and physical properties of the apatite mineral and influence the hardness, chemical reactivity, and stability of enamel, while preserving the apatite structures. Trace amounts of fluoride stabilize enamel by lowering acid solubility, decreasing the rate of demineralization, and enhancing the rate of remineralization.

Pulp–Dentin Complex

Dentin and pulp tissues are specialized connective tissues of mesodermal origin, formed from the dental papilla of the tooth bud. Many investigators consider these two tissues as a single tissue, which forms the pulp–dentin complex, with mineralized dentin constituting the mature end product of cell differentiation and maturation.

The dental pulp occupies the pulp cavity in the tooth and is a unique, specialized organ of the human body that serves four functions: (1) formative or developmental, (2) nutritive, (3) sensory or protective, and (4) defensive or reparative. The formative function is the production of primary and secondary dentin by odontoblasts. The nutritive function supplies nutrients and moisture to dentin through the blood vascular supply to the odontoblasts and their processes. The sensory function provides nerve fibers within the pulp to mediate the sensation of pain. Dentin receptors are unique because various stimuli elicit only pain as a response. The pulp usually does not differentiate between heat, touch, pressure, or chemicals. Motor fibers initiate reflexes in the muscles of the blood vessel walls for the control of circulation in the pulp.

Finally, the defensive function of the pulp is related primarily to its response to irritation by mechanical, thermal, chemical, or bacterial stimuli. The deposition of reparative dentin acts as a protective barrier against caries and various other irritating factors. In cases of severe irritation, the pulp responds by an inflammatory reaction similar to that for any other soft tissue injury. The inflammation may become irreversible, however, and can result in the death of the

pulp because the confined, rigid structure of the dentin limits the inflammatory response and the ability of the pulp to recover.

The pulp is circumscribed by the dentin and is lined peripherally by a cellular layer of odontoblasts adjacent to dentin. Anatomically, the pulp is divided into (1) coronal pulp located in the pulp chamber in the crown portion of the tooth, including the pulp horns that are directed toward the incisal ridges and cusp tips, and (2) radicular pulp located in the pulp canals in the root portion of the tooth. The radicular pulp is continuous with the periapical tissues by connecting through the apical foramen or foramina of the root. Accessory canals may extend from the pulp canals laterally through the root dentin to the periodontal tissues. The shape of each pulp conforms generally to the shape of each tooth (see Fig. 1-3).

The pulp contains nerves, arterioles, venules, capillaries, lymph channels, connective tissue cells, intercellular substance, odontoblasts, fibroblasts, macrophages, collagen, and fine fibers.¹ The pulp is circumscribed peripherally by a specialized odontogenic area composed of the odontoblasts, the cell-free zone, and the cell-rich zone.

Knowledge of the contour and size of the pulp cavity is essential during tooth preparation. In general, the pulp cavity is a miniature contour of the external surface of the tooth. Pulp cavity size varies with tooth size among individuals and even within a single person. With advancing age, the pulp cavity usually decreases in size. Radiographs are an invaluable aid in determining the size of the pulp cavity and any existing pathologic condition (Fig. 1-12). A primary objective during operative procedures must be the preservation of the health of the pulp.

Dentin formation, *dentinogenesis*, is accomplished by cells called *odontoblasts*. Odontoblasts are considered part of pulp and dentin tissues because their cell bodies are in the pulp cavity, but their long, slender cytoplasmic cell processes (Tomes fibers) extend well (100–200 μm) into the tubules in the mineralized dentin (Fig. 1-13).

Because of these odontoblastic cell processes, dentin is considered a living tissue, with the capability of reacting to physiologic and pathologic stimuli. Odontoblastic processes occasionally cross the DEJ into enamel; these are termed *enamel spindles* when their ends are thickened (Fig. 1-14). They may serve as pain receptors, explaining the enamel sensitivity experienced by some patients during tooth preparation.

Dentin forms the largest portion of the tooth structure, extending almost the full length of the tooth. Externally, dentin is covered by enamel on the anatomic crown and cementum on the anatomic root. Internally, dentin forms the

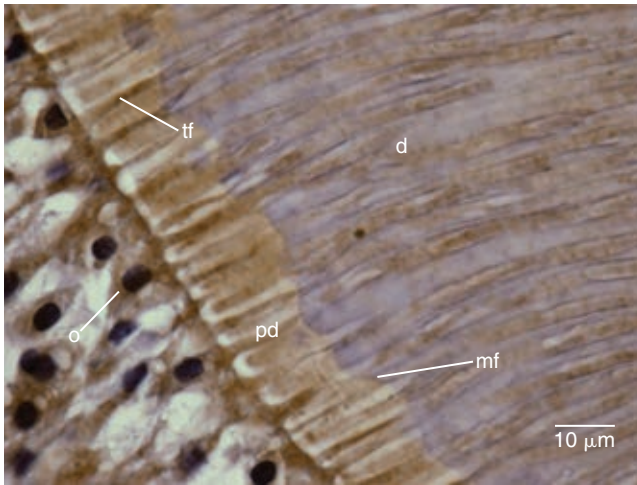


Fig. 1-13 Odontoblasts (*o*) have cell processes (Tomes fibers, [*tf*]) that extend through the predentin (*pd*) into dentin (*d*). *mf*, mineralization front.

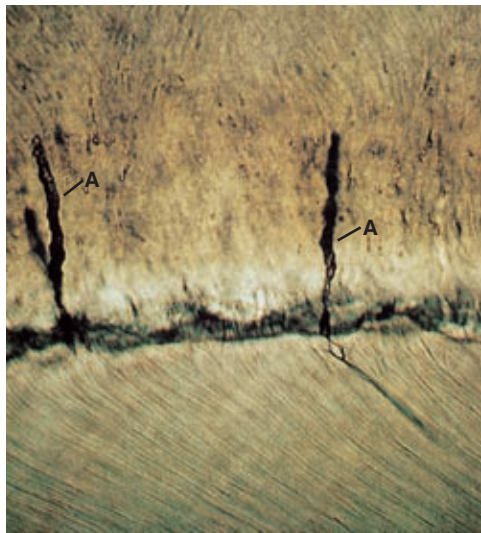


Fig. 1-14 Longitudinal section of enamel. Odontoblastic processes extend into enamel as enamel spindles (*A*). (From Berkovitz BKB, Holland GR, Moxham BJ: Oral anatomy, histology and embryology, ed 4, Edinburgh, 2009, Mosby. Courtesy of Dr. R. Sprinz.)

walls of the pulp cavity (pulp chamber and pulp canals) (Fig. 1-15). Dentin formation begins immediately before enamel formation. Odontoblasts generate an extracellular collagen matrix as they begin to move away from the adjacent ameloblasts. Mineralization of the collagen matrix, facilitated by modification of the collagen matrix by various noncollagenous proteins, gradually follows its secretion. The most recently formed layer of dentin is always on the pulpal surface. This unmineralized zone of dentin is immediately next to the cell bodies of odontoblasts and is called *predentin*. Dentin formation begins at areas subjacent to the cusp tip or incisal ridge and gradually spreads to the apex of the root (see Fig. 1-15). In contrast to enamel formation, dentin formation continues after tooth eruption and throughout the life of the pulp. The dentin forming the initial shape of the tooth is called

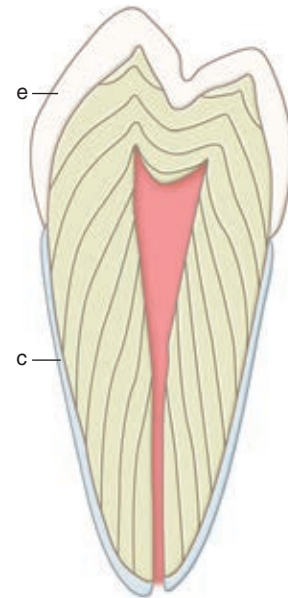


Fig. 1-15 Pattern of formation of primary dentin. This figure also shows enamel (*e*) covering the anatomic crown of the tooth and cementum (*c*) covering the anatomic root.

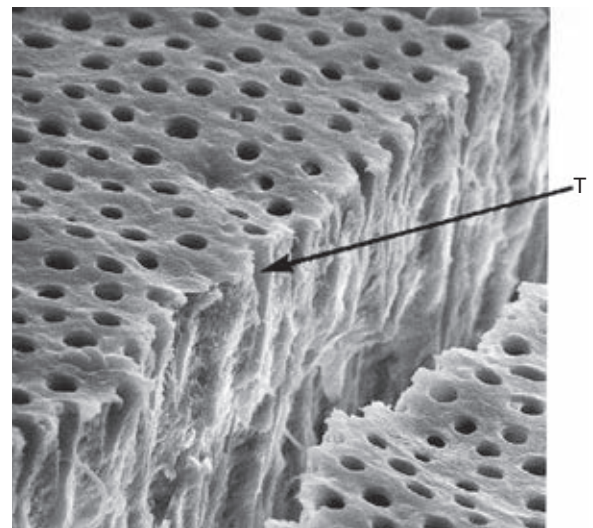


Fig. 1-16 Ground dentinal surface, acid-etched with 37% phosphoric acid. The artificial crack shows part of the dentinal tubules (*T*). The tubule apertures are opened and widened by acid application. (From Brännström M: Dentin and pulp in restorative dentistry, London, 1982, Wolfe Medical.)

primary dentin and is usually completed 3 years after tooth eruption (in the case of permanent teeth).

The dentinal tubules are small canals that extend through the entire width of dentin, from the pulp to the DEJ (Figs. 1-16 and 1-17). Each tubule contains the cytoplasmic cell process (Tomes fiber) of an odontoblast and is lined with a layer of peri-tubular dentin, which is much more mineralized than the surrounding intertubular dentin (see Fig. 1-17).

The surface area of dentin is much larger at the DEJ or dentinocemental junction than it is on the pulp cavity side. Because odontoblasts form dentin while progressing inward toward the pulp, the tubules are forced closer together. The number of

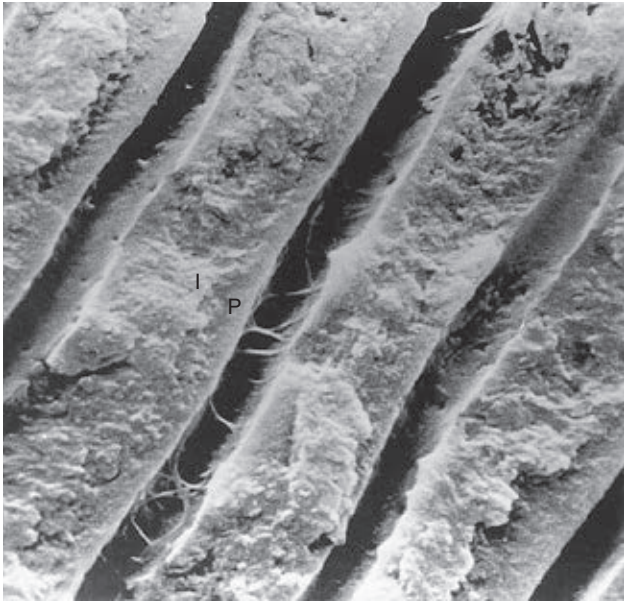


Fig. 1-17 Dentinal tubules in cross-section, 1.2 mm from pulp. Peri-tubular dentin (P) is more mineralized than intertubular dentin (I). (From Brännström M: Dentin and pulp in restorative dentistry, London, 1982, Wolfe Medical.)

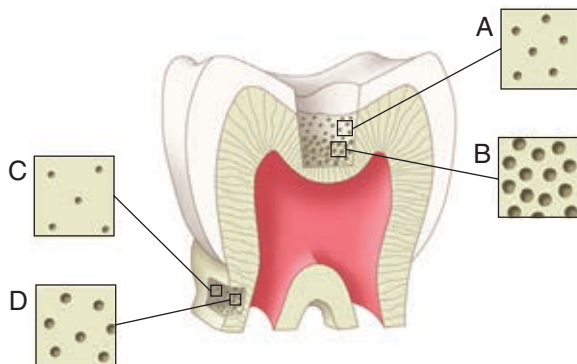


Fig. 1-18 Tubules in superficial dentin close to the dentinoenamel junction (DEJ) (A) are smaller and more sparsely distributed compared with deep dentin (B). The tubules in superficial root dentin (C) and deep root dentin (D) are smaller and less numerous than those in comparable depths of coronal dentin.

tubules increases from 15,000 to 20,000/mm² at the DEJ to 45,000 to 65,000/mm² at the pulp.² The lumen of the tubules also varies from the DEJ to the pulp surface. In coronal dentin, the average diameter of tubules at the DEJ is 0.5 to 0.9 μm, but this increases to 2 to 3 μm near the pulp (Fig. 1-18).

The course of the dentinal tubules is a slight S-curve in the tooth crown, but the tubules are straighter in the incisal ridges, cusps, and root areas (Fig. 1-19). The ends of the tubules are perpendicular to the DEJ. Along the tubule walls are small lateral openings called *canaliculi*. As the odontoblastic process proceeds from the cell in the pulp to the DEJ, lateral secondary branches extend into the canaliculi and can communicate with the lateral extensions of adjacent odontoblastic processes. Near the DEJ, the tubules divide into several terminal branches, forming an intercommunicating and anastomosing network (Fig. 1-20).



Fig. 1-19 Ground section of human incisor. Course of dentinal tubules is in a slight S-curve in the crown, but straight at the incisal tip and in the root. (From Young B, Lowe JS, Stevens A, Heath JW: Wheater's functional histology: A text and colour atlas, ed 5, Edinburgh, 2006, Churchill Livingstone.)

After the primary dentin is formed, dentin deposition continues at a reduced rate even without obvious external stimuli, although the rate and amount of this physiologic secondary dentin vary considerably among individuals. In secondary dentin, the tubules take a slightly different directional pattern in contrast to primary dentin (Fig. 1-21). Secondary dentin forms on all internal aspects of the pulp cavity, but in the pulp chamber, in multi-rooted teeth, it tends to be thicker on the roof and floor than on the side walls.³

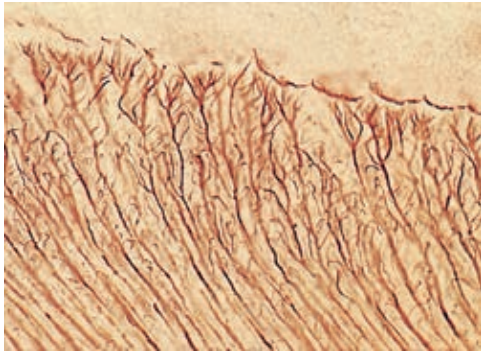


Fig. 1-20 Ground section showing dentinal tubules and their lateral branching close to the dentinoenamel junction (DEJ). (From Berkovitz BKB, Holland GR, and Moxham BJ: Oral anatomy, histology, and embryology, ed 4, Edinburgh, 2010, Mosby.)



Fig. 1-21 Ground section of dentin with pulpal surface at right. Dentinal tubules curve sharply (arrows) as they move from primary to secondary dentin. Dentinal tubules are more irregular in shape in secondary dentin. (From Nanci A: Ten Cate's oral histology: Development, structure, and function, ed 7, Mosby, 2008, St Louis.)

When moderate stimuli are applied to dentin, such as caries, attrition, and some operative procedures, the affected odontoblasts may die. Replacement odontoblasts (termed *secondary odontoblasts*) of pulpal origin then begin to form reparative dentin (*tertiary dentin*). The reparative dentin usually appears as a localized dentin deposit on the wall of the pulp cavity immediately subjacent to the area on the tooth that has received the injury (a dentin deposit underneath the affected tubules) (Fig. 1-22). Being highly atubular, the reparative dentin is structurally different from the primary and secondary dentin.

Sclerotic dentin results from aging or mild irritation (e.g., slowly advancing caries) and causes a change in the composition of the primary dentin. The peritubular dentin becomes wider, gradually filling the tubules with calcified material, progressing pulpally from the DEJ (Fig. 1-23). These areas are harder, denser, less sensitive, and more protective of the pulp against subsequent irritations. Sclerosis resulting from aging is called *physiologic dentin sclerosis*; sclerosis resulting from a mild irritation is called *reactive dentin sclerosis*. Reactive dentin sclerosis often can be seen radiographically in the form of a more radiopaque (lighter) area in the S-shape of the tubules.

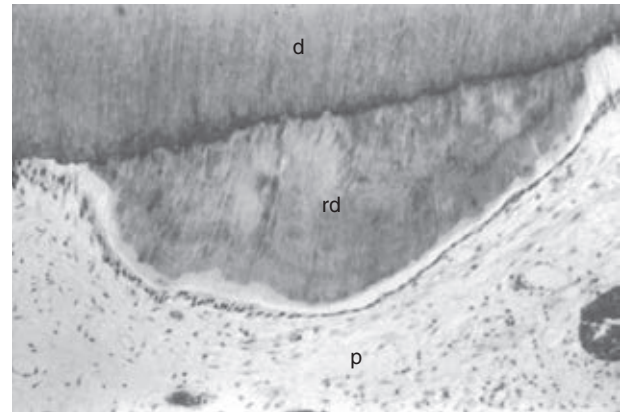


Fig. 1-22 Reparative dentin (rd) in response to a carious lesion (d, dentin, p, pulp). (From Trowbridge HO: Pulp biology: Progress during the past 25 years, Aust Endo J 29(1):5–12, 2003.)

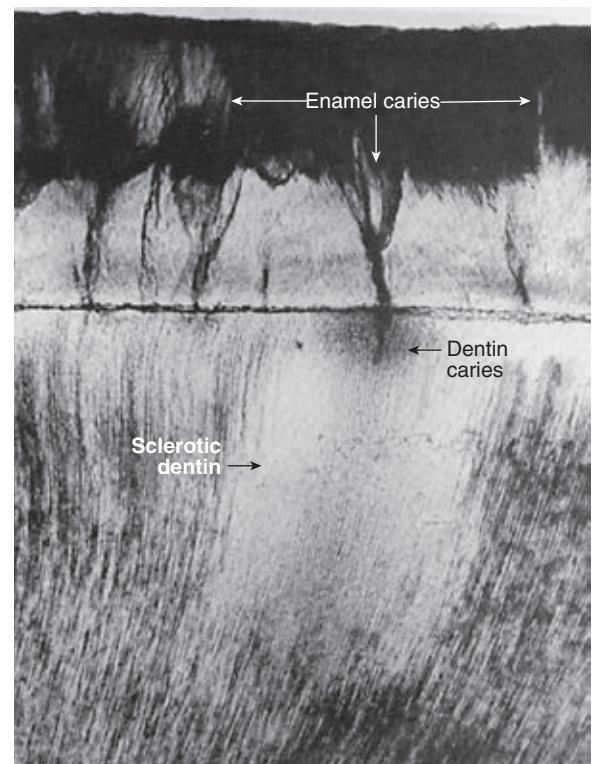


Fig. 1-23 Sclerotic dentin occurring under enamel caries with early penetration of dentin caries along the enamel lamella. (From Schour I: H. J. Noyes oral histology and embryology, Philadelphia, 1960, Lea & Febiger.)

Human dentin is composed of approximately 50% inorganic material and 30% organic material by volume. The organic phase is approximately 90% type I collagen and 10% noncollagenous proteins. Dentin is less mineralized than enamel but more mineralized than cementum or bone. The mineral content of dentin increases with age. This mineral phase is composed primarily of hydroxyapatite crystallites, which are arranged in a less systematic manner than are enamel crystallites. Dentinal crystallites are smaller than enamel crystallites, having a length of 20 to 100 nm and a width of about 3 nm, which is similar to the size seen in bone

and cementum.³ Dentin is significantly softer than enamel but harder than bone or cementum. The hardness of dentin averages one-fifth that of enamel, and its hardness near the DEJ is about three times greater than near the pulp. Dentin becomes harder with age, primarily as a result of increases in mineral content. Although dentin is a hard, mineralized tissue, it is flexible, with a modulus of elasticity of approximately 18 gigapascals (GPa).⁴ This flexibility helps support the more brittle, nonresilient enamel. Often small “craze lines” are seen in enamel, indicating minute fractures of that structure. The craze lines usually are not clinically significant unless associated with cracks in the underlying dentin. Dentin is not as prone to fracture as is the enamel rod structure. The ultimate tensile strength of dentin is approximately 98 megapascals (MPa), whereas the ultimate tensile strength of enamel is approximately 10 MPa. The compressive strength of dentin and enamel are approximately 297 and 384 MPa, respectively.⁴

During tooth preparation, dentin usually is distinguished from enamel by (1) color and opacity, (2) reflectance, (3) hardness, and (4) sound. Dentin is normally yellow-white and slightly darker than enamel. In older patients, dentin is darker, and it can become brown or black when it has been exposed to oral fluids, old restorative materials, or slowly advancing caries. Dentin surfaces are more opaque and dull, being less reflective to light than similar enamel surfaces, which appear shiny. Dentin is softer than enamel and provides greater yield to the pressure of a sharp explorer tine, which tends to catch and hold in dentin.

Sensitivity is encountered whenever odontoblasts and their processes are stimulated during operative procedures, even though the pain receptor mechanism appears to be within the dentinal tubules near the pulp. Physical, thermal, chemical, bacterial, and traumatic stimuli are transmitted through the dentinal tubules, although the precise mechanism of the transmissive elements of sensation has not been conclusively established. The most accepted theory of pain transmission is the hydrodynamic theory, which accounts for pain transmission through rapid movements of fluid within the dentinal tubules.⁵ Because many tubules contain mechanoreceptor nerve endings near the pulp, small fluid movements in the tubules arising from cutting, drying, pressure changes, osmotic shifts, or changes in temperature account for most pain transmission (Fig. 1-24).

Dentinal tubules are filled with dentinal fluid, a transudate of plasma. When enamel or cementum is removed during tooth preparation, the external seal of dentin is lost, allowing tubular fluid to move toward the cut surface. Pulpal fluid has a slight positive pressure that forces fluid outward toward any breach in the external seal. Permeability studies of dentin indicate that tubules are functionally much smaller than would be indicated by their measured microscopic dimensions as a result of numerous constrictions along their paths (see Fig. 1-17).⁶ Dentin permeability is not uniform throughout the tooth. Coronal dentin is much more permeable than root dentin. There also are differences within coronal dentin (Fig. 1-25).⁷ Dentin permeability primarily depends on the remaining dentin thickness (i.e., length of the tubules) and the diameter of the tubules. Because the tubules are shorter, more numerous, and larger in diameter closer to the pulp, deep dentin is a less effective pulpal barrier compared with superficial dentin (Fig. 1-26).

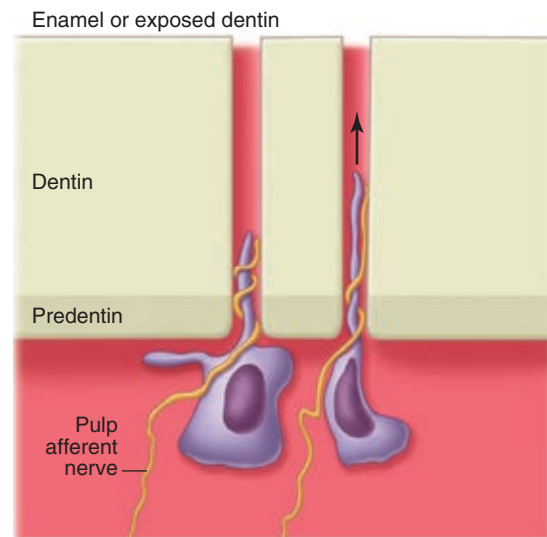


Fig. 1-24 Stimuli that induce fluid movements in dentinal tubules distort odontoblasts and afferent nerves, leading to a sensation of pain. Many operative procedures such as cutting or air-drying induce such fluid movement (arrow).

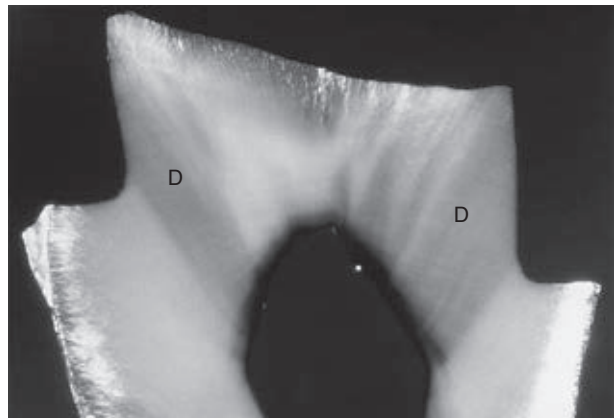


Fig. 1-25 Ground section of MOD (mesio-occluso-distal) tooth preparation on the third molar. Dark blue dye was placed in the pulp chamber under pressure after tooth preparation. Dark areas of dye penetration (D) show that the dentinal tubules of axial walls are much more permeable than those of the pulpal floor of preparation.

Cementum

Cementum is a thin layer of hard dental tissue covering the anatomic roots of teeth and is formed by cells known as *cementoblasts*, which develop from undifferentiated mesenchymal cells in the connective tissue of the dental follicle. Cementum is slightly softer than dentin and consists of about 45% to 50% inorganic material (hydroxyapatite) by weight and 50% to 55% organic matter and water by weight. The organic portion is composed primarily of collagen and protein polysaccharides. Sharpey's fibers are portions of the principal collagenous fibers of the periodontal ligament embedded in cementum and alveolar bone to attach the tooth to the alveolus (Fig. 1-27). Cementum is avascular.

Cementum is light yellow and slightly lighter in color than dentin. It is formed continuously throughout life because as the superficial layer of cementum ages, a new layer of

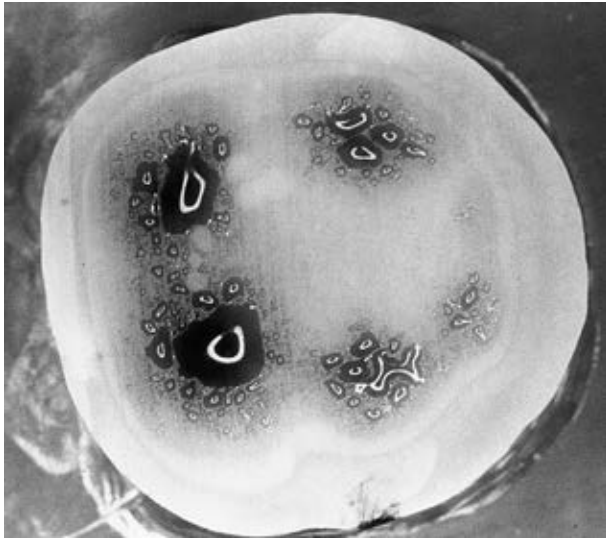


Fig. 1-26 Horizontal section in the occlusal third of molar crown. Dark blue dye was placed in the pulp chamber under pressure. Deep dentin areas (over pulp horns) are much more permeable than superficial dentin. (From Pashley DH, Andringa HJ, Derkson GD, Derkson ME, Kalathoor SR: *Regional variability in the permeability of human dentin*, Arch Oral Biol 32:519–523, 1987, with permission from Pergamon, Oxford, UK.)

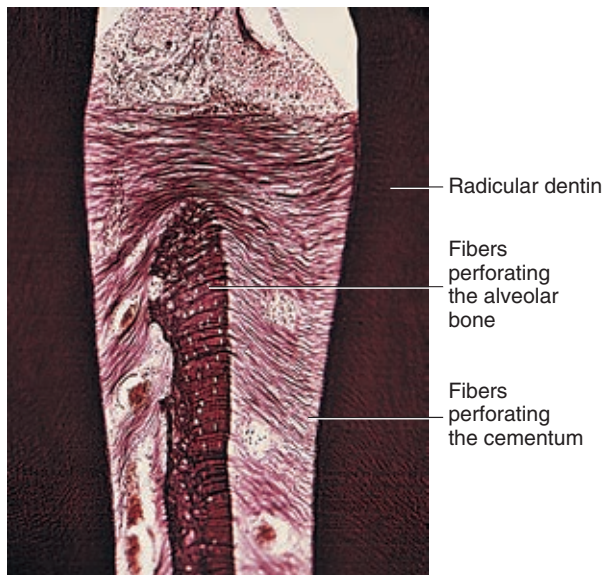


Fig. 1-27 Principal fibers of periodontal ligament continue to course into surface layer of cementum as Sharpey's fibers. (From Avery JK, Chiego DJ: *Essentials of oral histology and embryology: A clinical approach*, ed 3, St Louis, 2006, Mosby.)

cementum is deposited to keep the attachment intact. Two kinds of cementum are formed: acellular and cellular. The acellular layer of cementum is living tissue that does not incorporate cells into its structure and usually predominates on the coronal half of the root; cellular cementum occurs more frequently on the apical half. Cementum on the root end surrounds the apical foramen and may extend slightly onto the inner wall of the pulp canal. Cementum thickness can increase on the root end to compensate for attritional wear of the occlusal or incisal surface and passive eruption of the tooth.



Fig. 1-28 Radiograph showing root resorption on lateral incisor after orthodontic tooth movement.

The cementodentinal junction is a relatively smooth area in the permanent tooth, and attachment of cementum to dentin is firm, but this is not understood completely yet. Cementum joins enamel to form the CEJ. In about 10% of teeth, enamel and cementum do not meet, and this can result in a sensitive area. Abrasion, erosion, caries, scaling, and restoration finishing and polishing procedures can denude dentin of its cementum covering, which can cause the dentin to be sensitive to various stimuli (e.g., heat, cold, sweet substances, sour substances). Cementum is capable of repairing itself to a limited degree and is not resorbed under normal conditions. Some resorption of the apical portion of the root can occur, however, if orthodontic pressures are excessive and movement is too fast (Fig. 1-28).

Physiology of Tooth Form

Function

Teeth serve four main functions: (1) mastication, (2) esthetics, (3) speech, and (4) protection of supporting tissues. Normal tooth form and proper alignment ensure efficiency in the incising and reduction of food with the various tooth classes—incisors, canines, premolars, and molars—performing specific functions in the masticatory process and in the coordination of the various muscles of mastication. In esthetics, the form and alignment of the anterior teeth are important to a person's physical appearance. The form and alignment of anterior and posterior teeth assist in the articulation of certain sounds that can have a significant effect on speech. Finally, the form and alignment of the teeth assist in sustaining them in the dental arches by assisting in the development and protection of gingival tissue and alveolar bone that support them.

Contours

Facial and lingual surfaces possess a degree of convexity that affords protection and stimulation of supporting tissues during mastication. The convexity generally is located at the cervical third of the crown on the facial surfaces of all teeth and the lingual surfaces of incisors and canines. The lingual surfaces of posterior teeth usually have their height of contour in the middle third of the crown. Normal tooth contours act in deflecting food only to the extent that the passing food stimulates (by gentle massage) and does not irritate supporting tissues. If these curvatures are too great, tissues usually receive inadequate stimulation by the passage of food. Too little contour may result in trauma to the attachment apparatus.

These tooth contours must be considered in the performance of operative dental procedures. Improper location and degree of facial or lingual convexities can result in serious complications, as illustrated in Figure 1-29, in which the proper facial contour is disregarded in the placement of a cervical restoration on a mandibular molar. Over-contouring is the worst offender, usually resulting in increased plaque retention that leads to a chronic inflammatory state of the gingiva.

The proper form of the proximal surfaces of teeth is just as important to the maintenance of periodontal tissue as is the proper form of facial and lingual surfaces. The proximal height of contour serves to provide (1) contacts with the proximal surfaces of adjacent teeth, thus preventing food impaction, and (2) adequate embrasure space apical to the contacts for gingival tissue, supporting bone, blood vessels, and nerves that serve the supporting structures (Fig. 1-30).

Proximal Contact Area

When teeth erupt to make proximal contact with previously erupted teeth, initially a contact point is present. The contact point increases in size to become a proximal contact area as the two adjacent tooth surfaces abrade each other during physiologic tooth movement (Figs. 1-31 and 1-32).

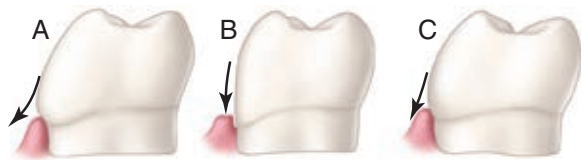


Fig. 1-29 Contours. Arrows show pathways of food passing over facial surface of mandibular molar during mastication. **A**, Over-contour deflects food from gingiva and results in under-stimulation of supporting tissues. **B**, Under-contour of tooth may result in irritation of soft tissue. **C**, Correct contour permits adequate stimulation for supporting tissue, resulting in healthy condition.

The proximal contact area is located in the incisal third of the approximating surfaces of maxillary and mandibular central incisors (Fig. 1-32). It is positioned slightly facial to the center of the proximal surface faciolingually (see Fig. 1-31). Proceeding posteriorly from the incisor region through all the remaining teeth, the contact area is located near the junction of the incisal (or occlusal) and middle thirds or in the middle third. Proximal contact areas typically are larger in the molar region, which helps prevent food impaction during mastication. Adjacent surfaces near the proximal contacts (embrasures) usually have remarkable symmetry.

Embrasures

Embrasures are V-shaped spaces that originate at the proximal contact areas between adjacent teeth and are named for the



Fig. 1-30 Portion of the skull, showing triangular spaces beneath proximal contact areas. These spaces are occupied by soft tissue and bone for the support of teeth. (Adapted from Bath-Balogh M, Fehrenbach MJ: *Illustrated dental embryology, histology, and anatomy*, ed 3, St. Louis, 2011, Saunders.)

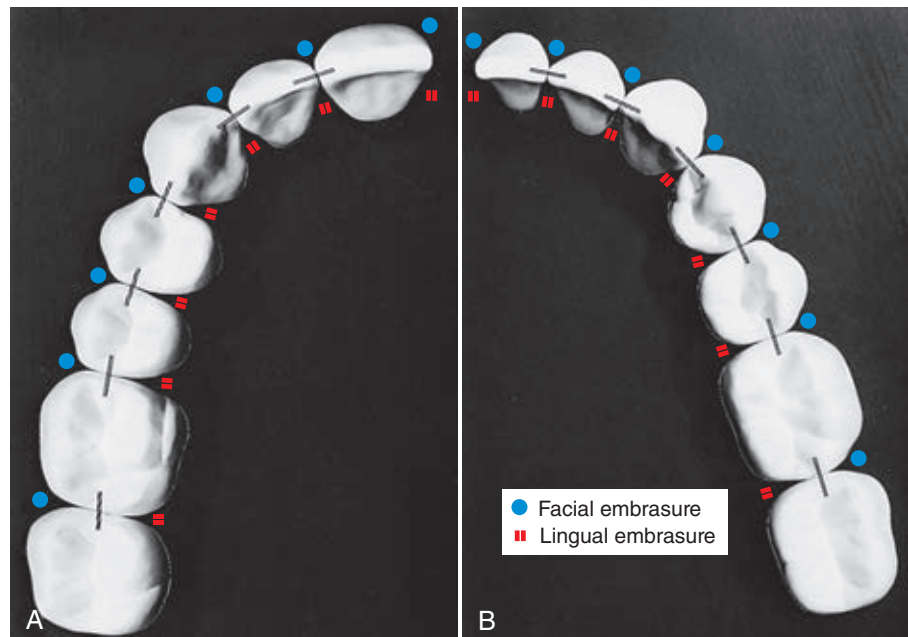


Fig. 1-31 Proximal contact points that have progressed to proximal contact areas. **A**, Maxillary teeth. **B**, Mandibular teeth. Facial and lingual embrasures are indicated.

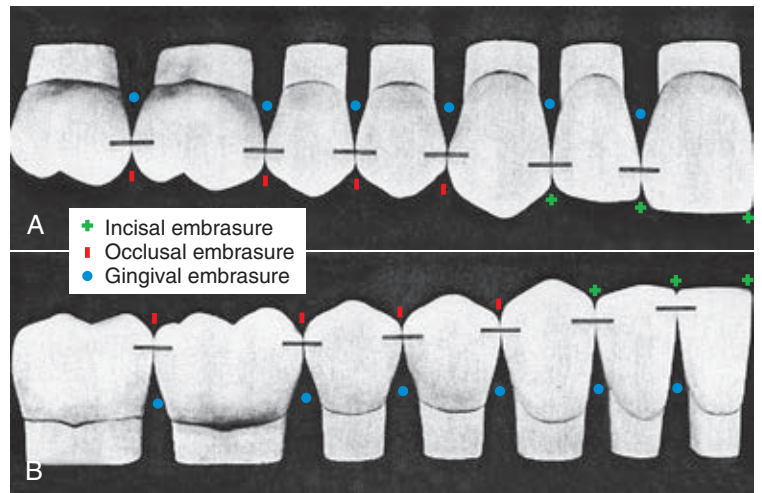


Fig. 1-32 Proximal contact areas. Black lines show positions of contacts incisogingivally and occlusogingivally. Incisal, occlusal, and gingival embrasures are indicated. **A**, Maxillary teeth. **B**, Mandibular teeth.

direction toward which they radiate. These embrasures are (1) facial, (2) lingual, (3) incisal or occlusal, and (4) gingival (see Figs. 1-31 and 1-32).

Initially, the interdental papilla fills the gingival embrasure. When the form and function of teeth are ideal and optimal oral health is maintained, the interdental papilla may continue in this position throughout life. When the gingival embrasure is filled by the papilla, trapping of food in this region is prevented. In a faciolingual vertical section, the papilla has a triangular shape between anterior teeth, whereas in posterior teeth, the papilla may be shaped like a mountain range, with facial and lingual peaks and the col (“valley”) lying beneath the contact area (Fig. 1-33). This col, a central faciolingual concave area beneath the contact, is more vulnerable to periodontal disease from incorrect contact and embrasure form because it is covered by nonkeratinized epithelium. The physiologic significance of properly formed and located proximal contacts and associated embrasures cannot be overemphasized; they promote normal healthy interdental papillae filling the interproximal spaces (Fig. 1-34). Improper contacts can result in food impaction between teeth, potentially increasing the risk of periodontal disease, caries, and tooth movement. In addition, retention of food is objectionable because of its physical presence and the halitosis that results from food decomposition. Proximal contacts and interdigitation of teeth through occlusal contacts stabilize and maintain the integrity of the dental arches.

The correct relationships of embrasures, cusps to sulci, marginal ridges, and grooves of adjacent and opposing teeth provide for the escape of food from the occlusal surfaces during mastication (Fig. 1-35). When an embrasure is decreased in size or absent, additional stress is created on teeth and the supporting structures during mastication. Embrasures that are too large provide little protection to the supporting structures as food is forced into the interproximal space by an opposing cusp. A prime example is the failure to restore the distal cusp of a mandibular first molar when placing a restoration (Fig. 1-36). Lingual embrasures are usually larger than facial embrasures and this allows more food to be displaced lingually because the tongue can return the food to the occlusal surface more easily than if the food is displaced facially into the buccal vestibule (see Fig. 1-31). The

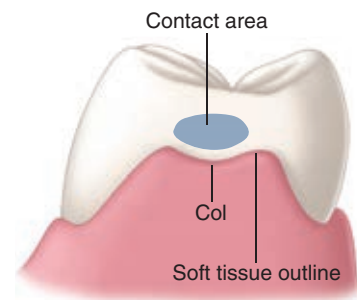


Fig. 1-33 Relationship of ideal interdental papilla to molar contact area.

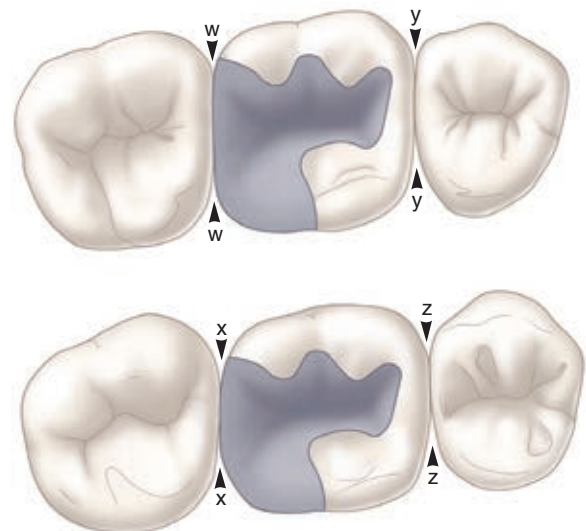


Fig. 1-34 Embrasure form. *w*, Improper embrasure form caused by overcontouring of restoration resulting in unhealthy gingiva from lack of stimulation. *x*, Good embrasure form. *y*, Frictional wear of contact area has resulted in decrease of embrasure dimension. *z*, When the embrasure form is good, supporting tissues receive adequate stimulation from foods during mastication.



Fig. 1-35 Maxillary and mandibular first molars in maximum intercusp contact. Note the grooves for escape of food.

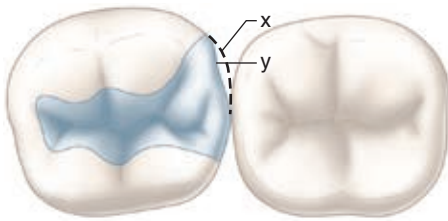


Fig. 1-36 Embrasure form. *x*, Portion of tooth that offers protection to underlying supporting tissue during mastication. *y*, Restoration fails to establish adequate contour for good embrasure form.

marginal ridges of adjacent posterior teeth should be at the same height to have proper contact and embrasure forms. When this relationship is absent, it causes an increase in the problems associated with weak proximal contacts and faulty embrasure forms.

Preservation of the curvatures of opposing cusps and surfaces in function maintains masticatory efficiency throughout life (see Fig. 1-2). Correct anatomic form renders teeth more self-cleansing because of the smoothly rounded contours that are more exposed to the cleansing action of foods and fluids and the frictional movement of the tongue, lips, and cheeks. Failure to understand and adhere to correct anatomic form can contribute to the breakdown of the restored system (Fig. 1-37).

Maxilla and Mandible

The human maxilla is formed by two bones, the maxilla proper and the premaxilla. These two bones form the bulk of the upper jaw and the major portion of the hard palate and help form the floor of the orbit and the sides and base of the nasal cavity. They contain 10 maxillary primary teeth initially and later contain 16 maxillary permanent teeth in the alveolar process (see Figs. 1-1 and 1-3, label 7).

The mandible, or the lower jaw, is horseshoe-shaped and relates to the skull on either side via the TMJs. The mandible is composed of a body of two horizontal portions joined at the midline symphysis mandibulae and the rami, the vertical parts. The coronoid process and the condyle make up the superior border of each ramus. The mandible initially contains 10 mandibular primary teeth and later 16 mandibular permanent teeth in the alveolar process. Maxillary and mandibular bones comprise approximately 38% to 43% inorganic material and 34% organic material by volume. The inorganic material is hydroxyapatite, and the organic material is

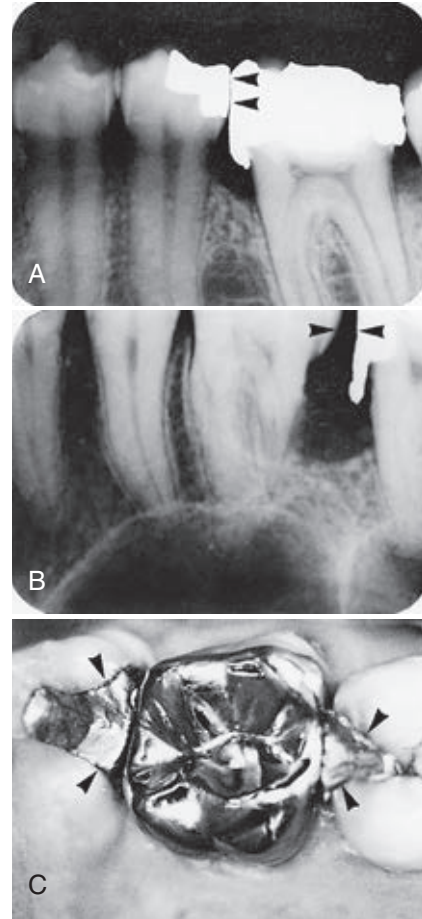


Fig. 1-37 Poor anatomic restorative form. **A**, Radiograph of flat contact and amalgam gingival excess. **B**, Radiograph of restoration with amalgam gingival excess and absence of contact resulting in trauma to supporting tissue. **C**, Poor occlusal margins.

primarily type I collagen, which is surrounded by a ground substance of glycoproteins and proteoglycans.

Oral Mucosa

The oral mucosa is the mucous membrane that covers all oral structures except the clinical crowns of teeth. It is composed of two layers: (1) the stratified squamous epithelium and (2) the supporting connective tissue, called *lamina propria*. (See the lamina propria of the gingiva in Fig. 1-38, label 8.) The epithelium may be keratinized, parakeratinized, or nonkeratinized, depending on its location. The lamina propria varies in thickness and supports the epithelium. It may be attached to the periosteum of alveolar bone, or it may be interposed over the submucosa, which may vary in different regions of the mouth (e.g., the floor of the mouth, the soft palate). The submucosa, consisting of connective tissues varying in density and thickness, attaches the mucous membrane to the underlying bony structures. The submucosa contains glands, blood vessels, nerves, and adipose tissue.

The oral mucosa is classified into three major functional types: (1) masticatory mucosa, (2) lining or reflective mucosa, and (3) specialized mucosa. The masticatory mucosa comprises the free and attached gingiva (see Fig. 1-38, labels 6

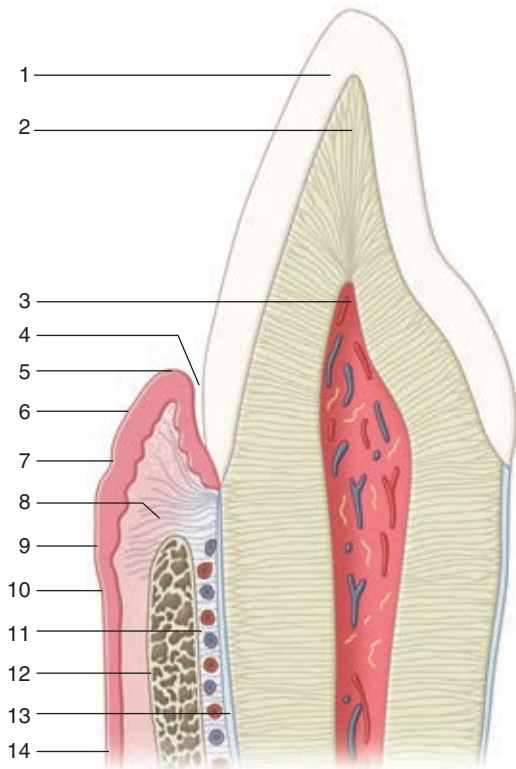


Fig. 1-38 Vertical section of a maxillary incisor illustrating supporting structures: 1, enamel; 2, dentin; 3, pulp; 4, gingival sulcus; 5, free gingival margin; 6, free gingiva; 7, free gingival groove; 8, lamina propria of gingiva; 9, attached gingiva; 10, mucogingival junction; 11, periodontal ligament; 12, alveolar bone; 13, cementum; 14, alveolar mucosa.

and 9) and the mucosa of the hard palate. The epithelium of these tissues is keratinized, and the lamina propria is a dense, thick, firm connective tissue containing collagenous fibers. The hard palate has a distinct submucosa except for a few narrow specific zones. The dense lamina propria of the attached gingiva is connected to the cementum and periosteum of the bony alveolar process (see Fig. 1-38, label 8).

The lining or reflective mucosa covers the inside of the lips, cheek, and vestibule, the lateral surfaces of the alveolar process (except the mucosa of the hard palate), the floor of the mouth, the soft palate, and the ventral surface of the tongue. The lining mucosa is a thin, movable tissue with a relatively thick, nonkeratinized epithelium and a thin lamina propria. The submucosa comprises mostly thin, loose connective tissue with muscle and collagenous and elastic fibers, with different areas varying from one another in their structures. The junction of the lining mucosa and the masticatory mucosa is the mucogingival junction, located at the apical border of the attached gingiva facially and lingually in the mandibular arch and facially in the maxillary arch (see Fig. 1-38, label 10). The specialized mucosa covers the dorsum of the tongue and the taste buds. The epithelium is nonkeratinized except for the covering of the dermal filiform papillae.

Periodontium

The periodontium consists of the oral hard and soft tissues that invest and support teeth. It can be divided into (1) the

gingival unit, consisting of free and attached gingiva and the alveolar mucosa, and (2) the attachment apparatus, consisting of cementum, the periodontal ligament, and the alveolar process (see Fig. 1-38).

Gingival Unit

As mentioned previously, the free gingiva and the attached gingiva together form the masticatory mucosa. The free gingiva is the gingiva from the marginal crest to the level of the base of the gingival sulcus (see Fig. 1-38, labels 4 and 6). The gingival sulcus is the space between the tooth and the free gingiva. The outer wall of the sulcus (inner wall of the free gingiva) is lined with a thin, nonkeratinized epithelium. The outer aspect of the free gingiva in each gingival embrasure is called *gingival or interdental papilla*. The free gingival groove is a shallow groove that runs parallel to the marginal crest of the free gingiva and usually indicates the level of the base of the gingival sulcus (see Fig. 1-38, label 7).

The attached gingiva, a dense connective tissue with keratinized, stratified, squamous epithelium, extends from the depth of the gingival sulcus to the mucogingival junction. A dense network of collagenous fibers connects the attached gingiva firmly to cementum and the periosteum of the alveolar process (bone).

The alveolar mucosa is a thin, soft tissue that is loosely attached to the underlying alveolar bone (see Fig. 1-38, labels 12 and 14). It is covered by a thin, nonkeratinized epithelial layer. The underlying submucosa contains loosely arranged collagen fibers, elastic tissue, fat, and muscle tissue. The alveolar mucosa is delineated from the attached gingiva by the mucogingival junction and continues apically to the vestibular fornix and the inside of the cheek.

Clinically, the level of the gingival attachment and gingival sulcus is an important factor in restorative dentistry. Soft tissue health must be maintained by teeth having the correct form and position to prevent recession of the gingiva and possible abrasion and erosion of the root surfaces. The margin of a tooth preparation should not be positioned subgingivally (at levels between the marginal crest of the free gingiva and the base of the sulcus) unless dictated by caries, previous restoration, esthetics, or other preparation requirements.

Attachment Apparatus

The tooth root is attached to the alveolus (bony socket) by the periodontal ligament (see Fig. 1-38, label 11), which is a complex connective tissue containing numerous cells, blood vessels, nerves, and an extracellular substance consisting of fibers and ground substance. Most of the fibers are collagen, and the ground substance is composed of a variety of proteins and polysaccharides. The periodontal ligament serves the following functions: (1) attachment and support, (2) sensory, (3) nutritive, and (4) homeostatic. Bundles of collagen fibers, known as *principal fibers of the ligament*, serve to attach cementum to alveolar bone and act as a cushion to suspend and support the tooth. Coordination of masticatory muscle function is achieved, through an efficient proprioceptive mechanism, by the sensory nerves located in the periodontal ligament. Blood vessels supply the attachment apparatus with nutritive substances. Specialized cells of the ligament function

to resorb and replace cementum, the periodontal ligament, and alveolar bone.

The alveolar process—a part of the maxilla and the mandible—forms, supports, and lines the sockets into which the roots of teeth fit. Anatomically, no distinct boundary exists between the body of the maxilla or the mandible and the alveolar process. The alveolar process comprises thin, compact bone with many small openings through which blood vessels, lymphatics, and nerves pass. The inner wall of the bony socket consists of the thin lamella of bone that surrounds the root of the tooth. It is termed *alveolar bone proper*. The second part of the bone is called *supporting alveolar bone*, which surrounds the alveolar bone proper and supports the socket. Supporting bone is composed of two parts: (1) the cortical plate, consisting of compact bone and forming the inner (lingual) and outer (facial) plates of the alveolar process, and (2) the spongy base that fills the area between the plates and the alveolar bone proper.

Occlusion

Occlusion literally means “closing”; in dentistry, the term means the contact of teeth in opposing dental arches when the jaws are closed (static occlusal relationships) and during various jaw movements (dynamic occlusal relationships). The sizes of the jaws and the arrangement of teeth within the jaws are subject to a wide range of variation in humans. The locations of contacts between opposing teeth (occlusal contacts) vary as a result of differences in the sizes and shapes of teeth and jaws and the relative position of the jaws. A wide variety of occlusal schemes can be found in healthy individuals. Consequently, definition of an ideal occlusal scheme is fraught with difficulty.⁸ Repeated attempts have been made to describe an ideal occlusal scheme, but these descriptions are so restrictive that few individuals can be found to fit the criteria. Failing to find a single adequate definition of an ideal occlusal scheme has resulted in the conclusion that “in the final analysis, optimal function and the absence of disease is the principal characteristic of a good occlusion.”⁸ The dental relationships described in this section conform to the concepts of normal, or usual, occlusal schemes and include common variations of tooth-and-jaw relationships. The masticatory system is highly adaptable and can function successfully over a wide range of differences in jaw size and tooth alignment. Despite this great adaptability, however, some patients are highly sensitive to changes in tooth contacts, which may be brought about by orthodontic and restorative dental procedures.

Occlusal contact patterns vary with the position of the mandible. Static occlusion is defined further by the use of reference positions that include fully closed, terminal hinge (TH) closure, retruded, protruded, and right and left lateral extremes. The number and location of occlusal contacts between opposing teeth have important effects on the amount and direction of muscle force applied during mastication and other parafunctional activities such as mandibular clenching, tooth grinding, or a combination of both (bruxism). In extreme cases, these forces can cause damage to teeth or their supporting tissues. Forceful tooth contact occurs routinely near the limits or borders of mandibular movement, showing the relevance of these reference positions.⁹

Tooth contact during mandibular movement is termed *dynamic occlusal relationship*. Gliding or sliding contacts occur during mastication and other mandibular movements. Gliding contacts may be advantageous or disadvantageous, depending on the teeth involved, the position of the contacts, and the resultant masticatory muscle response. The design of the restored tooth surface can have important effects on the number and location of occlusal contacts, and both static and dynamic relationships must be taken into consideration. The following sections discuss common arrangements and variations of teeth and the masticatory system. Mastication and the contacting relationships of anterior and posterior teeth are described with reference to the potential restorative needs of the teeth.

General Description

Tooth Alignment and Dental Arches

In Fig. 1-39, A, the cusps have been drawn as blunt, rounded, or pointed projections of the crowns of teeth. Posterior teeth have one, two, or three cusps near the facial and lingual surfaces of each tooth. The cusps are separated by distinct developmental grooves and sometimes have additional supplemental grooves on the cusp inclines. The facial cusps are separated from the lingual cusps by a deep groove, termed *central groove*. If a tooth has multiple facial cusps or multiple lingual cusps, the cusps are separated by facial or lingual developmental grooves. The depressions between the cusps are termed *fossae* (singular, is *fossa*). The cusps in both arches are aligned in a smooth curve. Usually, the maxillary arch is larger than the mandibular arch, which results in the maxillary cusps overlapping the mandibular cusps when the arches are in maximal occlusal contact (see Fig. 1-39, B). In Fig. 1-39, A, two curved lines have been drawn over the teeth to aid in the visualization of the arch form. These curved lines identify the alignment of similarly functioning cusps or fossae. On the left side of the arches, an imaginary arc connecting the row of facial cusps in the mandibular arch have been drawn and labeled *facial occlusal line*. Above that, an imaginary line connecting the maxillary central fossae is labeled *central fossa occlusal line*. The mandibular facial occlusal line and the maxillary central fossa occlusal line coincide exactly when the mandibular arch is fully closed into the maxillary arch. On the right side of the dental arches, the maxillary lingual occlusal line and mandibular central fossa occlusal line have been drawn and labeled. These lines also coincide when the mandible is fully closed.

In Fig. 1-39, B, the dental arches are fully interdigitated, with maxillary teeth overlapping mandibular teeth. The overlap of the maxillary cusps can be observed directly when the jaws are closed. *Maximum intercuspation (MI)* refers to the position of the mandible when teeth are brought into full interdigitation with the maximal number of teeth contacting. Synonyms for MI include *intercuspal contact*, *maximum closure*, and *maximum habitual intercuspation (MHI)*.

In Fig. 1-39, C (proximal view), the mandibular facial occlusal line and the maxillary central fossa occlusal line coincide exactly. The maxillary lingual occlusal line and the mandibular central fossa occlusal line identified in Fig. 1-39, A, also are coincidental. Cusps that contact opposing teeth along the central fossa occlusal line are termed *supporting cusps* (functional, centric, holding, or stamp cusps); the cusps

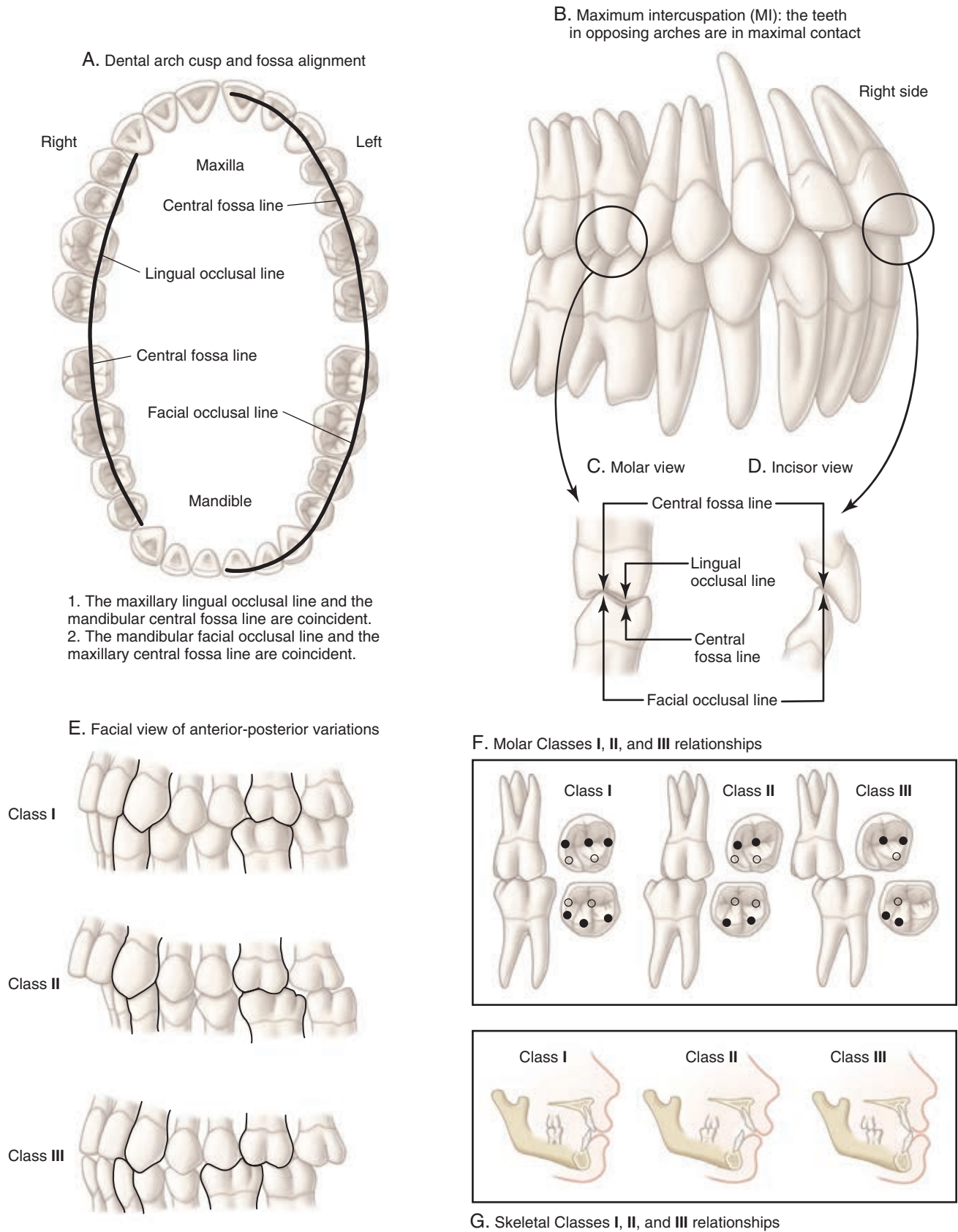


Fig. 1-39 Dental arch relationships.

that overlap opposing teeth are termed *nonsupporting cusps* (nonfunctional, noncentric, or nonholding cusps). The mandibular facial occlusal line identifies the mandibular supporting cusps, whereas the maxillary facial cusps are nonsupporting cusps. These terms are usually applied only to posterior teeth

to distinguish the functions of the two rows of cusps. In some circumstances, the functional role of the cusps can be reversed, as illustrated in Fig. 1-40, C-2. Posterior teeth are well suited to crushing food because of the mutual cusp–fossa contacts (Fig. 1-41, D).

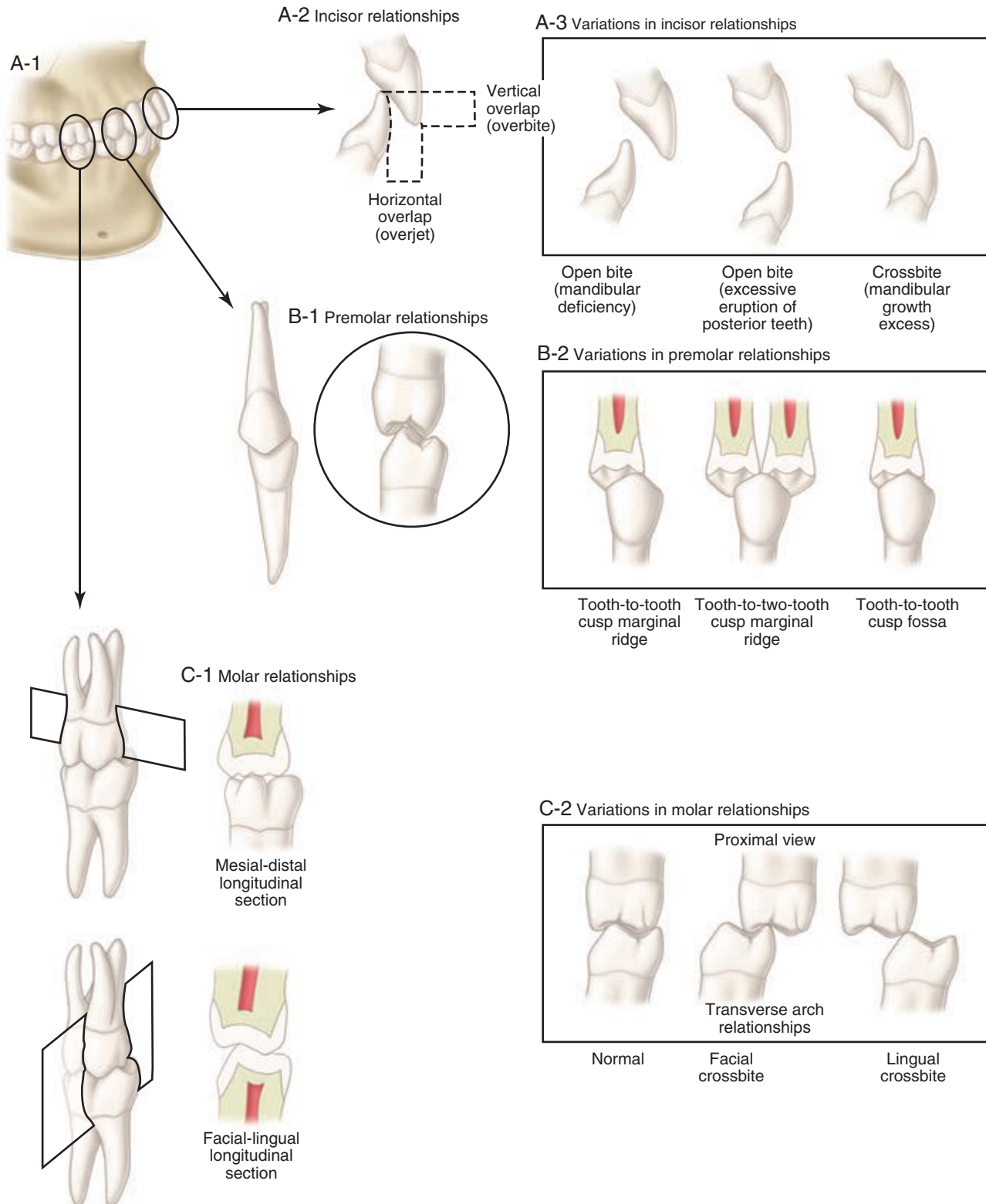


Fig. 1-40 Tooth relationships.

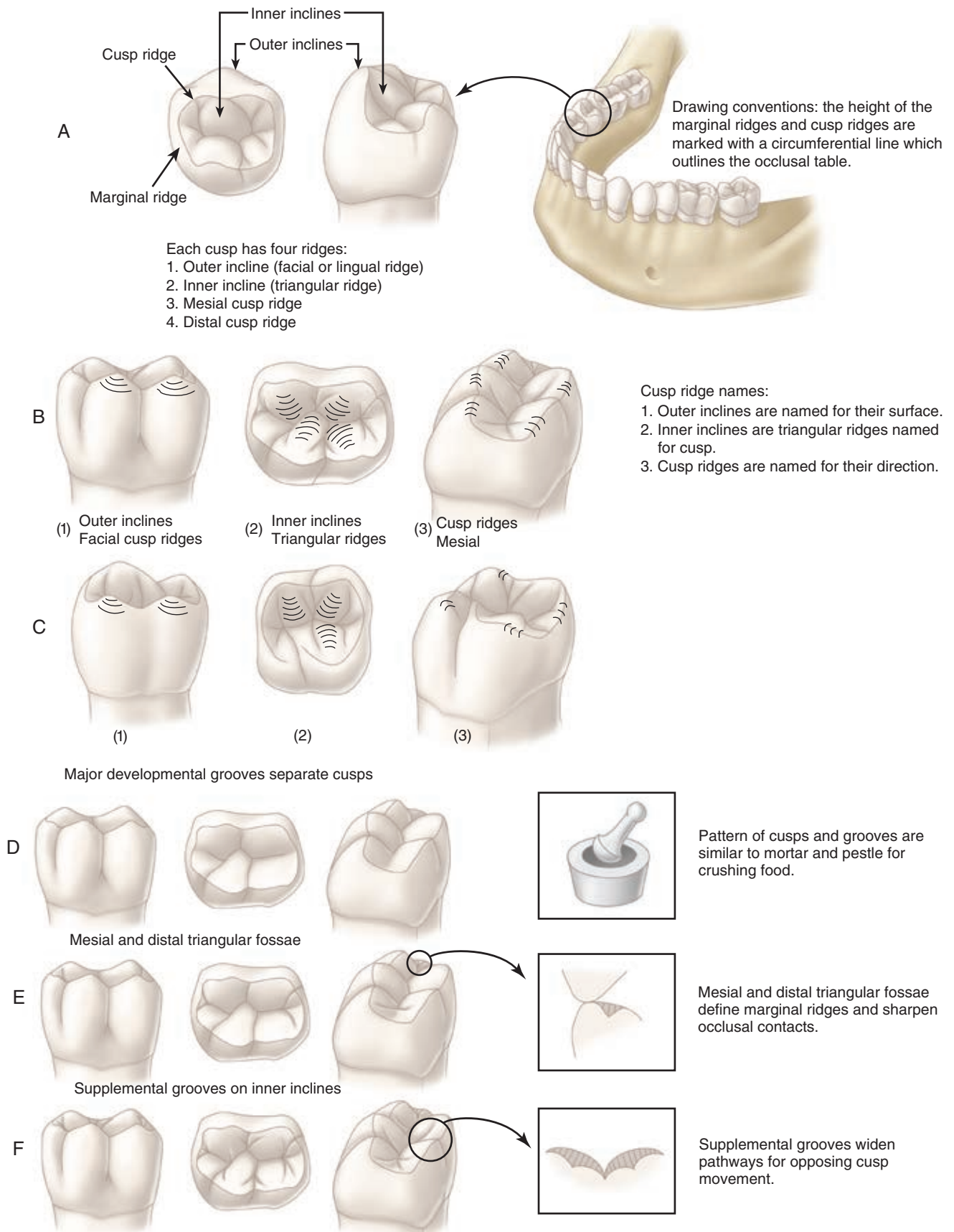


Fig. 1-41 Common features of all posterior teeth.

In Fig. 1-39, *D*, anterior teeth are seen to have a different relationship in MI, but they also show the characteristic maxillary overlap. Incisors are best suited to shearing food because of their overlap and the sliding contact on the lingual surface of maxillary teeth. In MI, mandibular incisors and canines contact the respective lingual surfaces of their maxillary opponents. The amount of horizontal (overjet) and vertical (overbite) overlap (see Fig. 1-40, *A-2*) can considerably influence mandibular movement and the cusp design of restorations of posterior teeth. Variations in the growth and development of the jaws and in the positions of anterior teeth result in open bite, in which vertical or horizontal discrepancies prevent teeth from contacting (see Fig. 1-40, *A-3*).

Anteroposterior Interarch Relationships

In Fig. 1-39, *E*, the cusp interdigitation pattern of the first molar teeth is used to classify anteroposterior arch relationships using a system developed by Angle.¹⁰ During the eruption of teeth, the tooth cusps and fossae guide the teeth into maximal contact. Three interdigitated relationships of the first molars are commonly observed. See Fig. 1-39, *F*, for an illustration of the occlusal contacts that result from different molar positions. The location of the mesiofacial cusp of the maxillary first molar in relation to the mandibular first molar is used as an indicator in Angle's classification. The most common molar relationship finds the maxillary mesiofacial cusp located in the mesiofacial developmental groove of the mandibular first molar. This relationship is termed *Angle Class I*. Slight posterior positioning of the mandibular first molar results in the mesiofacial cusp of the maxillary molar settling into the facial embrasure between the mandibular first molar and the mandibular second premolar. This is termed *Angle Class II* and occurs in approximately 15% of the U.S. population. Anterior positioning of the mandibular first molar relative to the maxillary first molar is termed *Angle Class III* and is the least common. In Class III relationships, the mesiofacial cusp of the maxillary first molar fits into the distofacial groove of the mandibular first molar; this occurs in approximately 3% of the U.S. population. Significant differences in these percentages occur in people in other countries and in different racial and ethnic groups.

Although Angle's classification is based on the relationship of the cusps, Figure 1-39, *G*, illustrates that the location of tooth roots in alveolar bone determines the relative positions of the crowns and cusps of teeth. When the mandible is proportionally similar in size to the maxilla, a Class I molar relationship is formed; when the mandible is proportionally smaller than the maxilla, a Class II relationship is formed; and when the mandible is relatively greater than the maxilla, a Class III relationship is formed.

Interarch Tooth Relationships

Fig. 1-40 illustrates the occlusal contact relationships of individual teeth in more detail. In Fig. 1-40, *A-2*, incisor overlap is illustrated. The overlap is characterized in two dimensions: (1) horizontal overlap (overjet) and (2) vertical overlap (overbite). Differences in the sizes of the mandible and the maxilla can result in clinically significant variations in incisor relationships, including open bite as a result of mandibular deficiency or excessive eruption of posterior teeth, and crossbite as a

result of mandibular growth excess (see Fig. 1-40, *A-3*). These variations have significant clinical effects on the contacting relationships of posterior teeth during various jaw movements because anterior teeth do not provide gliding contact.

Fig. 1-40, *B-1*, illustrates a normal Class I occlusion, in which each mandibular premolar is located one half of a tooth width anterior to its maxillary antagonist. This relationship results in the mandibular facial cusp contacting the maxillary premolar mesial marginal ridge and the maxillary premolar lingual cusp contacting the mandibular distal marginal ridge. Because only one antagonist is contacted, this is termed *tooth-to-tooth relationship*. The most stable relationship results from the contact of the supporting cusp tips against the two marginal ridges, termed *tooth-to-two-tooth contact*. Variations in the mesiodistal root position of teeth produce different relationships (see Fig. 1-40, *B-2*). When the mandible is slightly distal to the maxilla (termed *Class II tendency*), each supporting cusp tip occludes in a stable relationship with the opposing mesial or distal fossa; this relationship is a cusp–fossa contact.

Fig. 1-40, *C*, illustrates Class I molar relationships in more detail. Fig. 1-40, *C-1*, shows the mandibular facial cusp tips contacting the maxillary marginal ridges and the central fossa triangular ridges. A faciolingual longitudinal section reveals how the supporting cusps contact the opposing fossae and shows the effect of the developmental grooves on reducing the height of the nonsupporting cusps opposite the supporting cusp tips. During lateral movements, the supporting cusp can move through the facial and lingual developmental groove spaces. Faciolingual position variations are possible in molar relationships because of differences in the growth of the width of the maxilla or the mandible.

Fig. 1-40, *C-2*, illustrates the normal molar contact position, facial crossbite, and lingual crossbite relationships. Facial crossbite in posterior teeth is characterized by the contact of the maxillary facial cusps in the opposing mandibular central fossae and the mandibular lingual cusps in the opposing maxillary central fossae. Facial crossbite (also termed *buccal crossbite*) results in the reversal of roles of the cusps of the involved teeth. In this reversal example, the mandibular lingual cusps and maxillary facial cusps become supporting cusps, and the maxillary lingual cusps and mandibular facial cusps become nonsupporting cusps. Lingual crossbite results in a poor molar relationship that provides little functional contact.

Posterior Cusp Characteristics

Four cusp ridges can be identified as common features of all the cusps. The outer incline of a cusp faces the facial (or the lingual) surface of the tooth and is named for its respective surface. In the example using a mandibular second premolar (see Fig. 1-41, *A*), the facial cusp ridge of the facial cusp is indicated by the line that points to the outer incline of the cusp. The inner inclines of the posterior cusps face the central fossa or the central groove of the tooth. The inner incline cusp ridges are widest at the base and become narrower as they approach the cusp tip. For this reason, they are termed *triangular ridges*. The triangular ridge of the facial cusp of the mandibular premolar is indicated by the arrow to the inner incline. Triangular ridges are usually set off from the other cusp ridges by one or more supplemental grooves. In Figure 1-41, *B-1* and *C-1*, the outer inclines of the facial cusps of the mandibular and maxillary first molars are highlighted. In

Figure 1-41, B-2 and C-2, the triangular ridges of the facial and lingual cusps are highlighted.

The mesial and distal cusp ridges extend from the cusp tip mesially and distally and are named for their directions. The mesial and distal cusp ridges extend downward from the cusp tips, forming the characteristic facial and lingual profiles of the cusps as viewed from the facial or lingual aspect. At the base of the cusp, the mesial or distal cusp ridge abuts to another cusp ridge, forming a developmental groove, or the cusp ridge turns toward the center line of the tooth and fuses with the marginal ridge. Marginal ridges are elevated, the rounded ridges being located on the mesial and distal edges of the tooth's occlusal surface (see Fig. 1-41, A). The occlusal table of posterior teeth is the area contained within the mesial and distal cusp ridges and the marginal ridges of the tooth. The occlusal table limits are indicated in the drawings by a circumferential line connecting the highest points of curvature of these cusp ridges and marginal ridges.

Some cusps are modified to produce the characteristic form of individual posterior teeth. Mandibular first molars have longer triangular ridges on the distofacial cusps, causing a deviation of the central groove (see Fig. 1-41, B-2). The mesiolingual cusp of a maxillary molar is much larger than the mesiofacial cusp. The distal cusp ridge of the maxillary first molar mesiolingual cusp curves facially to fuse with the triangular ridge of the distofacial cusp (see Fig. 1-41, C-2). This junction forms the oblique ridge, which is characteristic of maxillary molars. The transverse groove crosses the oblique ridge where the distal cusp ridge of the mesiolingual cusp meets the triangular ridge of the distofacial cusp.

Supporting Cusps

In Figure 1-42, the lingual occlusal line of maxillary teeth and the facial occlusal line of mandibular teeth mark the locations of the supporting cusps. These cusps contact opposing teeth in their corresponding faciolingual center on a marginal ridge or a fossa. Supporting cusp–central fossa contact has been compared to a mortar and pestle because the supporting cusp cuts, crushes, and grinds fibrous food against the ridges forming the concavity of the fossa (see Fig. 1-41, D). The natural tooth form has multiple ridges and grooves ideally suited to aid in the reduction of the food bolus during chewing. During chewing, the highest forces and the longest duration of contact occur at MI. Supporting cusps also serve to prevent drifting and passive eruption of teeth—hence the term *holding cusps*. Supporting cusps (see Fig. 1-42) can be identified by five characteristic features:¹¹

1. They contact the opposing tooth in MI.
2. They support the vertical dimension of the face.
3. They are nearer the faciolingual center of the tooth than nonsupporting cusps.
4. Their outer incline has the potential for contact.
5. They have broader, more rounded cusp ridges than nonsupporting cusps.

Because the maxillary arch is larger than the mandibular arch, the supporting cusps are located on the maxillary lingual occlusal line (see Fig. 1-42, D), whereas the mandibular supporting cusps are located on the mandibular facial occlusal line (see Figs. 1-42, A and B). The supporting cusps of both

arches are more robust and better suited to crushing food than are the nonsupporting cusps. The lingual tilt of posterior teeth increases the relative height of the supporting cusps with respect to the nonsupporting cusps (see Fig. 1-42, C), and the central fossa contacts of the supporting cusps are obscured by the overlapping nonsupporting cusps (see Figs. 1-42, E and F). Removal of the nonsupporting cusps allows the supporting cusp–central fossa contacts to be studied (see Figs. 1-42, G and H). During fabrication of restorations, it is important that supporting cusps are not contacting opposing teeth in a manner that results in the lateral deflection of teeth. Rather, the restoration should provide contacts on plateaus or smoothly concave fossae so that masticatory forces are directed approximately parallel to the long axes of teeth.

Nonsupporting Cusps

Figure 1-43 illustrates that the nonsupporting cusps form a lingual occlusal line in the mandibular arch (see Fig. 1-43, D) and a facial occlusal line in the maxillary arch (see Fig. 1-43, B). The nonsupporting cusps overlap the opposing tooth without contacting the tooth. The nonsupporting cusps are located in the anteroposterior plane in facial (lingual) embrasures or in the developmental groove of opposing teeth, creating an alternating arrangement when teeth are in MI (see Figs. 1-43, E and F). The maxillary premolar nonsupporting cusps also play an essential role in esthetics. In the occlusal view, the nonsupporting cusps are farther from the faciolingual center of the tooth than are the supporting cusps. The nonsupporting cusps have sharper cusp ridges that may serve to shear food as they pass close to the supporting cusp ridges during chewing strokes. The overlap of the cusps helps keep the soft tissue of the tongue and cheeks out from the occlusal tables, preventing self-injury during chewing.

Mechanics of Mandibular Motion

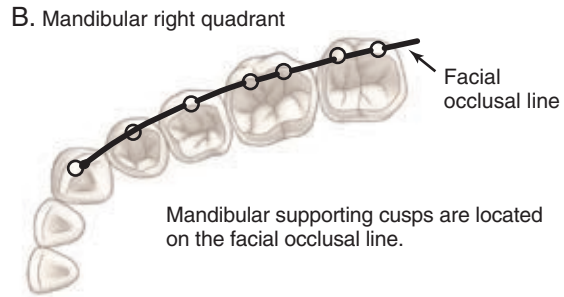
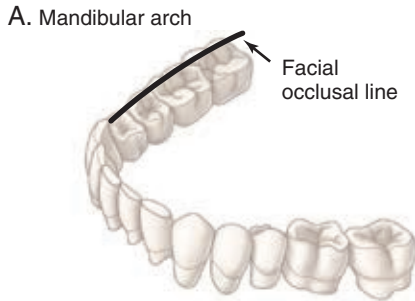
Mandible and Temporomandibular Joints

The mandible articulates with a depression in each temporal bone called the *glenoid fossa*. The joints are termed *temporomandibular joints (TMJs)* because they are named for the two bones forming the articulation. The TMJs allow the mandible to move in all three planes (Fig. 1-44, A).

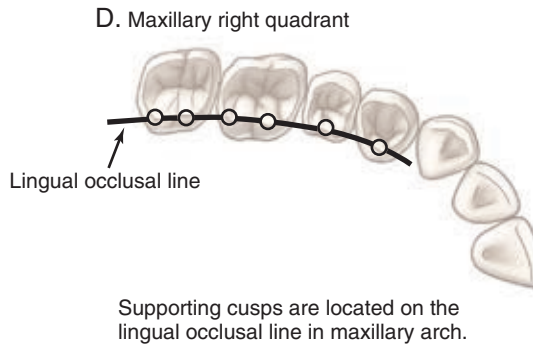
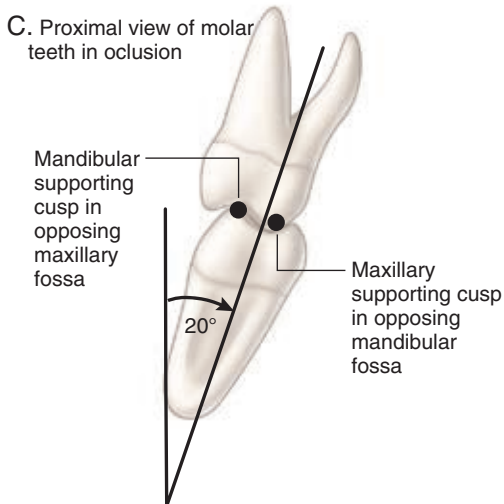
A TMJ is similar to a ball-and-socket joint, but it differs from a true mechanical ball-and-socket joint in some important features. The ball part, the mandibular condyle (see Fig. 1-44, B), is smaller than the socket, or glenoid fossa. The space resulting from the size difference is filled by a tough, pliable, and movable stabilizer termed the *articular disc*. The disc separates the TMJ into two articulating surfaces lubricated by synovial fluid in the superior and inferior joint spaces. Rotational opening of the mandible occurs as the condyles rotate under the discs (see Fig. 1-44, C). Rotational movement occurs between the inferior surface of the discs and the condyle. During wide opening or protrusion of the mandible, the condyles move anteriorly in addition to the rotational opening (see Figs. 1-44, D and E).

The disks move anteriorly with the condyles during opening and produce a sliding movement in the superior joint space between the superior surface of the discs and the articular eminences (see Fig. 1-44, B). The TMJs allow free movement of the condyles in the anteroposterior direction but resist

Synonyms for supporting cusps include:
 1. Centric cusps
 2. Holding cusps
 3. Stamp cusps



The mandibular arch is smaller than the maxillary arch so the supporting cusps are located on the facial occlusal line. The mandibular lingual cusps that overlap the maxillary teeth are nonsupporting cusps.



E. Lingual view of left dental arches in occlusion



F. Facial view of left dental arches in occlusion

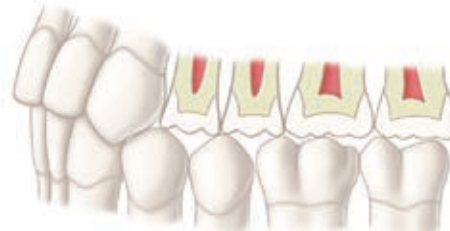


G. Mandibular nonsupporting cusps removed



Maxillary supporting cusps occluding in opposing fossae and on marginal ridges

H. Maxillary nonsupporting cusps removed



Mandibular supporting cusps occluding in opposing fossae and on marginal ridges

- Supporting cusp features:
1. Contact opposing tooth in MI
 2. Support vertical dimension
 3. Nearer faciolingual center of tooth than nonsupporting cusps
 4. Outer incline has potential for contact
 5. More rounded than nonsupporting cusps

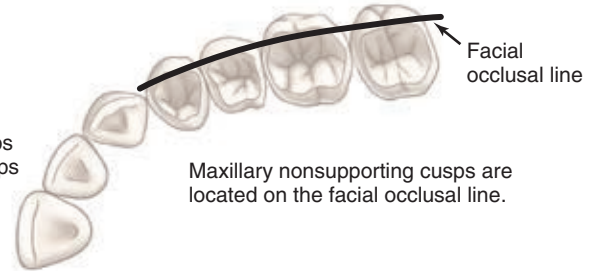
Fig. 1-42 Supporting cusps.

A. Maxillary arch



The maxillary arch is larger than the mandibular arch causing the maxillary facial line (nonsupporting cusps) to overlap the mandibular teeth.

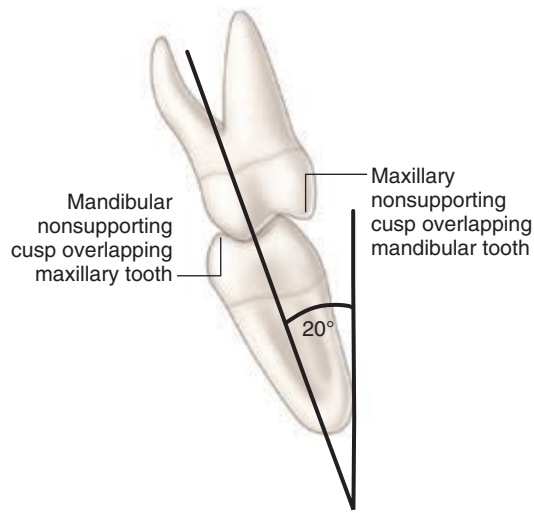
B. Maxillary left quadrant



Maxillary nonsupporting cusps are located on the facial occlusal line.

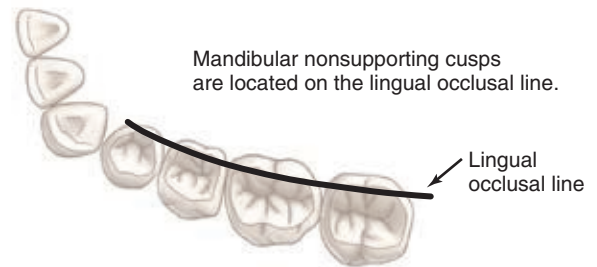
Synonyms for nonsupporting cusps include:
 1. Noncentric cusps
 2. Nonholding cusps

C. Molar teeth in occlusion



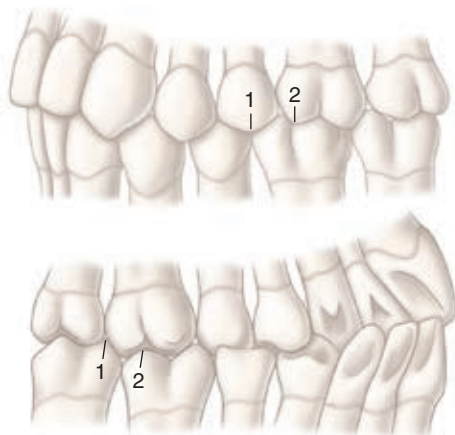
Nonsupporting cusp features:
 1. Do not contact opposing tooth in MI
 2. Keep soft tissue of tongue or cheek off occlusal table
 3. Farther from faciolingual center of tooth than supporting cusps
 4. Outer incline has no potential for contact
 5. Have sharper cusp ridges than supporting cusps

D. Mandibular left quadrant



Mandibular nonsupporting cusps are located on the lingual occlusal line.

E. Views of left dental arches in occlusion showing interdigitation of nonsupporting cusps



Nonsupporting cusp location:
 1. Opposing embrasure
 2. Opposing developmental groove

F. Views of left dental arches in occlusion showing facial and lingual occlusal lines

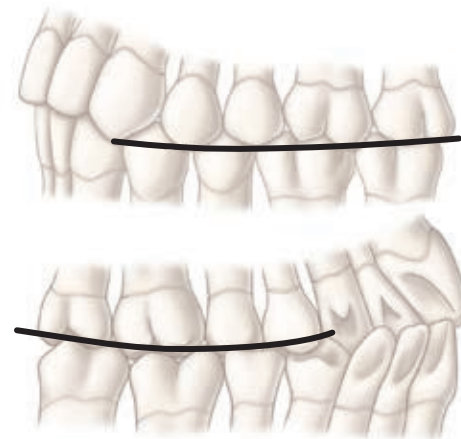


Fig. 1-43 Nonsupporting cusps.

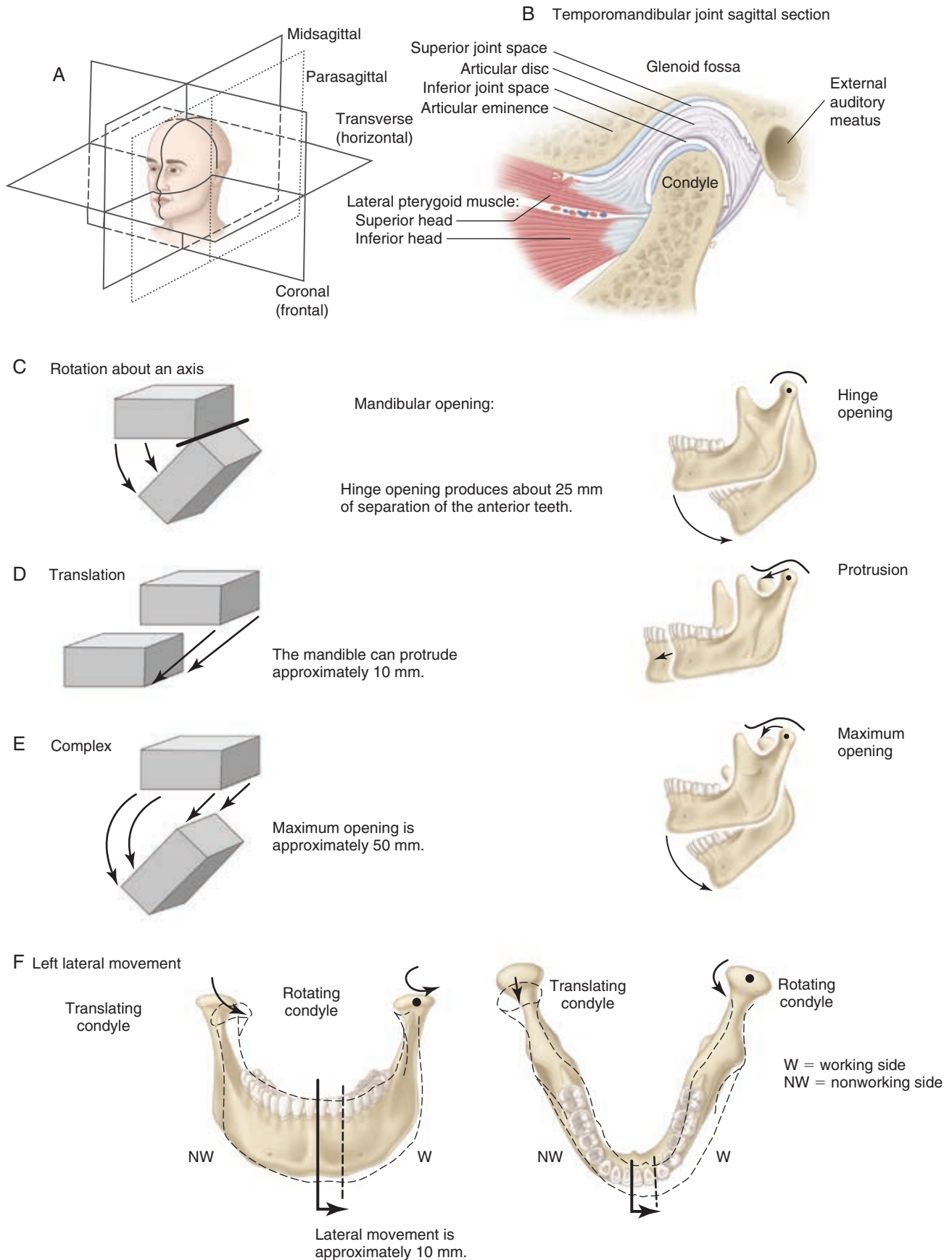


Fig. 1-44 Types and directions of mandibular movements.

lateral displacement. The discs are attached firmly to the medial and lateral poles of the condyles in normal, healthy TMJs (see Fig. 1-45, B). The disk–condyle arrangement of the TMJ allows simultaneous sliding and rotational movement in the same joint. Therefore, the TMJ may be described as a *ginglymoarthroidal* joint.

Because the mandible is a semi-rigid, U-shaped bone with joints on both ends, movement of one joint produces a reciprocal movement in the other joint. The disk–condyle complex is free to move anteroposteriorly, providing sliding movement between the disk and the glenoid fossa. One condyle may move anteriorly, while the other remains in the fossa. Anterior movement of only one condyle produces reciprocal lateral rotation in the opposite TMJ.

The TMJ does not behave like a rigid joint as those on articulators (mechanical devices used by dentists to simulate jaw movement and reference positions). Because soft tissues cover the two articulating bones and an intervening disk composed of soft tissue is present, some resilience is to be expected in the TMJs. In addition to resilience, normal, healthy TMJs have flexibility, allowing small posterolateral movements of the condyles. In healthy TMJs, the movements are restricted to slightly less than 1 mm laterally and a few tenths of a millimeter posteriorly.

When morphologic changes occur in the hard and soft tissues of a TMJ because of disease, the disk–condyle relationship is possibly altered in many ways, including distortion, perforation, or tearing of the disk, and remodeling of the soft tissue articular surface coverings or their bony support. Diseased TMJs have unusual disk–condyle relationships, different geometry, and altered jaw movements and reference positions. Textbooks on TMJ disorders and occlusion should be consulted for information concerning the evaluation of diseased joints.¹² The remainder of this description of the movement and position of the mandible is based on normal, healthy TMJs and may not apply to diseased joints.

Review of Normal Masticatory Muscle Function and Mandibular Movement

The masticatory muscles work together to allow controlled, subtle movements of the mandible. The relative amount of muscle activity depends on the interarch relationships of maxillary and mandibular teeth as well as the amount of resistance to movement.¹³⁻¹⁶ Primary muscles involved in mandibular movements include the anterior temporalis, middle temporalis, posterior temporalis, superficial masseter, deep masseter, superior lateral pterygoid, inferior lateral pterygoid, medial pterygoid, and digastric muscles.^{14,15,17} The suprahyoid, infrahyoid, mylohyoid, and geniohyoid muscles also are involved in mandibular movements but not usually included in routine clinical examinations.^{15,18} The relative amount of muscle activity of the various muscles has been identified through the use of electromyographic technology, in which electrodes were placed in the evaluated muscles,^{14,15,19} as well as on the skin immediately adjacent to the muscles of interest.^{5,9,14,15,17,18-27} The strategic three-dimensional arrangement of the muscles and the corresponding force vectors allow for the complete range of finely controlled mandibular movements. Consult an appropriate human anatomy textbook to identify the location, size, shape, three-dimensional orientation, and bony insertion of the various muscles discussed in this section.

Simple jaw opening requires the activation of digastric and inferior lateral pterygoid muscles.^{14,15,19} Fine control of opening is accomplished by simultaneous mild antagonistic activity of the medial pterygoid.^{14,15} When resistance is applied to jaw opening, mild masseter activation allows further stabilization and fine control.^{14,15}

Jaw closure requires activation of the masseter and medial pterygoid.¹⁵ Once teeth come into contact, the temporalis (anterior, middle, and posterior) muscles activate as well.^{14,15} Clenching involves maximum activation of the masseter and temporalis, moderate activation of the medial pterygoid and superior lateral pterygoid, and recruitment of the inferior lateral pterygoid, digastric, and mylohyoid muscles.^{14,15,19} In general, the superficial masseter has slightly higher activity than the deep masseter during clenching.¹⁷ Coactivation of cooperating and antagonistic muscles allows for controlled force to be applied to teeth.¹⁴

Protrusion requires maximum bilateral activation of the inferior lateral pterygoid, with moderate activation of the medial pterygoid, masseter, and digastric muscles. During protrusion minimal activation of the temporalis and superior lateral pterygoid occurs. The superior lateral pterygoid has muscle fibers that insert into the temporomandibular disc as well as the neck of the mandibular condyle (see Fig. 1-44).¹⁹ It is important to note that minimal activation of the superior lateral pterygoid is necessary if the temporomandibular disc is to rotate to the top of the condylar head as the condyle translates down the articular eminence during mandibular protrusive or excursive movements.¹⁴

Incisal biting with posterior disclusion requires maximum bilateral activity of the superficial masseter to force the incisors toward each other, as well as maximum activity of the inferior lateral pterygoid to maintain the protruded position of the condylar head down the slope of the articular eminence.¹⁴ Incisal biting also requires moderate activity of the anterior temporalis, medial pterygoid, anterior digastric, and superior lateral pterygoid.¹⁴ Note that the shift in the level of activity of the superior lateral pterygoid from protrusion to incisal biting indicates a dual role in condylar positioning and temporomandibular disc positioning or stabilization. The middle and posterior temporalis regions have minimal activity during incisal biting.¹⁵

Retrusion of the mandible requires bilateral maximum activation of the posterior and middle temporalis as well as moderate activity of the anterior temporalis and anterior digastric.^{14,15} The superior lateral pterygoid is maximally active when the mandible is retruded and the posterior teeth are clenched.¹⁴ The masseter has minimal activity in retrusion.¹⁴ The inferior lateral pterygoid and the medial pterygoid have minimal to no activity during retrusion.^{14,15}

Movement of the mandible to the right requires moderate to maximal activity of the left inferior lateral pterygoid and medial pterygoid muscles as well as the right posterior temporalis, middle temporalis, and anterior digastric.¹⁴⁻¹⁶ In addition to these, the right superior lateral pterygoid, right anterior temporalis, and left anterior digastric are minimally to moderately active.¹⁴⁻¹⁶ Activation of the right superior lateral pterygoid provides resistance to right condyle distalization as well positional support of the right temporomandibular disc. The right superficial masseter, right inferior lateral pterygoid, right medial pterygoid, left superior lateral pterygoid, left anterior temporalis, left middle temporalis, left posterior temporalis,

and left superficial masseter all have minimal activity.¹⁴⁻¹⁶ Minimal activity of the left superior lateral pterygoid allows the disk to shift distally, as needed, to remain between the condylar head and the articular eminence while translation and rotation of the left condylar head occurs. Activation of the elevator muscles on the left side provides for the translating left condyle–disk complex to remain in contact with the articular eminence. Movement of the mandible to the left follows the same pattern of coordinated muscle activity except in reverse.

Wide opening requires bilateral moderate to maximal activity of the inferior lateral pterygoid and anterior digastric muscles.¹⁴ In addition to these the medial pterygoid muscles are minimally to moderately active.¹⁴ The temporalis, masseter, and superior lateral pterygoid muscles have minimal to no activity during wide opening.^{14,15}

During mastication, the typical mandibular movement involves opening with corresponding bilateral anterior, inferior, and rotating condylar motion.^{9,28} As closure begins, the entire mandible moves laterally.⁹ As closure continues, the working side condyle shifts back to its terminal hinge position before the teeth occlude and remains nearly stationary.⁹ As the closure continues, the working side condyle shifts medially while the nonworking side condyle shifts superiorly, distally, and laterally to its terminal hinge position.⁹ The medial shift of the working side condyle may be caused by the influence of the superior lateral pterygoid muscle contraction. The opening and closing paths of the incisors vary from individual to individual and also depend on the consistency of the food being masticated.⁹ The realistic normal lower limit for the incisal opening in patients between 10 and 70 years of age is 40 mm.²⁹

To describe mandibular motion, its direction and length must be specified in three mutually perpendicular planes. By convention, these planes are sagittal, coronal (frontal), and transverse (horizontal) (see Fig. 1-44, A). The mid-sagittal plane is a vertical (longitudinal) plane that passes through the center of the head in an anteroposterior direction. A vertical plane off the center line, such as a section through the TMJ, is termed *parasagittal plane*. The coronal plane is a vertical plane perpendicular to the sagittal plane. The transverse plane is a horizontal plane that passes from anterior to posterior and is perpendicular to the sagittal and frontal planes. Mandibular motion is described in each of these planes.

Types of Motion

Centric relation (CR) is the position of the mandible when the condyles are positioned superiorly in the fossae in healthy TMJs. In this position, the condyles articulate with the thinnest avascular portion of the disks and are in an anterosuperior position against the shapes of the articular eminences. This position is independent of tooth contacts.

Rotation is a simple motion of an object around an axis (see Fig. 1-44, C). The mandible is capable of rotation about an axis through centers located in the condyles. The attachments of the disks to the poles of the condyles permit the condyles to rotate under the disks. Rotation with the condyles positioned in CR is termed *terminal hinge (TH) movement*. TH is used in dentistry as a reference movement for construction of restorations and dentures. Initial contact between teeth during a TH closure provides a reference point termed *centric*

occlusion (CO). Many patients have a small slide from CO to MI, referred to as *slide in centric*, which may have forward and lateral components, resulting in a slight superior mandibular movement. Maximum rotational opening in TH is limited to approximately 25 mm measured between the incisal edges of anterior teeth.

Translation is the bodily movement of an object from one place to another (see Fig. 1-44, D). The mandible is capable of translation by the anterior movement of the disk–condyle complex from the TH position forward and down the articular eminence and back. Simultaneous, direct anterior movement of both condyles, or mandibular forward thrusting, is termed *protrusion*. The pathway followed by anterior teeth during protrusion may not be smooth or straight because of contact between anterior teeth and sometimes posterior teeth. (See the superior border of Posselt's diagram in Fig. 1-45, A.) Protrusion is limited to approximately 10 mm by the ligamentous attachments of masticatory muscles and the TMJs.

Fig. 1-44, E, illustrates complex motion, which combines rotation and translation in a single movement. Most mandibular movement during speech, chewing, and swallowing consists of rotation and translation. The combination of rotation and translation allows the mandible to open 50 mm or more.

Fig. 1-44, F, illustrates the left lateral movement of the mandible. It is the result of forward translation of the right condyle and rotation of the left condyle. Right lateral movement of the mandible is the result of forward translation of the left condyle and rotation of the right condyle.

Capacity of Motion of the Mandible

In 1952, Posselt recorded mandibular motion and developed a diagram (termed *Posselt's diagram*) to illustrate it (see Fig. 1-45, A).³⁰ By necessity, the original recordings of mandibular movement were done outside of the mouth, which magnified the vertical dimension but not the horizontal dimension. Modern systems using digital computer techniques can record mandibular motion in actual time and dimensions and then compute and draw the motion as it occurred at any point in the mandible and teeth.⁹ This makes it possible to accurately reconstruct mandibular motion simultaneously at several points. Three of these points are particularly significant clinically—incisor point, molar point, and condyle point (Fig. 1-46, A).³¹ The incisor point is located on the midline of the mandible at the junction of the facial surface of mandibular central incisors and the incisal edge. The molar point is the tip of the mesiofacial cusp of the mandibular first molar on a specified side. The condyle point is the center of rotation of the mandibular condyle on the specified side.

Limits of Mandibular Motion: The Borders

In Fig. 1-45, A, the limits for movement of the incisor point are illustrated in the sagittal plane. The mandible is not drawn to scale with the drawing of the sagittal borders. Also, in this particular diagram, CO coincides with MI. (As mentioned earlier, in some patients, a small slide may occur from CO to MI.) The starting point for this diagram is CO, the first contact of teeth when the condyles are in CR. The posterior border of the diagram from CO to *a* in Fig. 1-45, A, is formed by the

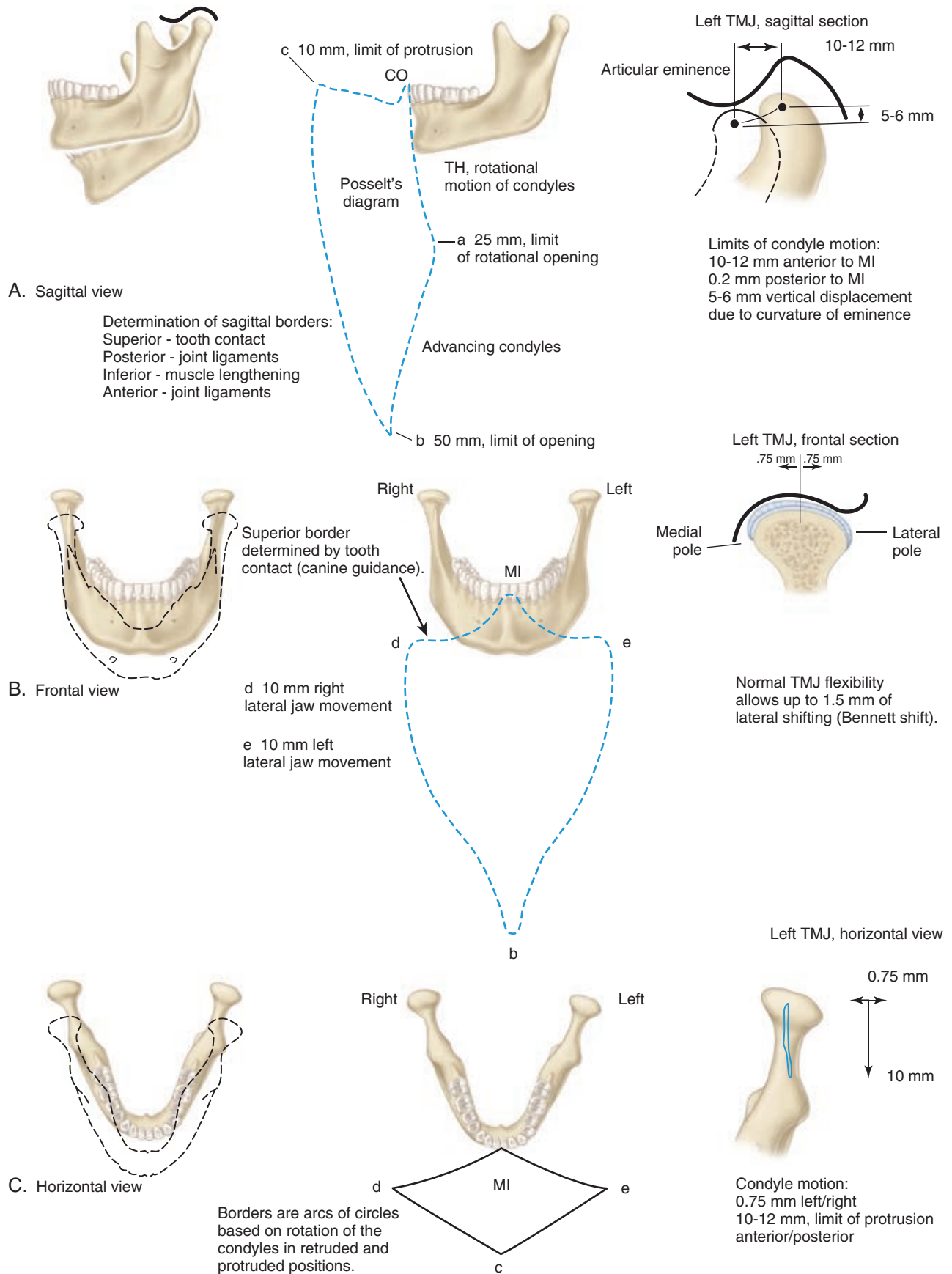


Fig. 1-45 Capacity of mandibular movement. (Mandible drawings are not to scale with border diagrams.)

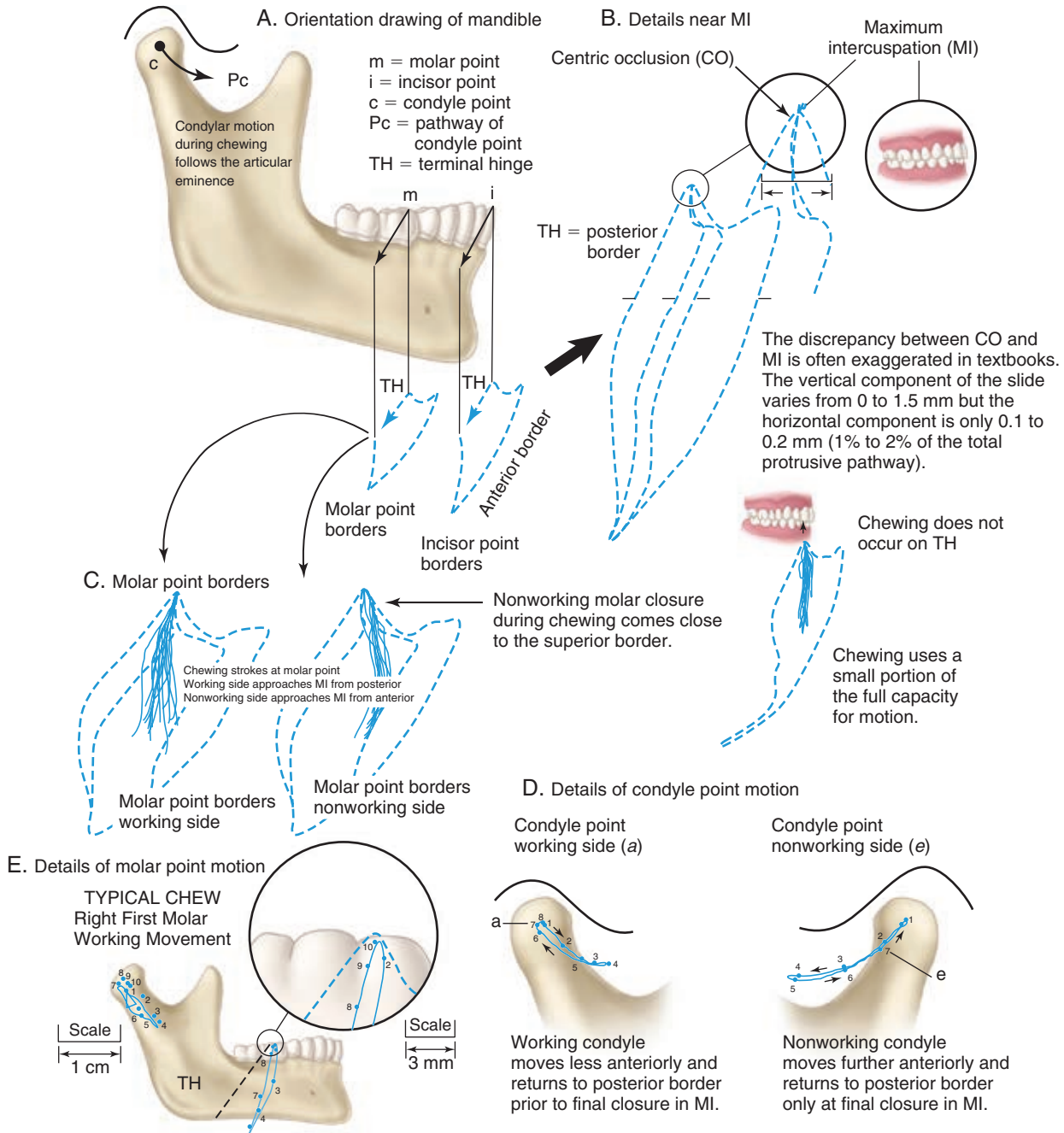


Fig. 1-46 Mandibular capacity for movement: sagittal view.

rotation of the mandible around the condyle points. This border from CO to *a* is the TH movement. *Hinge axis* is the term used to describe an imaginary line connecting the centers of rotation in the condyles (condyle points) and is useful for reference to articulators. Hinge-axis closure is a reference movement used in prosthetic dentistry and is valid only when the TMJs are properly positioned in the fossae. The inferior limit to this hinge opening occurs at approximately 25 mm and is indicated by *a* in Fig. 1-45, A. The superior limit of the posterior border occurs at the first tooth contact and is identified by CO. In many healthy adults, a sliding tooth contact movement positions the mandible slightly anteriorly or slightly anterolaterally from CO into MI (see Fig. 1-46, B).

This anterior or anterolateral movement is termed *slide in centric*.

At point *a* in Fig. 1-45, A, further rotation of the condyles is impossible because of the stretch limits of the joint capsule, ligamentous attachments to the condyles, and the mandible-opening muscles. Further opening can be achieved only by translation of the condyles anteriorly, producing the line *a-b*. Maximum opening (point *b*) in adults is approximately 50 mm. These measures are important diagnostically. Mandibular opening limited to 25 mm suggests blockage of condylar translation, usually the result of a disc derangement. Limitation of opening in the 35 to 45 mm range suggests masticatory muscle hypertonicity. The line CO-*a-b* represents

the maximum retruded opening path. This is the posterior border, or the posterior limit of mandibular opening. The line *b-c* represents the maximum protruded closure. This is achieved by a forward thrust of the mandible that keeps the condyles in their maximum anterior positions, while arching the mandible closed.

Retrusion, or posterior movement of the mandible, results in the irregular line *c-CO*. The irregularities of the superior border are caused by tooth contacts; the superior border is a tooth-determined border. Protrusion is a reference mandibular movement starting from *CO* and proceeding anteriorly to point *c*. Protrusive mandibular movements are used by dentists to evaluate occlusal relationships of teeth and restorations. The complete diagram, *CO-a-b-c-CO*, represents the maximum possible motion of the incisor point in all directions in the sagittal plane. The area of most interest to dentists is the superior border produced by tooth contact. (Mandibular movement in the sagittal plane is illustrated in more detail in Fig. 1-46.)

The motion of the condyle point during chewing is strikingly different from the motion of the incisor point. Motion of the condyle point is a curved line that follows the articular eminence. The maximum protrusion of the condyle point is 10 to 12 mm anteriorly when following the downward curve of the articular eminence. The condyle point does not drop away from the eminence during mandibular movements. Chewing movements in the sagittal plane are characterized by a nearly vertical up-and-down motion of the incisor point, whereas the condyle points move anteriorly and then return posteriorly over a curved surface (see Fig. 1-46, *B*).

In the frontal view shown in Fig. 1-45, *B*, the incisor point and chin are capable of moving about 10 mm to the left or right. This lateral movement—or excursion—is indicated by the lines *MI-d* to the right and *MI-e* to the left. Points *d* and *e* indicate the limit of the lateral motion of the incisor point. Lateral movement is often described with respect to only one side of the mandible for the purpose of defining the relative motion of mandibular teeth to maxillary teeth. In a left lateral movement, the left mandibular teeth move away from the midline, and the right mandibular teeth move toward the midline.

Mandibular pathways directed away from the midline are termed *working* (synonyms include *laterotrusion*, *functional*), and mandibular pathways directed toward the midline are termed *nonworking* (synonyms include *mediotrusion*, *non-functional*, and *balancing*). The terms *working* and *nonworking* are based on observations of chewing movements in which the mandible is seen to shift during closure toward the side of the mouth containing the food bolus. The working side is used to crush food, whereas the nonworking side is without a food bolus.

The left lateral mandibular motion indicated by the line *MI-e* (see Fig. 1-45, *B*) is the result of rotation of the left condyle (working side condyle) and translation of the right condyle (nonworking side condyle) to its anterior limit (see Fig. 1-44, *F*). The translation of the nonworking condyle in a right lateral motion of the mandible can be seen in the horizontal view in Figure 1-47, *A* and *B*. The line *e-b* in Figure 1-45, *B*, is completed by mandibular opening that is the result of rotation of both condyles and translation of the working condyle to its maximum anterior position. The line *b-d-MI* represents similar motions on the right side.

The vertical displacement in the incisor point line from *MI* to *e* or *d*, shown in Fig. 1-45, *B*, is the result of teeth, usually canines, gliding over each other. Vertical displacement of the mandible secondary to gliding contact of canine teeth is termed *canine guidance* and has significance for restorative procedures. The gliding tooth contact supplied by canine guidance provides some of the vertical separation of posterior teeth during lateral jaw movements and prevents potentially damaging collisions of their cusps secondary to the increased elevator muscle activity that occurs when posterior teeth come into contact. When the canine guidance is shallow, the occlusal surface of posterior teeth must be altered to prevent potentially damaging contacts in lateral movements. An articulator aids in the evaluation of the relationships of posterior teeth during fabrication of indirect posterior restorations.

Flexibility in the TMJs allows the condyles to move slightly to the working side during the closing stroke. This lateral shift of the condylar head, illustrated in the frontal view of a right TMJ in Fig. 1-45, *B*, is termed *Bennett shift* or *lateral shift* and varies from patient to patient (see Figs. 1-47, *B-D*). The magnitude of the shift in normal TMJs varies from 0 to 1.5 and normally has little effect on posterior teeth. Excessive lateral shift may be associated with morphologic changes of the TMJs. Excessive lateral condylar shifting coupled with shallow canine guidance poses a significant problem, however, for restorative procedures because the resulting lateral mandibular movements are flat; consequently, little separation of posterior teeth occurs, resulting in increased contact of posterior teeth.

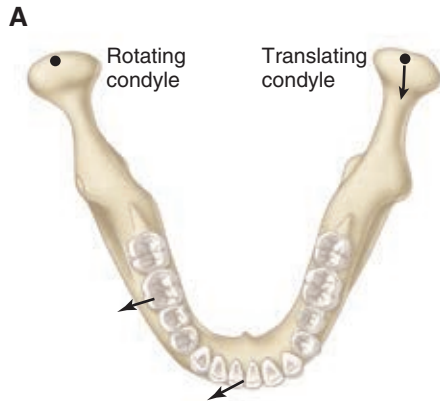
In Fig. 1-45, *C*, the horizontal view illustrates the capability of the mandible to translate anteriorly. Extreme left lateral motion is indicated by *MI-e* produced by rotation of the left condyle (working condyle) and translation of the right condyle (non-working condyle) to its anterior limit. From point *e*, protrusion of the left condyle moves the incisor point to *c*, the maximum protruded position where both condyles have translated.

Sagittal View

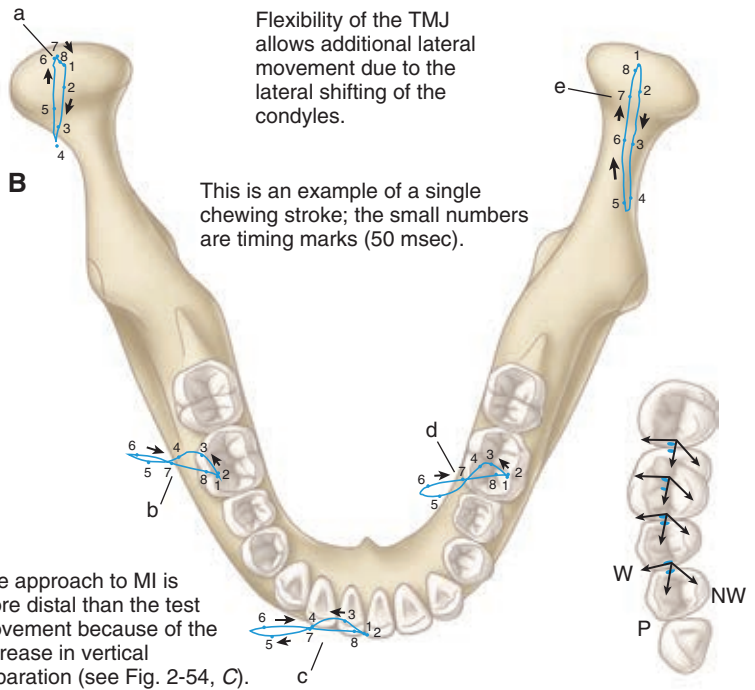
In Fig. 1-46, the drawing of the mandible is used to orient the sagittal border diagrams. Projected below the mandible are diagrams of the incisor point (*i*) and molar point (*m*) borders (see Fig. 1-46, *A*). The molar point borders are similar to the incisor point diagram but are shorter in the vertical dimension because the molar point is closer to the TMJ. Closure of the jaw on the posterior border is termed *TH closure*. *TH closure* is a simple arc of a circle with a radius equal to the length from the incisor point to the center of the hinge axis (condyle point *c*). The area near *MI* is enlarged to illustrate the details of the *TH closure* (see Fig. 1-46, *B*). *CO* and *MI* are located close to each other. In the magnified view, teeth can be seen to guide the mandible from *CO* to *MI*. The gliding (sliding) contact typically is 1 to 2 mm long and can occur on any of the posterior teeth. The horizontal component of this slide is only a few tenths of a millimeter in healthy joints but may position the condyle(s) on the slope of the articular eminence, a position which requires protrusive muscle activity to maintain.^{14,19}

The clinical significance of the shift between *CO* and *MI* has been a source of debate in dentistry, resulting in extensive literature on the topic.^{32,33} Clinical ramifications may include

Lateral movement is produced by anterior translation of one condyle, producing rotation about the center in the opposite condyle.



Test movements such as this right lateral movement are made in the direction opposite to the corresponding chewing closure illustrated in B.



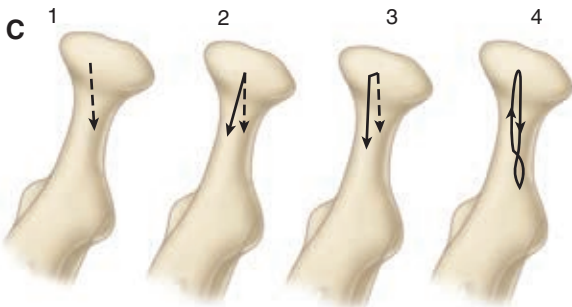
This is an example of a single chewing stroke; the small numbers are timing marks (50 msec).

The approach to MI is more distal than the test movement because of the increase in vertical separation (see Fig. 2-54, C).

Opposing maxillary teeth with superimposed working (W), non-working (NW), and protrusion (P) test movements.

Nonworking condyle movement:

1. Condylar translation with rotation about the center of the opposite condyle
2. Solid line indicates the change in the condylar path due to progressive shifting of the center of rotation in the opposite condyle
3. Solid line indicates the condylar path resulting from immediate shifting of the center of rotation of the opposite condyle
4. Observed motion of the condyle during chewing: note shifting as closing is initiated and the return to normal position at the end of closure



- Effect of shifting at first molar:
1. Little change on working side
 2. Wide lateral motion on nonworking side

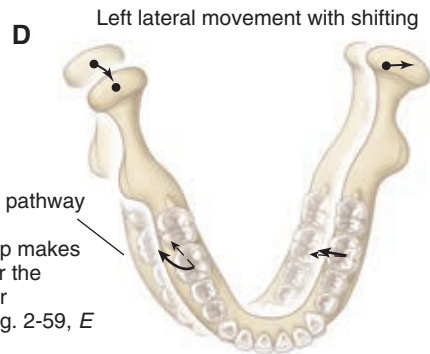


Fig. 1-47 Mandibular capacity for movement: horizontal view.

an increased risk of the development of pathologic changes in the TMJs and/or pain associated with the muscles of mastication. It has been observed that asymmetrical shifts between CO and MI were related to symptoms and signs of temporomandibular disorders, whereas symmetrical shifts were not.²⁹ It has been noted that increasing symptoms and signs of temporomandibular disorders were associated with increasing shift distance from CO to MI.³⁴ However, a shift of greater than 2 mm, mediotrusive posterior tooth interferences, and a large overjet were only weakly associated with masticatory muscle pain, suggesting other factors in addition to occlusal relationships are involved.^{35,36} Failure to recognize that some patients have damaged TMJs can further complicate the determination of the clinical significance of a CO–MI slide. Damage to the TMJs as a consequence of arthritic processes or internal derangements may change the relationship of CO to MI.

Chewing movements at the incisor point involve an almost vertical opening and a loop slightly to the posterior on closing, using only a small percentage of the total area of the sagittal border diagram. During chewing, the only border contact occurs at MI. The closing strokes never approach TH, indicating that at least one condyle (on the nonworking side) remains advanced during the closing stroke. The condyle point moves along the pathway *Pc* during all movements other than TH (see Fig 1-46). In contrast to the nearly vertical closing strokes at incisor point, the sagittal closing strokes at the molar point involve an anterior component on the working side and a posterior component on the nonworking side. This difference in molar point movement is caused by the deviation of the jaw to the working side during closure, illustrated by the difference in motion of the working side and nonworking side condyles. The nonworking side closing strokes closely approach the superior border, indicating the potential for undesirable contact on the nonworking side (see Fig. 1-46, C).

Horizontal View

Fig. 1-47, A, shows a horizontal view (or occlusal view when referring to teeth) of the mandible with superimposed incisor, molar, and condyle point test movements. Chewing movements are characterized by wide lateral movement of the mandible to the working side during closure (see Fig. 1-47, B). When viewed from above, the pathways of the molar and incisor points are typically in a figure-of-8 pattern, with an S-shaped lateral opening motion and a straight medial closing stroke. Important differences exist in the directions of closure for the molar point on the working and nonworking sides. During closure on the working side (labeled *b* in Fig. 1-47, B), mandibular teeth medially approach maxillary teeth from a slightly posterior position and move slightly anteriorly into MI. During closure on the nonworking side (the contralateral side, labeled *d* in Fig. 1-47, B), mandibular molar teeth approach the maxillary teeth in a medial-to-lateral direction from a slightly anterior position and move slightly posteriorly into MI. The closing strokes are the same pathways generated by guided (test) lateral mandibular movements used to check the occlusion except the directions traveled are opposite (see Fig. 1-47, B, inset). On the inset drawing of the maxillary left teeth in Figure 1-47, B, the working, nonworking, and protrusive pathways are marked *W*, *NW*, and *P*. These are the guided test movements employed by dentists to assess the occlusal function of teeth.

The horizontal, enlarged view of the mandible showing condyle point movement (working side labeled *a*; nonworking side labeled *e*) during chewing is important because it illustrates the lateral shift of the condyles during the closing stroke (see Fig. 1-47, B). Opening, in the typical chewing motion illustrated here, involves movement of both condyle points on the mid-sagittal path, producing the vertical drop in the incisor point seen in the sagittal view. Lateral opening may be seen in normal children and adults with worn and flattened teeth. As closing is initiated, the mandible shifts laterally, moving both condyle points to the working side. The nonworking condyle movement closely approaches its medial border during the closing stroke (see Fig. 1-47, C). During final closure, when teeth are brought into MI, the condyle points return to their starting positions. Contact and gliding on the inclines of teeth are responsible for bringing the mandible into its final, fully closed position (MI).

Allowance for lateral displacement of the condyles during lateral jaw movements is built into semi-adjustable articulators in the form of a Bennett angle or progressive lateral shift adjustment. The progressive lateral shift allows the condyles to shift gradually during lateral mandibular movement. As a result of mandibular movement studies, more recent articulator models have replaced the progressive lateral shift with immediate shift. Shifting of the mandible, as depicted by the shift in the condyle points, results in a similar shift at the teeth that cannot be simulated by progressive shift (see Fig. 1-47, C).

Frontal view

In Fig. 1-48, A, lateral movement of the mandible on the superior border is controlled by three elements—the rotating condyle, the translating condyle, and the working-side canine. During chewing closures, mandibular teeth approach maxillary teeth from a lateral position. Frequent contact with the border occurs in the incisor and molar point tracings, indicating that lateral tooth gliding is common during chewing. This gliding contact occurs on the teeth having the highest projecting cusps that form the superior border (usually canines).

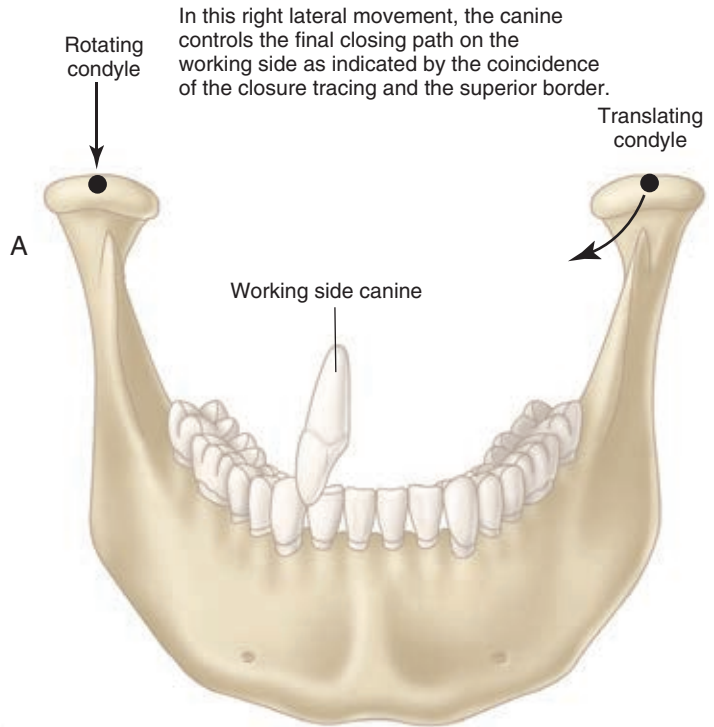
The incisor point tracing is projected below the drawing of the mandible in Fig. 1-48, A. The chewing strokes show the gliding contact on the border. The incisor-point superior border is shaped by the lingual surfaces of the guiding teeth, which most frequently are maxillary canines. In Fig. 1-48, B, the lateral side of the molar-point superior border is shaped by the working side tooth guidance, which is usually the maxillary canine. The medial side of the molar-point superior border is predominately formed by the nonworking condyle moving over the articular eminence. The shape of the superior border at the molar point is the critical factor for determining the location and height of the molar cusps during restorative procedures. It is easy to visualize the effect of changes in the cusp height when viewing the close-up of molar teeth in the magnified inset.

Articulators and Mandibular Movements

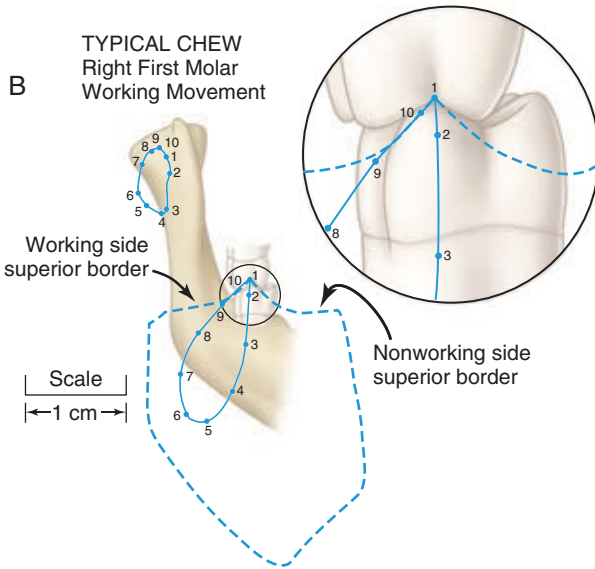
Figures 1-49 to 1-52 illustrate the scientific basis for the use of articulators to aid in diagnostic evaluation of occlusion and fabrication of dental restorations.^{34,37-39} In these figures, the

Text continued on p. 36

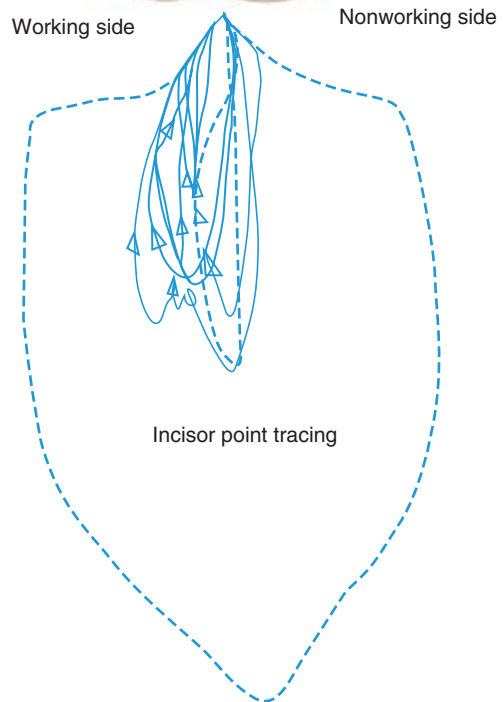
The superior border of the incisor point tracing is determined by the canine teeth, but the molar point superior border is influenced by the pathway of the condyle point. Canine guidance and articular eminence slope are mechanically coupled to produce the superior border of the molar point tracing but they do not contribute equally. The canine is primarily responsible for the superior border of molar point on the working pathway (away from the midline). The nonworking side articular eminence has the dominant influence on the nonworking pathway (toward the midline) on the molar point superior border.



If the molar cusps are higher than the border then they will collide during chewing. This is more likely to occur on the nonworking side.



Mandibular closure during chewing approaches MI from a laterally shifted position.



Chewing movements show frequent encounters with the superior border in the incisor point tracing suggesting frequent contact of the canine teeth during closing.

Fig. 1-48 Mandibular capacity for movement: frontal view.

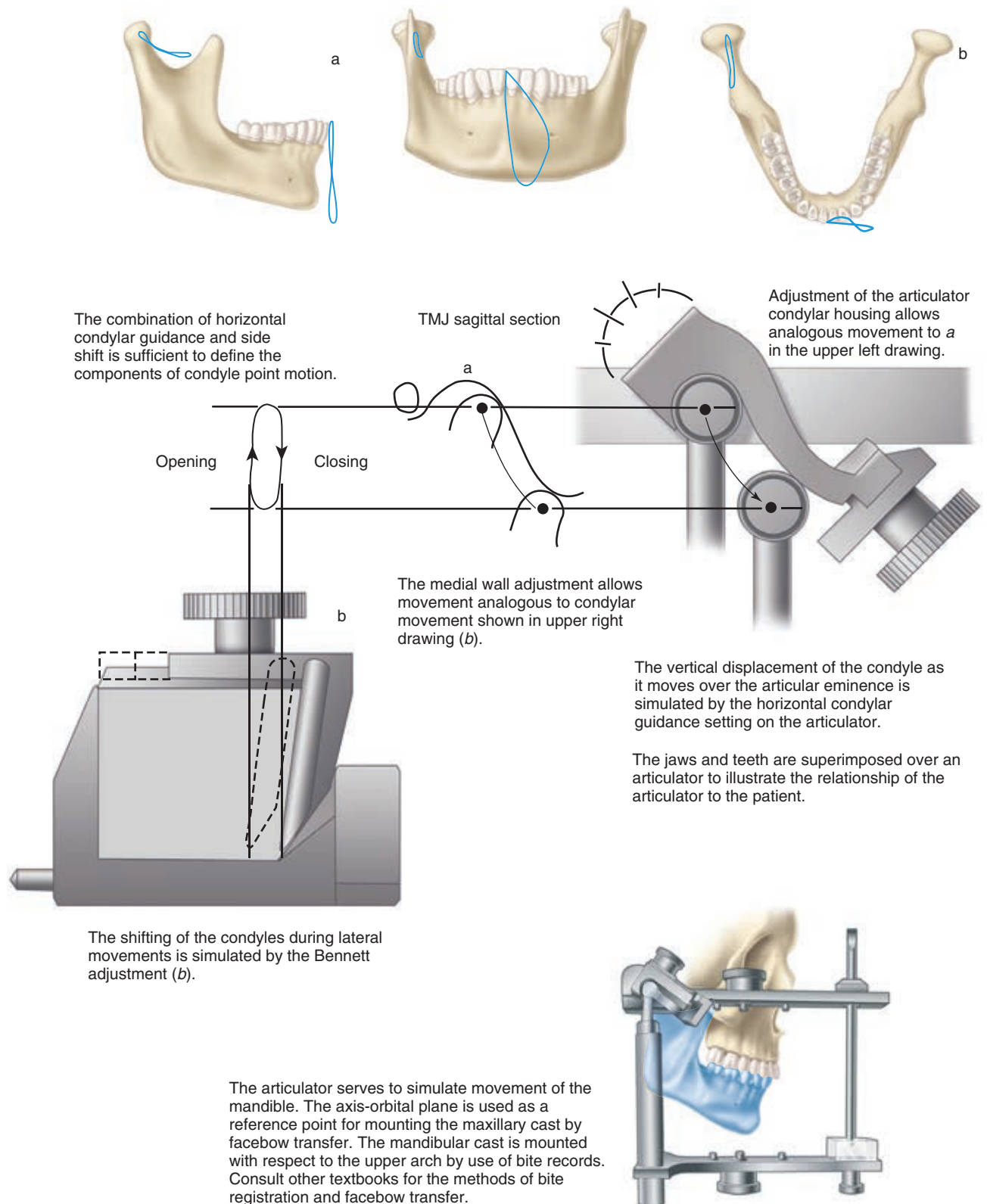
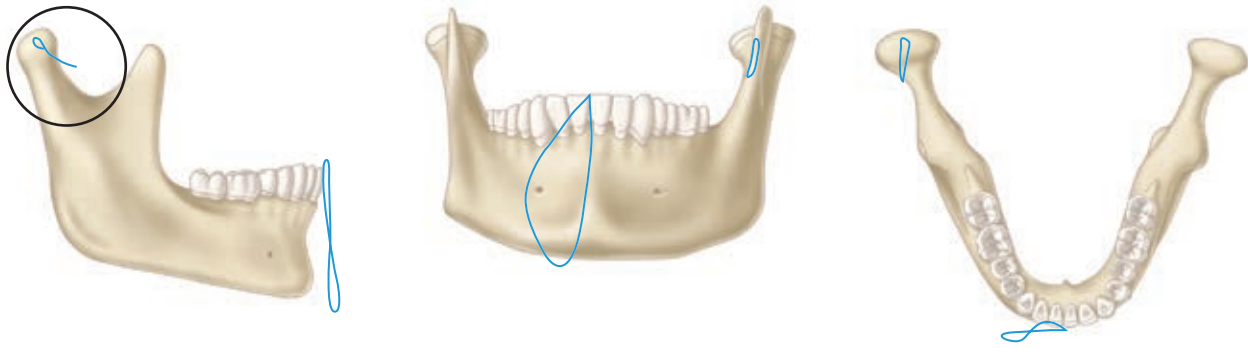
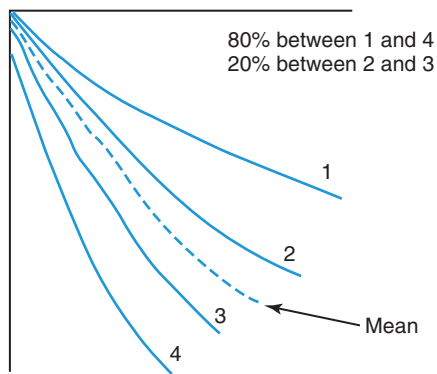


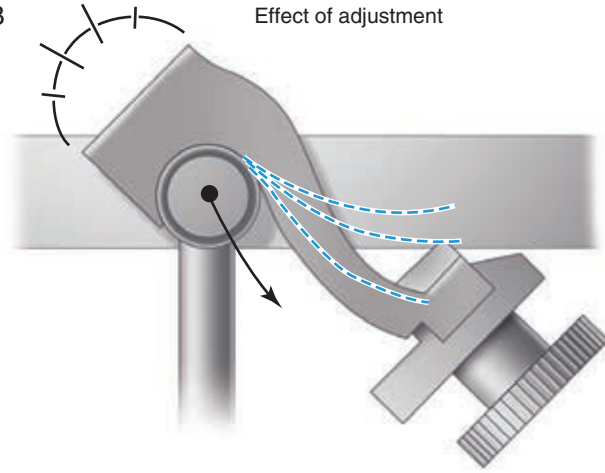
Fig. 1-49 Relationship between condylar movement and articulator settings.



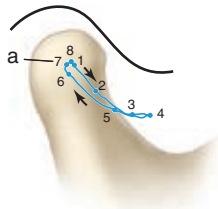
A Observed pathways



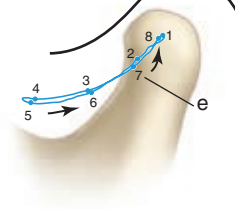
B Effect of adjustment



C Working condyle point (a) movement



D Nonworking condyle point (e) movement



E, F, and G illustrate the combined effect of anterior and posterior guidance on the superior border of molar point. The angulation of the posterior guidance is indicated in degrees for each figure. The absence of anterior guidance is indicated by *a* and presence of anterior guidance by *b*. The tracing of the movement of the mesiolingual cusp of the maxillary molar is made on the grid in each figure. Note that the absence of anterior guidance reduces the separation of the posterior teeth, but has the greatest effect when the posterior guidance is shallow.

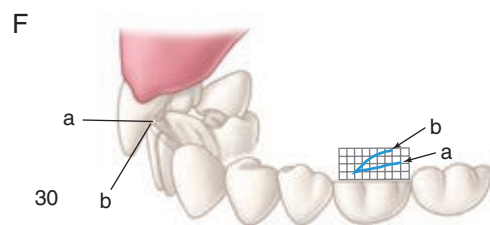
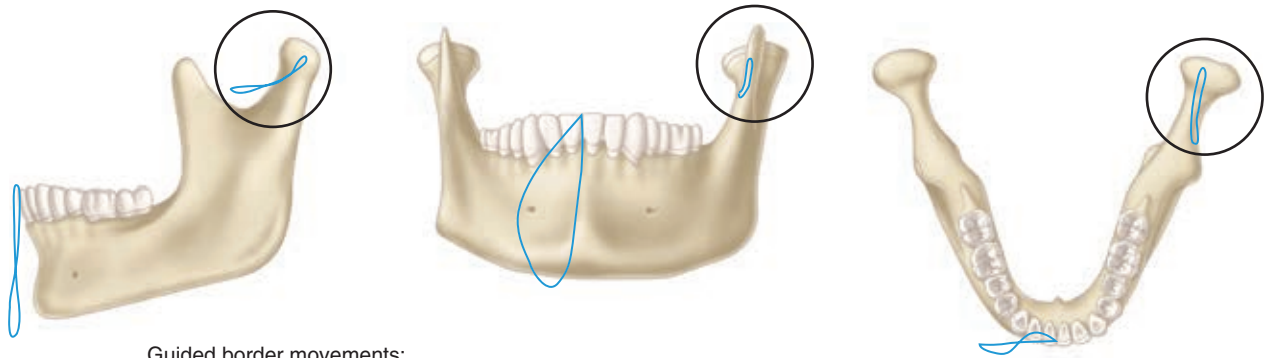
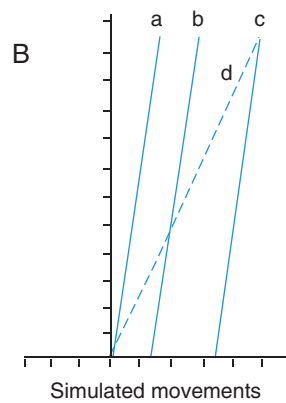
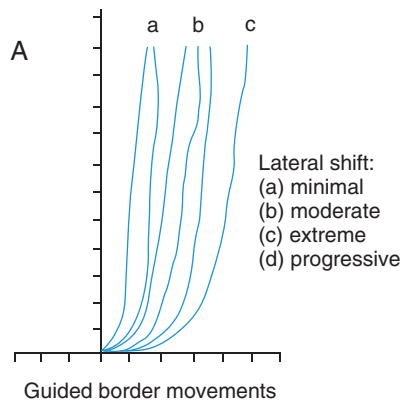


Fig. 1-50 Horizontal condylar guidance.

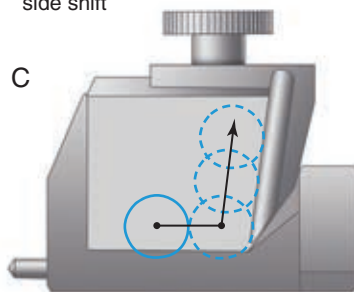


Guided border movements:
 1. Follow chewing pathway in reverse direction
 2. Differences are due to amount of side shift
 3. Progressive side shift was not observed

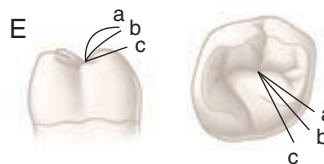
Simulated movements:
 1. Are arcs of circles
 2. Differ by side shift
 3. Are comparable to guided movements



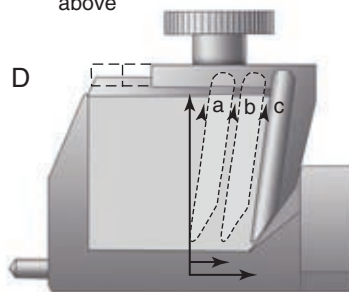
Underside of condylar housing
 condylar ball movement at extreme
 side shift



Maxillary molar; showing
 change in nonworking
 movement of mandibular
 distofacial cusp with
 increasing lateral shift



Adjustment of the lateral shift to
 produce simulated movements
 above



Mandibular molar; showing
 change in nonworking
 movement of maxillary
 mesiolingual cusp with
 increasing lateral shift

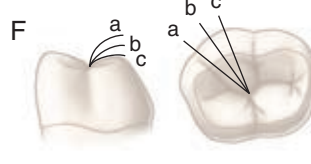


Fig. 1-51 Lateral condylar guidance: the medial wall.

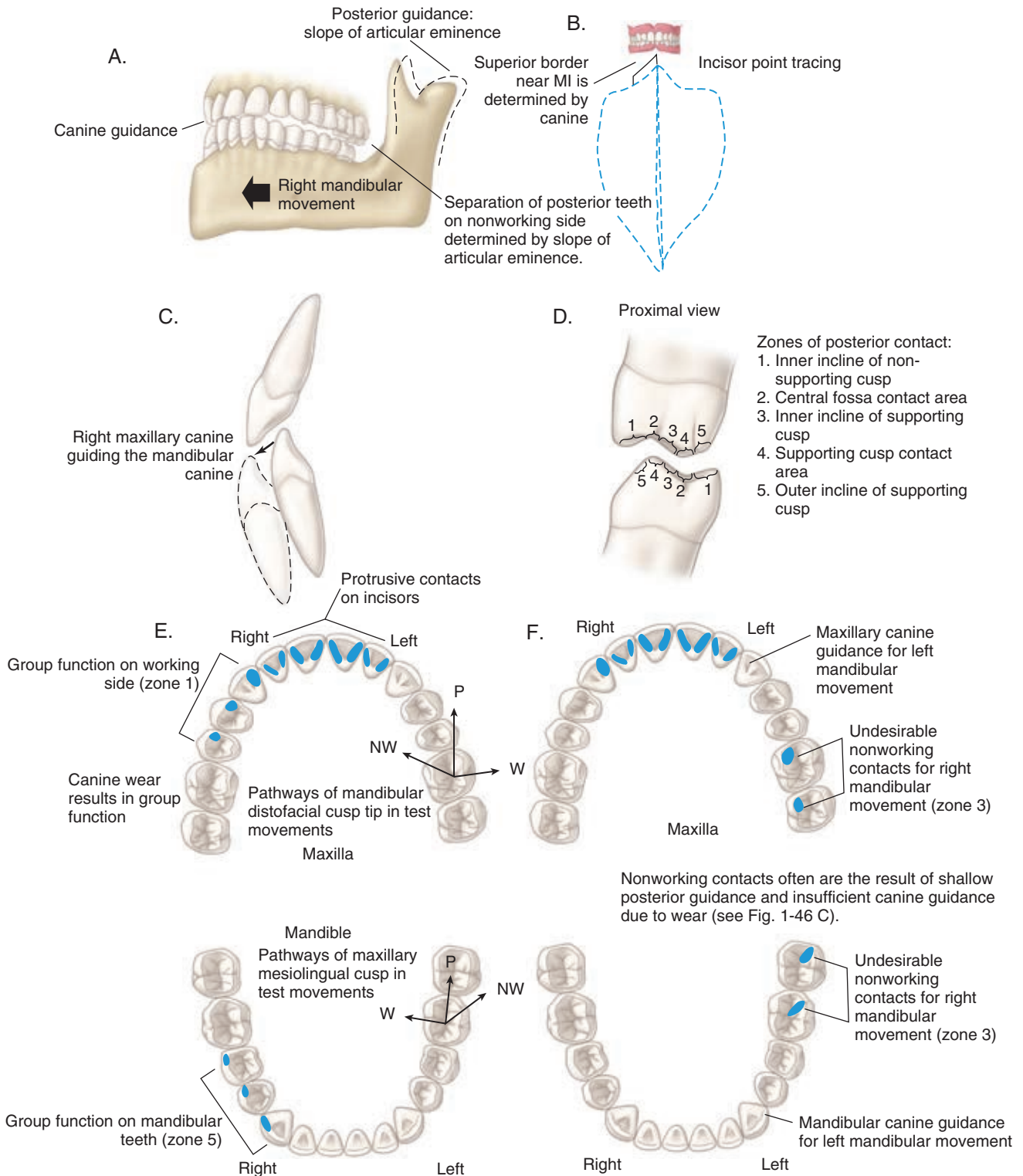


Fig. 1-52 Tooth contacts during mandibular movement.

characteristics of chewing movements and dentist-guided test movements are compared with the characteristics of movements produced by simple articulators. This can be done by comparing the cusp movement near MI produced by the articulator with the cusp movement observed in chewing studies or guided movements. Additionally, the changes in

cusp movement near MI that occur because of variations in the adjustment of articulators are discussed with respect to their effects on dental restorations.

Fig. 1-49 illustrates the relationship between condylar movement and articulator settings. Together, the horizontal condylar guidance setting and the medial-wall setting of an

articulator supply sufficient information to approximate the condyle point movement near MI. The horizontal condylar guidance setting approximates the slope of the articular eminence; the medial-wall setting approximates the lateral shift. Collectively, these two settings are referred to as *posterior guidance*.

Posterior guidance alone is not sufficient to simulate mandibular movements near MI because tooth guidance also is involved in forming the superior border. Full-arch casts mounted in the articulator, with the use of techniques that correctly position the maxillary cast relative to the artificial TMJs, supply the information concerning anterior guidance from the canines and the incisors. The mechanical coupling of the anterior guidance and posterior guidance settings provides sufficient information to simulate the movement of posterior teeth on the superior border. The articulator can be used to diagnose the need to alter the anterior guidance and to design restorations that avoid cusp collisions in mandibular movements.

In Fig. 1-50, horizontal condylar guidance is used to describe the shape of the pathway of condyle point movement in the anteroposterior direction. The condyles move in contact with the curved surface of the articular eminence. More recent designs of semi-adjustable articulators have adopted curved surfaces to simulate the curvature of the articular eminence. Rotation of the condylar housing downward increases the slope of the guiding surface of the articulator. The range of adjustment of horizontal condylar inclination is well within the range of measured movements in human subjects (see Figs. 1-50, A and B).⁴⁰ Although differences may exist in the relative anterior movements of the two condyles (see Figs. 1-50, C and D), only the first few millimeters of movement have significant effects on the posterior teeth. Horizontal condylar guidance and anterior guidance (supplied by the mounted casts) are mechanically coupled to produce the separation of posterior teeth. The combined guidance determines the amount of (or lack of) vertical separation of posterior teeth as the mandible leaves or enters MI during protrusion and lateral movements.

Lateral mandibular movements also produce separation of posterior teeth. Horizontal guidance of the nonworking condyle coupled with working-side canine guidance determines the amount of vertical separation of posterior teeth on both sides as the mandible leaves or enters MI during lateral movements (see Fig. 1-48). This information can be used to design restorations with the proper cusp location and height to avoid collisions during chewing and other mandibular movements.

The slope of the articular eminence varies considerably among individuals. The effect of different slopes can be evaluated by altering the horizontal condylar guidance on articulators. Increasing the horizontal condylar guidance increases the steepness of the mandibular molar movement in protrusion. The movement of the maxillary mesiolingual cusp relative to the mandibular molar is plotted in Figure 1-50, E through G, for 20-, 30-, and 50-degree slopes.⁴¹ The effect of removing the anterior guidance (*a*) is drawn on the same grid. The loss of anterior guidance has the greatest effect when the horizontal condylar guidance is shallow (20 degrees) and has the least effect when the horizontal condylar guidance is steep (50 degrees). Anterior guidance has an additive effect on the molar pathway at all degrees of horizontal guidance. This is an

important observation because anterior guidance often can be changed by the dentist. The anterior guidance can be increased by restorative or orthodontic means to facilitate the separation of posterior teeth in patients who have shallow horizontal guidance.

TMJ lateral shift may be measured clinically and transferred to an adjustable articulator. A series of tracings of guided movements from different patients is shown in Fig. 1-51, A.^{42,43} All the tracings are parallel after the first few millimeters of movement. The difference from one patient to the next is the result of the amount of lateral shift. Fig. 1-51, B, illustrates simulations of arcs at different degrees of lateral shift; the similarity of lines *a*, *b*, and *c* to the lines similarly marked in Fig. 1-51, A, should be noted. None of the tracings of lateral condylar movement exhibits the “progressive” lateral shift indicated by the dashed line in Fig. 1-51, B. Fig. 1-51, C, illustrates the underside of a condylar housing of an articulator. Shifting the medial wall simulates TMJ lateral shift and allows movements similar to those illustrated in Fig. 1-51, A. Fig. 1-51, D, illustrates how movements *a*, *b*, and *c* were made for Fig. 1-51, B, by shifting the medial wall of the condylar box. Increasing lateral shift of the TMJ results in significant changes in movement of the molar point near MI (see Fig. 1-51, E). The working-side movement is least affected because it is already a directly lateral movement. The nonworking molar-point movement is changed in the lateral and horizontal components. The lateral pathway is extended progressively more laterally in patients with excessive lateral shift of the TMJs. The horizontal effect is a “flattening” of the pathway by reduction of the vertical separation. These effects are illustrated by tracings of molar-point movement on an articulator as the amount of lateral shift is increased from 0 to 3. The effect of increasing lateral shift is to increase the likelihood of collisions of the mesiolingual cusps of the maxillary molars with the mandibular distofacial cusps of the molars on the nonworking side (see Figs. 1-51, E and F). These types of undesirable contact between the opposing supporting cusps are termed *nonworking interferences*.

Tooth Contacts during Mandibular Movements

Dentists must design restorations capable of withstanding the forces of mastication and clenching. The choice of restorative material and the design of the restoration frequently are influenced by the need to withstand forceful contact with opposing teeth. Evaluation of the location, direction, and area of tooth contacts during various mandibular movements is an essential part of the preoperative evaluation of teeth to be restored. Anterior teeth support gliding contacts, whereas posterior teeth support the heavy forces applied during chewing and clenching. Fig. 1-52 shows a variety of tooth contact relationships. In Fig. 1-52, A, a right mandibular movement is illustrated, showing the separation of the posterior teeth on the left, or nonworking, side. This separation of posterior teeth results from the combined effects of the canine guidance and the slope of the articular eminence on the nonworking side. The effect of the canine guidance is illustrated in the incisor point tracing in Fig. 1-52, B. The superior border on either side of MI is determined by the shape of the lingual surfaces of maxillary canine teeth. Guiding contact between the right canines is illustrated in Fig. 1-52, C. A variety of areas on

posterior teeth may contact the opposing tooth during mandibular movements. In Fig. 1-52, *D*, the opposing surfaces of molar teeth are divided into five areas:

1. *Inner incline of the nonsupporting (noncentric) cusp.* This area has the potential for undesirable contact in working side movements by contacting the outer aspect of the supporting (centric) cusp (area 5).
2. *Fossa or marginal ridge contact area.* This is the main holding contact (or centric stop) area for the opposing supporting cusp.
3. *Inner incline of the supporting (centric holding) cusp.* This area has the potential for undesirable contact during nonworking movements.
4. *Contact area of the supporting (centric holding) cusp.* This is the main cusp contact area.
5. *Outer aspect of the supporting (centric holding) cusp.* This area sometimes participates in working side movements by contacting the inner incline of the nonsupporting (noncentric) cusp (area 1).

Anterior Tooth Contacts

During anterior movement of the mandible (i.e., protrusion), the lower anterior teeth glide along the lingual surfaces of maxillary anterior teeth (see Figs. 1-52, *E* and *F*). The combination of the anterior guidance (slope and vertical overlap of anterior teeth) and the slope of the articular eminence (horizontal condylar guidance on the articulator) determines the amount of vertical separation of the posterior teeth as the mandible moves anteriorly. Some texts refer to this separation as *disocclusion* (or *disclusion*) of the posterior teeth. Multiple contacts between the opposing dental arches on anterior teeth are desirable in protrusion movements. With protrusion, multiple contacts serve to prevent excessive force on any individual pair of gliding teeth. Posterior tooth contact during protrusion is not desirable because it may overload the involved teeth secondary to the increased elevator muscle activity that occurs when posterior teeth come into contact. It has been shown that when anterior teeth are in contact and posterior teeth are discluded, elevator muscles are less active.^{13-16,20,24,27,44}

Articulator-mounted casts can be used to assess the superior border near MI, which is the critical zone for tooth contact. This information is useful during the fabrication of indirect restorations because the position and height of the restored cusps can be evaluated and adjusted in the laboratory, which minimizes the chairside time and effort required to adjust the completed restorations.

Posterior Tooth Contacts

In idealized occlusal schemes designed for restorative dentistry, posterior teeth should contact only in MI such that the force which results from maximum activation of the elevator muscles is distributed evenly over multiple teeth.^{13-16,20,24,25,27,44} Any movement of the mandible should result in the separation of posterior teeth by the combined effects of anterior guidance and the slope of the articular eminence (horizontal condylar guidance on the articulator). This separation of posterior teeth during protrusion or excursion results in a decrease in the level of activity and force being generated by the elevator muscles.^{13,15,16,18,20,24,27,44}

Forceful contact of individual posterior tooth cusps during chewing and clenching may lead to muscle discomfort, damage to teeth and supporting structures, or both in some patients. In patients with shallow anterior guidance or open bite, restoration is more difficult without the introduction of undesirable tooth contacts. Articulator-mounted casts may be used to assess and solve restorative problems that are difficult to manage by direct intraoral techniques.

The side of the jaw where the bolus of food is placed is termed *the working side*. Working side also is used in reference to jaws or teeth when the patient is not chewing (e.g., in guided test movements directed laterally). The term also can identify a specific side of the mandible (i.e., the side toward which the mandible is moving). During chewing, the working side closures start from a lateral position and are directed medially to MI. Test movements are used by dentists to assess the occlusal contacts on the working side; for convenience, these movements are started in MI and are continued laterally. The working side test movement follows the same pathway as the working side chewing closure but occurs in the opposite direction. The preferred occlusal relationship for restorative purposes is one that limits the working side contact to canines only. This is directly related to the observation that compared with canine guidance alone, guidance from canines and posterior teeth will allow greater activation of the anterior temporalis muscle and longer activation of the masseter and temporalis muscles during excursive movements.^{24,27,44}

Tooth contact posterior to the canine on the working side may occur naturally in worn dentitions. As canines are shortened by wear, separation of the posterior teeth diminishes. Lateral mandibular movements in worn dentitions successively bring into contact more posterior teeth as the heights of the canines decrease. Multiple tooth contacts during lateral jaw movements are termed *group function*. Right-sided group function is illustrated in Fig. 1-52, *E*, compared with left canine guidance contact in Fig. 1-52, *F*. Because the amount of torque and wear imposed on teeth increases closer to the muscle attachments on the mandible, molar contact in group function is undesirable. Group function occurs naturally in a worn dentition. Group function may be a therapeutic goal when the bony support of canines is compromised by periodontal disease or Class II occlusions in which canine guidance is impossible.

The nonworking side is opposite the working side and normally does not contain a food bolus during chewing. During chewing closures, mandibular teeth on the nonworking side close from an anteromedial position and approach MI by moving posterolaterally. Contact of the molar cusps on the nonworking side may overload these teeth, compromise the ipsilateral TMJ, or both because of a resultant increase in the activity of the masseter, anterior temporalis, and posterior temporalis muscles and the ipsilateral superior lateral pterygoid.^{13-15,17} Each of these muscles counteracts the action of the nonworking side inferior lateral pterygoid, which is responsible (along with the contralateral posterior temporalis and digastric muscles) for effecting the down and forward translation of the nonworking side condyle. Additional activity of the ipsilateral superior lateral pterygoid muscle should not occur during condylar translation when the TMJ disk needs to rotate posteriorly toward the top of the condylar head to maintain its position between the condyle and the articular eminence. Even in light of this normal physiologic muscle

response to nonworking side tooth contact, it has been observed that the presence of a nonworking side contact does not necessarily mean that it is an interference to mandibular function.⁴⁵ Great variation exists among patients in the level of masticatory system tolerance to nonworking side contacts. An understanding of the neuromuscular response to nonworking side posterior contacts leads to the conclusion that avoidance of these contacts is an important goal for restorative procedures on molars. Undesirable nonworking side contacts are illustrated in Fig. 1-52, F.

Neurologic Correlates and Control of Mastication

This summary of neurologic control is based on an excellent review by Lund.⁴⁶ The control of mastication depends on sensory feedback. Sensory feedback serves to control the coordination of the lips, tongue, and mandibular movement during manipulation of the food bolus through all stages of mastication and preparation for swallowing. Physiologists divide an individual chewing cycle into three components: *opening*, *fast-closing*, and *slow-closing*. The slow-closing segment of chewing is associated with the increased forces required for crushing food. The central nervous system receives several types of feedback from muscle spindles, periodontal receptors, and touch receptors in the skin and mucosa. This feedback controls the mandibular closing muscles during the slow-closing phase. Sensory feedback often results in inhibition of movement (e.g., because of pain). During mastication, some sensory feedback from teeth is excitatory, causing an increase in the closing force as the food bolus is crushed. An upper limit must, however, be present where inhibition occurs; this prevents the buildup of excessive forces on teeth during the occlusal stage.

A group of neurons in the brainstem produces bursts of discharges at regular intervals when excited by oral sensory stimuli. These bursts drive motor neurons to produce contractions of the masticatory muscles at regular intervals, resulting in rhythmic mandibular movement. The cluster of neurons in the brainstem that drives the rhythmic chewing is termed the *central pattern generator*. The chewing cycles illustrated in Figures 1-46, 1-47, and 1-48 are caused by central pattern generator rhythms. Oral sensory feedback can modify the basic central pattern generator pattern and is essential for the coordination of the lips, tongue, and mandible. Sensory input from the periodontal and mucosal receptors maintains the rhythmic chewing. During opening, the mandibular opening muscles are contracted, and the closing muscles are inhibited. During closing, the mandibular closing muscles are activated, but the opening muscles are not inhibited. Coactivation of the opening and closing muscles serves to protect the dentition from excessively forceful contact, makes the mandible more rigid, and probably serves to brace the condyles while the food is crushed.

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Dental Caries: Etiology, Clinical Characteristics, Risk Assessment, and Management

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This chapter presents basic definitions and information on dental caries, clinical characteristics of the caries lesion, caries risk assessment, and caries management, in the context of clinical operative dentistry.

What is Dental Caries?

Dental caries is a multifactorial, transmissible, infectious oral disease caused primarily by the complex interaction of cariogenic oral flora (biofilm) with fermentable dietary carbohydrates on the tooth surface over time. Traditionally, this tooth-biofilm-carbohydrate interaction has been illustrated by the classical Keyes-Jordan diagram (Fig. 2-1).¹ However, dental caries onset and activity are, in fact, much more complex than this three-way interaction, as not all persons with teeth, biofilm, and consuming carbohydrates will have caries over time. Several modifying risk and protective factors influence the dental caries process, as will be discussed later in this chapter.

At the tooth level, caries activity is characterized by localized demineralization and loss of tooth structure (Figs. 2-2 and 2-3). Cariogenic bacteria in the biofilm metabolize refined carbohydrates for energy and produce organic acid by-products. These organic acids, if present in the biofilm ecosystem for extended periods, can lower the pH in the biofilm to below a critical level (5.5 for enamel, 6.2 for dentin). The low pH drives calcium and phosphate from the tooth to the biofilm in an attempt to reach equilibrium, hence resulting in a net loss of minerals by the tooth, or *demineralization*. When the pH in the biofilm returns to neutral and the concentration of soluble calcium and phosphate is supersaturated relative to that in the tooth, mineral can then be added back to partially demineralized enamel, in a process called *remineralization*. At the tooth surface and sub-surface level, therefore, dental caries results from a dynamic process of attack (demineralization)

and restitution (remineralization) of the tooth matter. These events take place several times a day over the life of the tooth and are modulated by many factors, including number and type of microbial flora in the biofilm, diet, oral hygiene, genetics, dental anatomy, use of fluorides and other chemotherapeutic agents, salivary flow and buffering capacity; and inherent resistance of the tooth structure and composition that will differ from person to person, tooth to tooth, and site to site. The balance between demineralization and remineralization has been illustrated in terms of pathologic factors (i.e., those favoring demineralization) and protective factors (i.e., those favoring remineralization) (Fig. 2-4).² Individuals in whom the balance tilts predominantly toward protective factors (remineralization) are much less likely to develop dental caries than those in which the balance is tilted toward pathologic factors (demineralization). ***Understanding the balance between demineralization and remineralization is key to caries management.***

Repeated demineralization events may result from a predominantly pathologic environment causing the localized dissolution and destruction of the calcified dental tissues, evidenced as a caries lesion or a “cavity.” Severe demineralization of enamel results in the formation of a cavitation in the enamel surface. Severe demineralization of dentin results in the exposure of the protein matrix, which is denatured initially by host matrix metalloproteinases (MMPs) and is subsequently degraded by MMPs and other bacterial proteases. Demineralization of the inorganic phase and denaturation and degradation of the organic phase result in dentin cavitation.³

It is essential to understand that caries lesions, or cavitations in teeth, are signs of an underlying condition, an imbalance between protective and pathologic factors favoring the latter. In clinical practice, it is very easy to lose sight of this fact and focus entirely on the restorative treatment of caries lesions, failing to treat the underlying cause of the disease

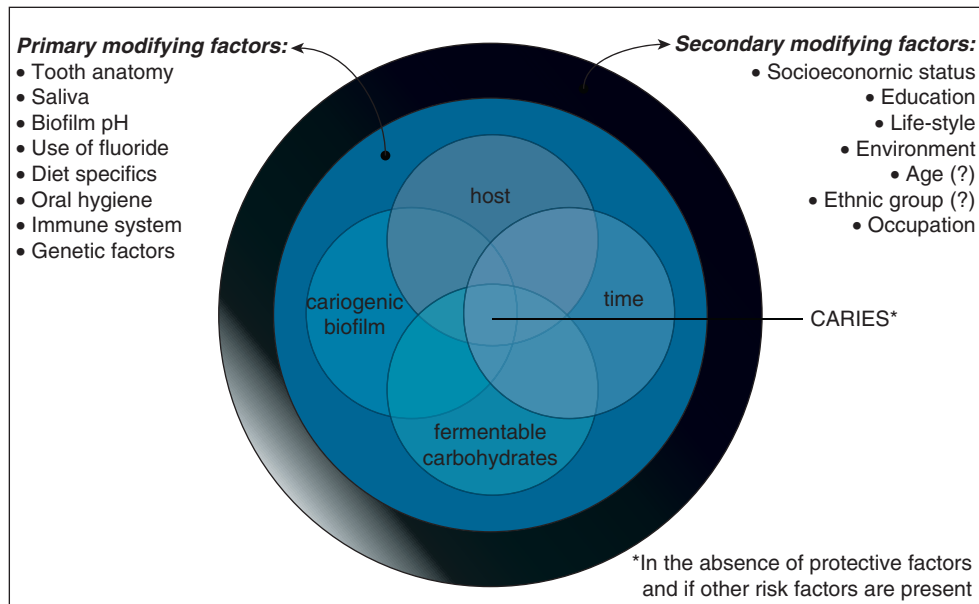


Fig. 2-1 Modified Keyes-Jordan diagram. As a simplified description, dental caries is a result of the interaction of cariogenic oral flora (biofilm) with fermentable dietary carbohydrates on the tooth surface (host) over time. However, dental caries onset and activity are, in fact, much more complex, as not all persons with teeth, biofilm, and who are consuming carbohydrates will have caries over time. Several modifying risk factors and protective factors influence the dental caries process. (Modified from Keyes PH, Jordan HV: *Factors influencing initiation, transmission and inhibition of dental caries*. In Harris RJ, editor: *Mechanisms of hard tissue destruction*, New York, 1963, Academic Press.)

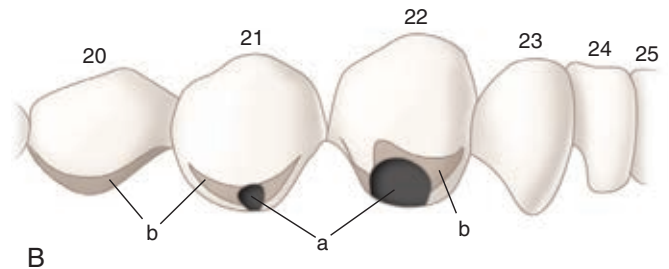
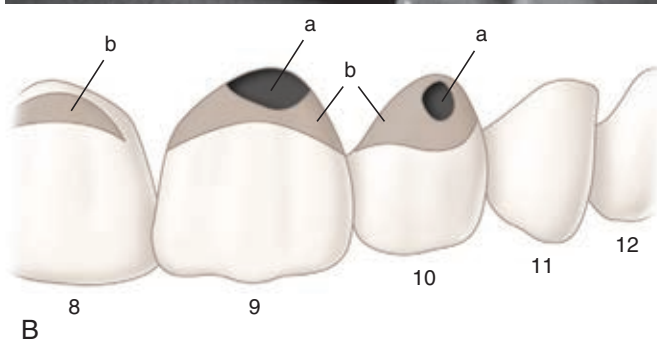
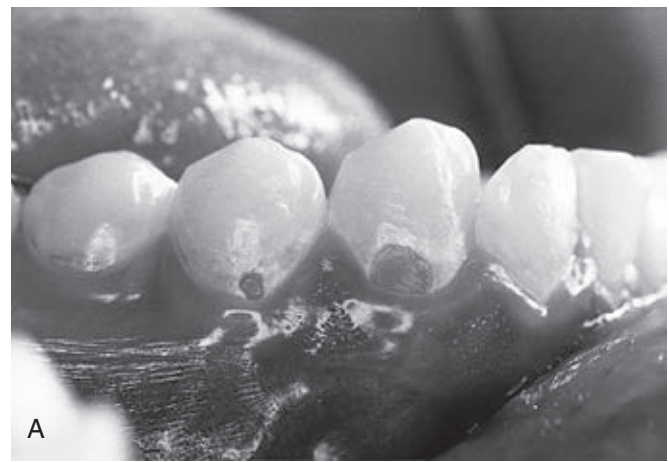


Fig. 2-2 **A**, Young adult with multiple active caries lesions involving teeth No. 8-10. **B**, Cavitated areas (a) are surrounded by areas of extensive demineralization that are chalky and opaque (b). Some areas of noncavitated caries have superficial stain.

Fig. 2-3 Extensive active caries in a young adult (same patient as in Fig. 2-2). **A**, Mirror view of teeth No. 20-22. **B**, Cavitated lesions (a) are surrounded by extensive areas of chalky, opaque demineralized areas (b). The presence of smooth-surface lesions such as these is associated with rampant caries. Occlusal and interproximal smooth-surface caries usually occur in advance of facial smooth-surface lesions. The presence of these types of lesions should alert the dentist to the possibility of extensive caries activity elsewhere in the mouth. The interproximal gingiva is swollen red and would bleed easily on probing. These gingival changes are the consequence of long-standing irritation from the plaque adherent to the teeth.

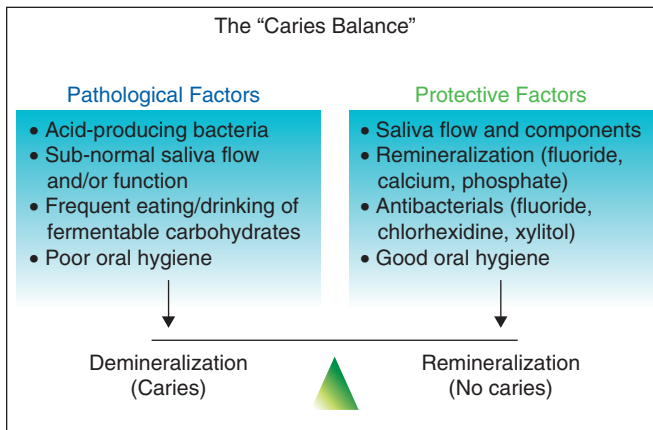


Fig. 2-4 The caries balance. The balance between demineralization and remineralization is illustrated in terms of pathologic factors (i.e., those favoring demineralization) and protective factors (i.e., those favoring remineralization). (Modified from Featherstone JDB: *Prevention and reversal of dental caries: Role of low level fluoride*, Community Dent Oral Epidemiol 27:31–40, 1999.)

Table 2-1 Caries Management Based on the Medical Model

Primary Etiology	Cariogenic Biofilm (Infection)
Symptoms	Demineralization lesions in teeth
Treatment, symptomatic	Restoration of cavitated lesions
Treatment, therapeutic	Improvement of host resistance by (1) biofilm control, (2) elevating biofilm pH, and (3) enhancing remineralization
Post-treatment assessment, symptomatic	Examination of teeth for new lesions
Post-treatment assessment, therapeutic	Re-evaluation of etiologic conditions and primary and secondary risk factors; and continuous management based on findings

(Table 2-1). Although symptomatic treatment is important, failure to identify and treat the underlying causative factors allows the disease to continue. This chapter emphasizes the components of a caries management program that is based first on risk assessment and then on modifying the biofilm ecology to enhance protective factors and minimize pathologic factors.⁴

This chapter also presents information on clinical characteristics of caries lesion as they relate to clinical operative dentistry. Use of correct and consistent terms when referring to caries lesions is important. Box 2-1 summarizes the most common terms used in this textbook to define caries lesions based on their location, cavitation status, and activity status.

Ecologic Basis of Dental Caries: The Role of the Biofilm

Dental plaque is a term historically used to describe the soft, tenacious film accumulating on the surface of teeth.

Box 2.1 Caries Lesion Definitions

This box summarizes the most common terms used in this textbook to define caries lesions based on their location, cavitation status, and activity status.

- **Caries lesion.** Tooth demineralization as a result of the caries process. Other texts may use the term *carious lesion*. Laypeople may use the term *cavity*.
- **Smooth-surface caries.** A caries lesion on a smooth tooth surface.
- **Pit-and-fissure caries.** A caries lesion on a pit-and-fissure area.
- **Occlusal caries.** A caries lesion on an occlusal surface.
- **Proximal caries.** A caries lesion on a proximal surface.
- **Enamel caries.** A caries lesion in enamel, typically indicating that the lesion has not penetrated into dentin. (Note that many lesions detected clinically as enamel caries may very well have extended into dentin histologically.)
- **Dentin caries.** A caries lesion into dentin.
- **Coronal caries.** A caries lesion in any surface of the anatomic tooth crown.
- **Root caries.** A caries lesion in the root surface.
- **Primary caries.** A caries lesion not adjacent to an existing restoration or crown.
- **Secondary caries.** A caries lesion adjacent to an existing restoration, crown, or sealant. Other term used is *caries adjacent to restorations and sealants (CARS)*. Also referred to as *recurrent caries*, implying that a primary caries lesion was restored but that the lesion reoccurred.
- **Residual caries.** Refers to carious tissue that was not completely excavated prior to placing a restoration. Sometimes residual caries can be difficult to differentiate from secondary caries.
- **Cavitated caries lesion.** A caries lesion that results in the breaking of the integrity of the tooth, or a *cavitation*.
- **Non-cavitated caries lesion.** A caries lesion that has not been cavitated. In enamel caries, non-cavitated lesions are also referred to as “white spot” lesions.
(Clinically, the distinction between a cavitated and a non-cavitated caries lesion is not as simple as it may seem. Although historically any roughness detectable with a sharp explorer has been considered a cavitated lesion, more recent caries detection guidelines establish that only lesions in which a blunt probe (e.g., WHO[World Health Organization]/CPI[Community Periodontal Index]/PSR[Periodontal Screening and Recording] probe) penetrates are to be considered cavitated. This distinction has important implications on lesion management.)
- **Active caries lesion.** A caries lesion that is considered to be biologically active, that is, lesion in which tooth demineralization is in frank activity at the time of examination.
- **Inactive caries lesion.** A caries lesion that is considered to be biologically inactive at the time of examination, that is, in which tooth demineralization caused by caries may have happened in the past but has stopped and is currently stalled. Also referred to as *arrested caries*, meaning that the caries process has been arrested but that the clinical signs of the lesion itself are still present.
- **Rampant caries.** Term used to describe the presence of extensive and multiple cavitated and active caries lesions in the same person. Typically used in association with “baby bottle caries,” “radiation therapy caries,” or “meth-mouth caries.” These terms refer to the etiology of the condition.

Dental plaque has been more recently referred to as a *plaque biofilm*, or simply *biofilm*, which is a more complete and accurate description of its composition (bio) and structure (film).⁵ Biofilm is composed mostly of bacteria, their by-products, extracellular matrix, and water (Figs. 2-5 to 2-9). Biofilm is not adherent food debris, as is widely and erroneously thought, nor does it result from the haphazard collection of opportunistic microorganisms. The accumulation of biofilm on teeth is a highly organized and ordered sequence of events. Many of the organisms found in the mouth are not found elsewhere in nature. Survival of microorganisms in the oral environment depends on their ability to adhere to a

surface. Free-floating organisms are cleared rapidly from the mouth by salivary flow and frequent swallowing. Only a few specialized organisms, primarily streptococci, are able to adhere to oral surfaces such as the mucosa and tooth structure.

Significant differences exist in the biofilm communities found in various habitats (ecologic environments) within the oral cavity (Fig. 2-10). Teeth normally have a biofilm community dominated by *Streptococcus sanguis* and *S. mitis*. The population size of mutans streptococci (MS) on teeth varies. Normally, it is a small percentage of the total biofilm population, but it can be one-half the facultative streptococcal

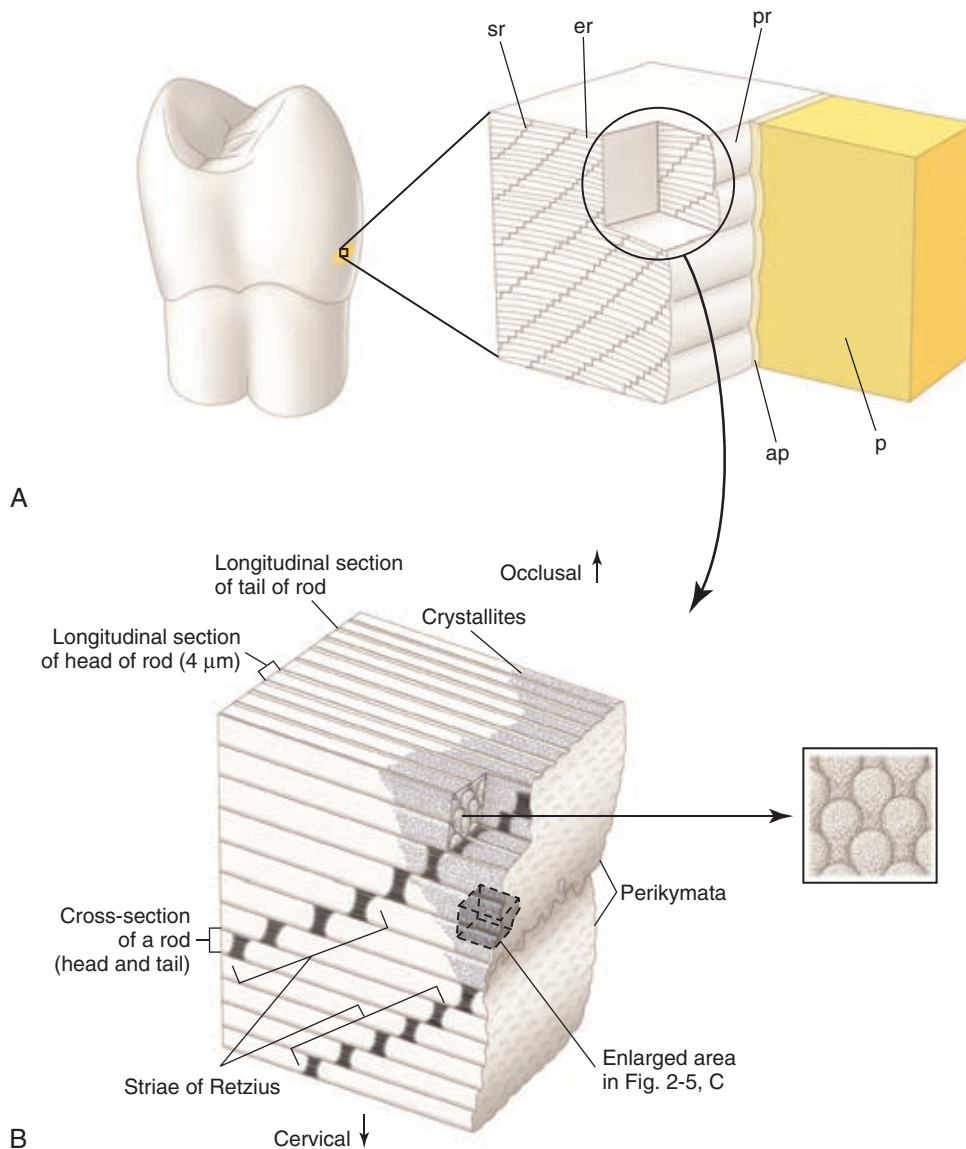


Fig. 2-5 A, Composite diagram illustrating the relationship of plaque biofilm (*p*) to the enamel in a smooth-surface noncavitated lesion. A relatively cell-free layer of precipitated salivary protein material, the acquired pellicle (*ap*), covers the perikymata ridges (*pr*). The plaque bacteria attach to the pellicle. Overlapping perikymata ridges can be seen on surface of enamel (see Fig. 2-6). Figs. 2-7 to 2-9 are photomicrographs of cross-sections of plaque biofilm. The enamel is composed of rod-like structures (*er*) that course from the inner dentinoenamel junction (DEJ) to the surface of the crown. Striae of Retzius (*sr*) can be seen in cross-sections of enamel. **B**, Higher power view of the cutout portion of enamel in **A**. Enamel rods interlock with each other in a head-to-tail orientation. The rod heads are visible on the surface as slight depressions on the perikymata ridges. The enamel rods comprise tightly packed crystallites. The orientation of the crystallites changes from being parallel to the rod in the head region to being perpendicular to the rod axis in the tail end. Striae of Retzius form a descending diagonal line, descending cervically.

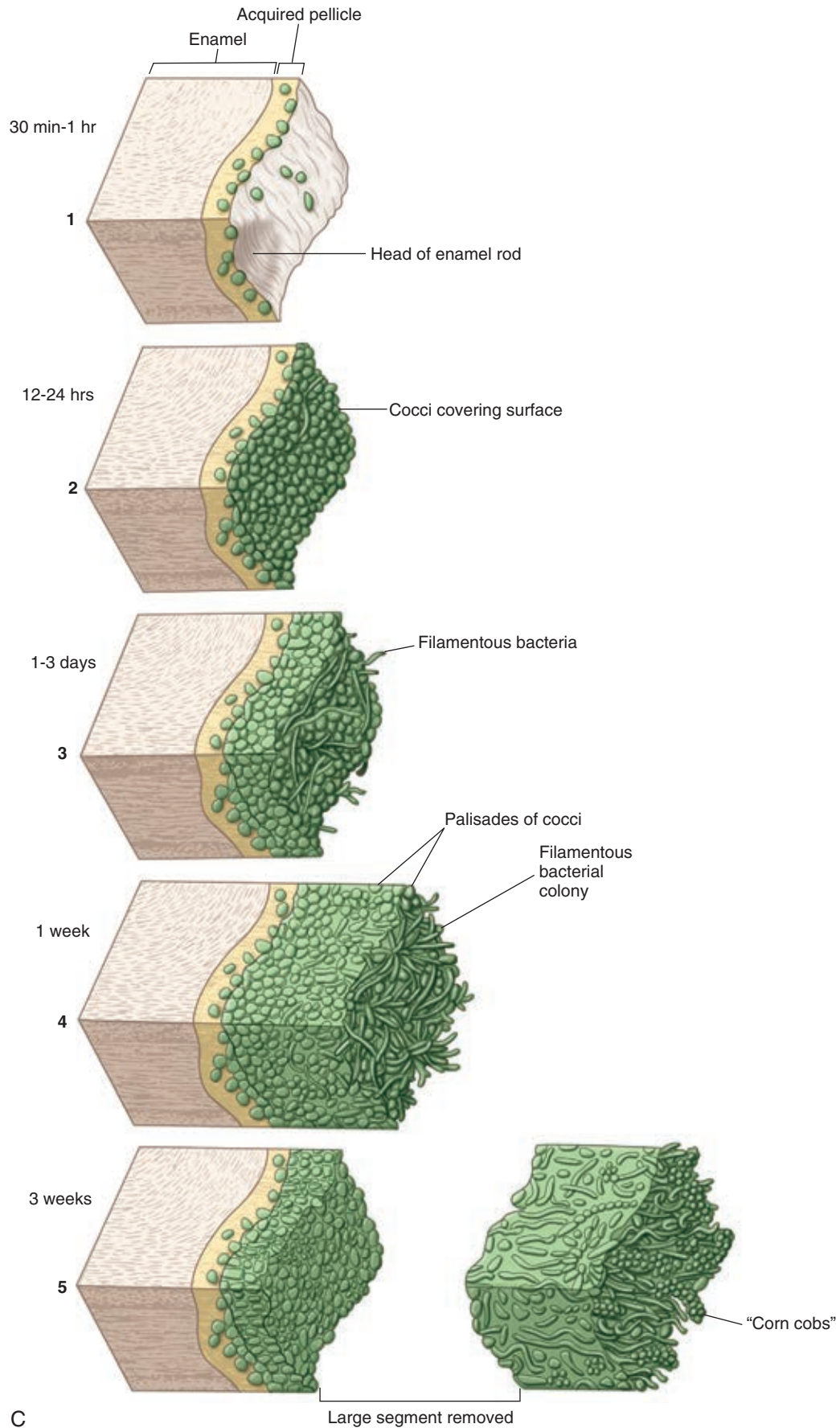


Fig. 2-5, cont'd C. Drawings 1 through 5 illustrate the various stages in colonization during plaque formation on the shaded enamel block shown in *B*. The accumulated mass of bacteria on the tooth surface may become so thick that it is visible to the unaided eye. Such plaques are gelatinous and tenaciously adherent; they readily take up disclosing dyes, aiding in their visualization for oral hygiene instruction. Thick plaque biofilms (4 and 5) are capable of great metabolic activity when sufficient nutrients are available. The gelatinous nature of the plaque limits outward diffusion of metabolic products and serves to prolong the retention of organic acid metabolic byproducts.

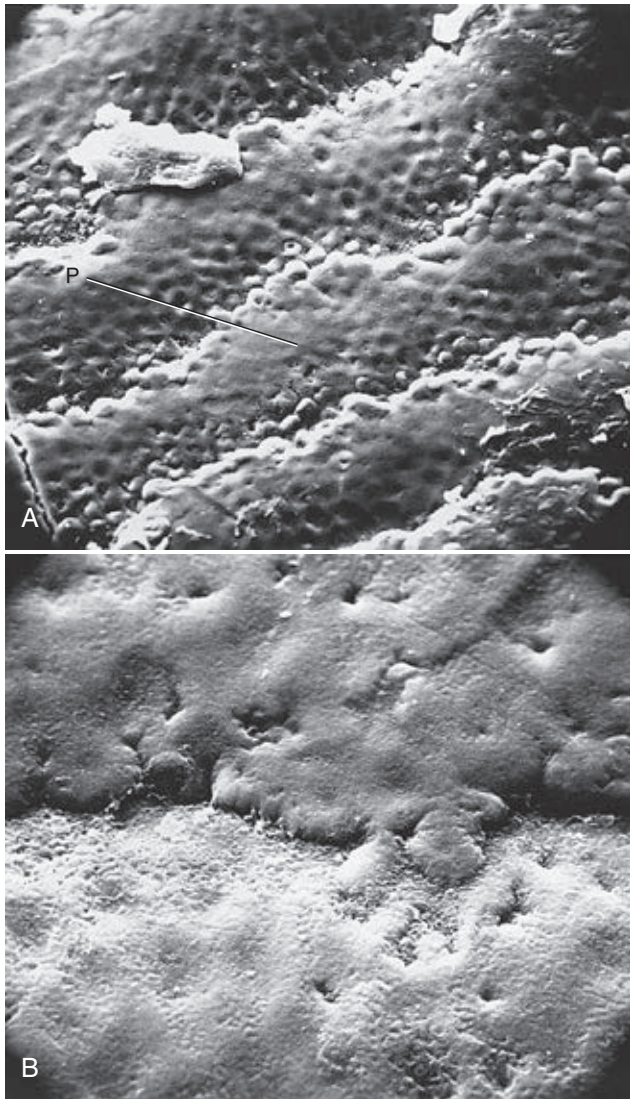


Fig. 2-6 **A**, Scanning electron microscope view (×600) of overlapping perikymata (P) in sound enamel from unerupted molar. **B**, Higher power view (×2300) of overlapped site rotated 180 degrees. Surface of non-cavitated enamel lesions has “punched-out” appearance. (From Hoffman S: *Histopathology of caries lesions*. In Menaker L, editor: *The biologic basis of dental caries*, New York, 1980, Harper & Row.)

flora in other biofilms. Mature plaque biofilm communities have tremendous metabolic potential and are capable of rapid anaerobic metabolism of any available carbohydrates (Fig. 2-11).

Many distinct habitats may be identified on individual teeth, with each habitat containing a unique biofilm community (Table 2-2). Although the pits and fissures on the crown may harbor a relatively simple population of streptococci, the root surface in the gingival sulcus may harbor a complex community dominated by filamentous and spiral bacteria. Facial and lingual smooth surfaces and proximal surfaces also may harbor vastly different biofilm communities. The mesial surface of a molar may be carious and have a biofilm dominated by large populations of MS and lactobacilli, whereas



Fig. 2-8 Plaque biofilm formation at 1 week. Filamentous bacteria (f) appear to be invading cocci microcolonies. Plaque near gingival sulcus has fewer coccal forms and more filamentous bacteria (×860). (From Listgarten MA, Mayo HE, Tremblay R: *Development of dental plaque on epoxy resin crowns in man. A light and electron microscopic study*, J Periodontol 46(1):10–26, 1975.)



Fig. 2-7 Photomicrograph of one-day old plaque biofilm. This plaque biofilm consists primarily of columnar microcolonies of cocci (C) growing perpendicular to crown surface (S) (×1350). (From Listgarten MA, Mayo HE, Tremblay R: *Development of dental plaque on epoxy resin crowns in man. A light and electron microscopic study*, J Periodontol 46(1):10–26, 1975.)

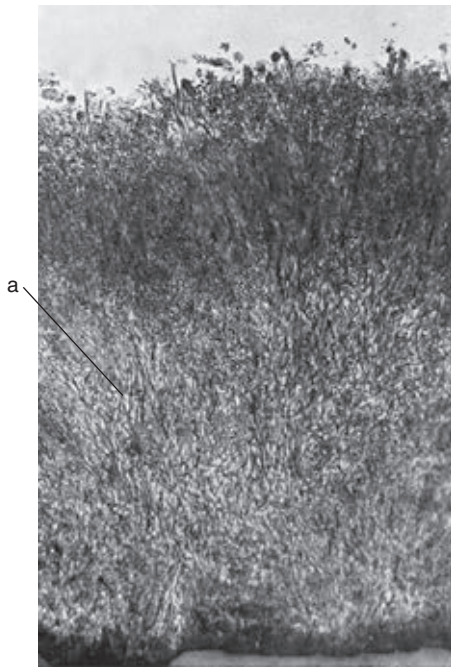


Fig. 2-9 At 3 weeks old, plaque biofilm is almost entirely composed of filamentous bacteria. Heavy plaque formers have spiral bacteria (a) associated with subgingival plaque (¥660). (From Listgarten MA, Mayo HE, Tremblay R: Development of dental plaque on epoxy resin crowns in man. A light and electron microscopic study, J Periodontol 46(1):10–26, 1975.)

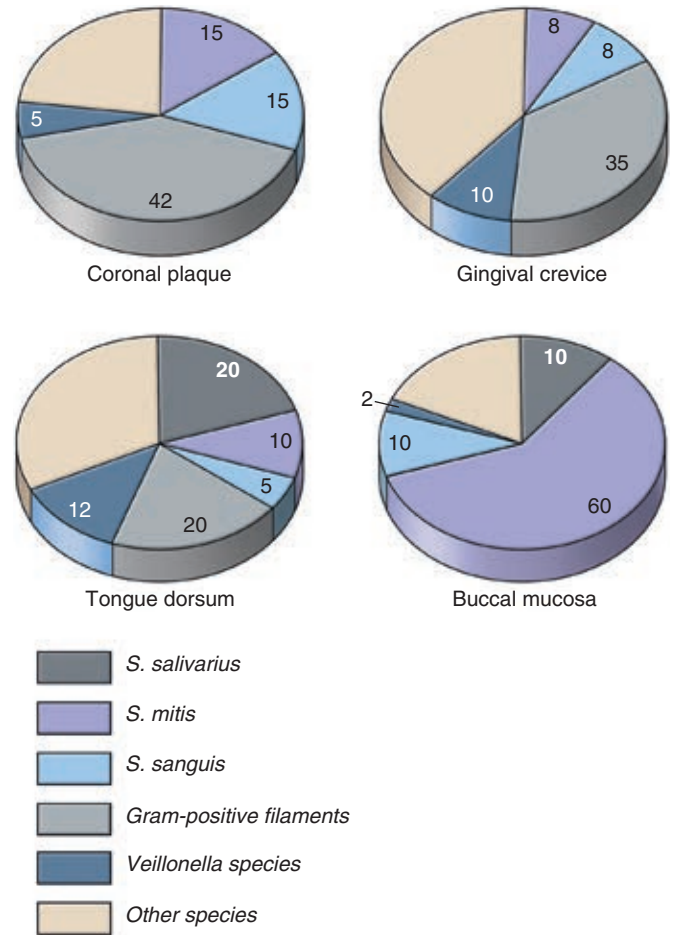
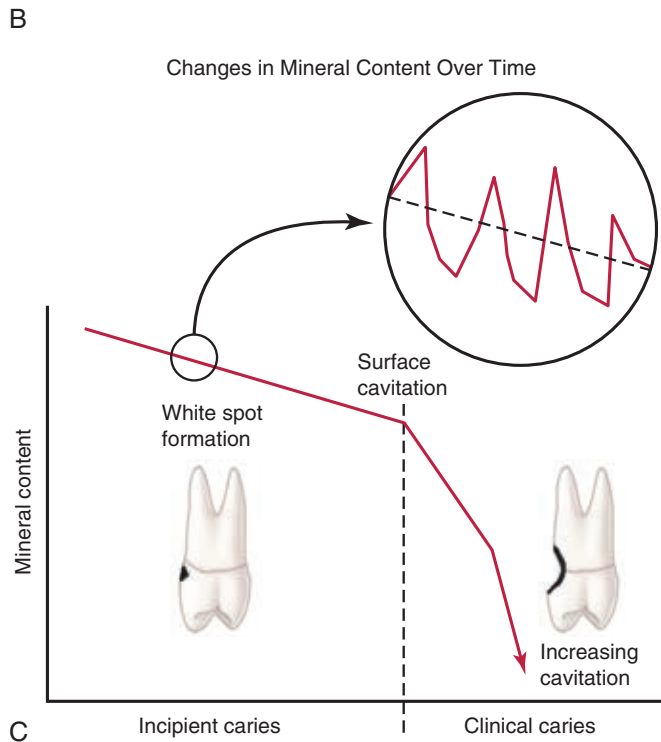
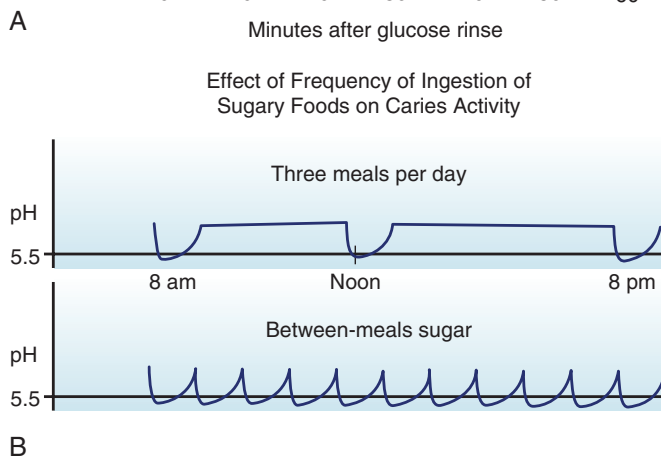
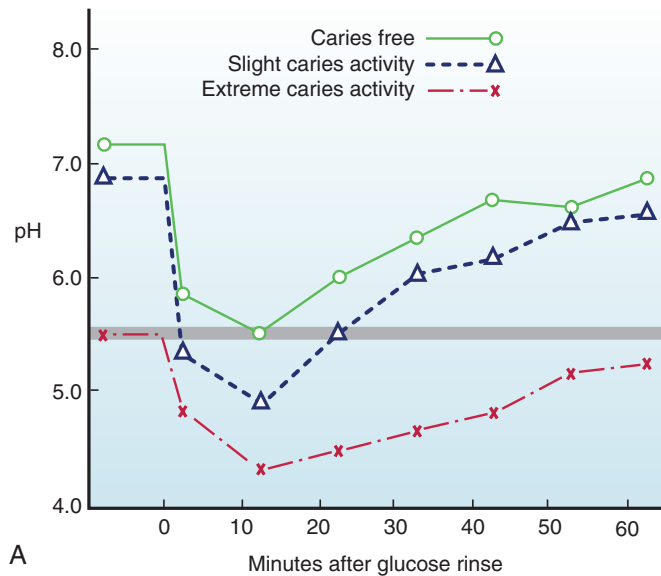


Fig. 2-10 Approximate proportional distribution of predominant cultivable flora of four oral habitats. (Redrawn from Morhart R, Fitzgerald R: Composition and ecology of the oral flora. In Menaker L, editor: The biologic basis of dental caries, New York, 1980, Harper & Row.)

Table 2-2 Oral Habitats*		
Habitat	Predominant Species	Environmental Conditions within Plaque
Mucosa	<i>S. mitis</i> <i>S. sanguis</i> <i>S. salivarius</i>	Aerobic pH approximately 7 Oxidation-reduction potential positive
Tongue	<i>S. salivarius</i> <i>S. mutans</i> <i>S. sanguis</i>	Aerobic pH approximately 7 Oxidation-reduction potential positive
Teeth (non-carious)	<i>S. sanguis</i>	Aerobic pH 5.5 Oxidation-reduction negative
Gingival crevice	<i>Fusobacterium</i> <i>Spirochaeta</i> <i>Actinomyces</i> <i>Veillonella</i>	Anaerobic pH variable Oxidation-reduction very negative
Enamel caries	<i>S. mutans</i>	Anaerobic pH <5.5 Oxidation-reduction negative
Dentin caries	<i>S. mutans</i> <i>Lactobacillus</i>	Anaerobic pH <5.5 Oxidation-reduction negative
Root caries	<i>Actinomyces</i>	Anaerobic pH <5.5 Oxidation-reduction negative

*The micro-environmental conditions in the habitats associated with host health are generally aerobic, near neutrality in pH, and positive in oxidation-reduction potential. Significant micro-environmental changes are associated with caries and periodontal disease. The changes are the result of the plaque community metabolism.



the distal surface may lack these organisms and be caries-free. Generalization about biofilm communities is difficult. Nevertheless, the general activity of biofilm growth and maturation is predictable and sufficiently well known to be of therapeutic importance in the prevention of caries.

Professional tooth cleaning is intended to control biofilm (plaque) and prevent disease. After professional removal of all organic material and bacteria from the tooth surface, a new coating of organic material begins to accumulate immediately. Within 2 hours, a cell-free, structureless organic film, the acquired enamel pellicle (AEP, see Figs. 2-5, A and C), can cover the previously denuded area completely. The pellicle is formed primarily from the selective precipitation of various components of saliva. The functions of the pellicle are believed to be as follows: (1) to protect the enamel, (2) to reduce friction between teeth, and (3) possibly to provide a matrix for remineralization.⁶

Tooth Habitats for Cariogenic Biofilm

The tooth surface is unique because it is not protected by the surface shedding mechanisms (continual replacement of epithelial cells) used throughout the remainder of the alimentary canal. The tooth surface is stable and covered with the pellicle of precipitated salivary glycoproteins, enzymes, and immunoglobulins. It is the ideal surface for the attachment of many oral streptococci. If left undisturbed, biofilm rapidly builds up to sufficient depth to produce an anaerobic environment adjacent to the tooth surface. Tooth habitats favorable for harboring pathogenic biofilm include (1) pits and fissures (Fig. 2-12); (2) the smooth enamel surfaces immediately gingival to the proximal contacts and in the gingival third of the facial and

Fig. 2-11 **A**, Mature plaque biofilm communities have tremendous metabolic potential and are capable of rapid anaerobic metabolism of any available carbohydrates. Classic studies by Stephan show this metabolic potential by severe pH drops at the plaque-enamel interface after glucose rinse. It is generally agreed that a pH of 5.5 is the threshold for enamel demineralization. Exposure to a glucose rinse for an extreme caries activity plaque results in a sustained period of demineralization (pH 5.5). Recording from a slight caries activity plaque shows a much shorter period of demineralization. **B**, The frequency of sucrose exposure for cariogenic plaque greatly influences the progress of tooth demineralization. The top line illustrates pH depression, patterned after Stephan's curves in A. Three meals per day results in three exposures of plaque acids, each lasting approximately 1 hour. The plaque pH depression is relatively independent of the quantity of sucrose ingested. Between-meal snacks or the use of sweetened breath mints results in many more acid attacks, as illustrated at the bottom. The effect of frequent ingestion of small quantities of sucrose results in a nearly continuous acid attack on the tooth surface. The clinical consequences of this behavior can be seen in Fig. 2-35. **C**, In active caries, a progressive loss of mineral content subjacent to the cariogenic plaque occurs. Inset illustrates that the loss is not a continuous process. Instead, alternating periods of mineral loss (demineralization) occur, with intervening periods of remineralization. The critical event for the tooth is cavitation of the surface, marked by the vertical dashed line. This event marks an acceleration in caries destruction of the tooth and irreversible loss of tooth structure. For these reasons, restorative intervention is required. (A, adapted and redrawn from Stephan RM: *Intra-oral hydrogen-ion concentration associated with dental caries activity*, *J Dent Res* 23:257, 1944.)

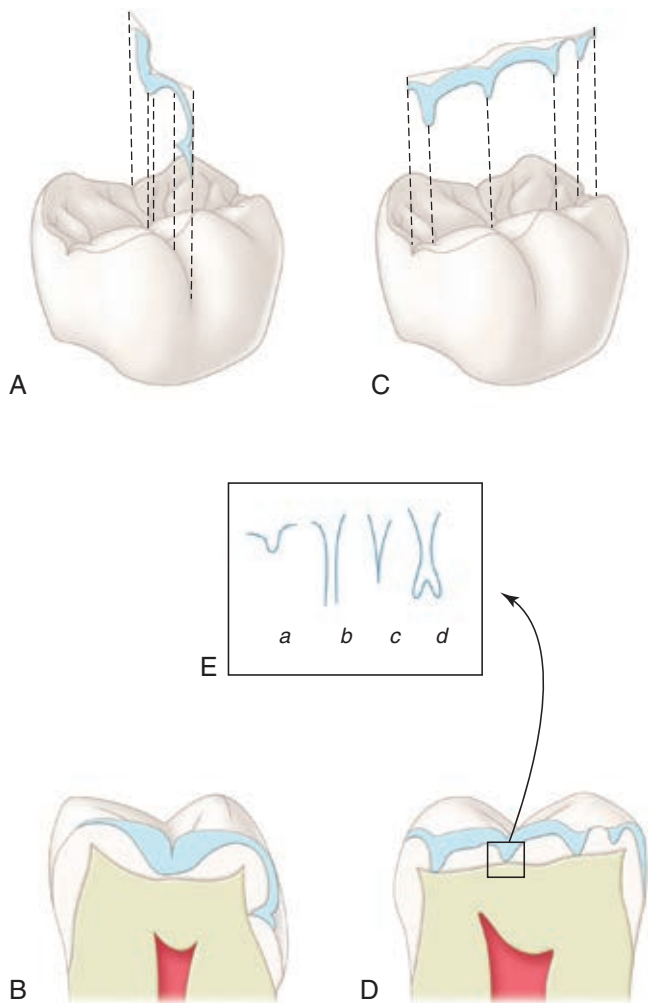


Fig. 2-12 Developmental pits, grooves, and fissures on the crowns of the teeth can have complex and varied anatomy. **A** and **B**, The facial developmental groove of the lower first molar often terminates in a pit. The depth of the groove and the pit varies. **C** and **D**, The central groove extends from the mesial pit to the distal pit. Sometimes grooves extend over the marginal ridges. **E**, The termination of pits and fissures may vary from a shallow groove (a) to complete penetration of the enamel (b). The end of the fissure may end blindly (c) or open into an irregular chamber (d).

lingual surfaces of the clinical crown (Fig. 2-13); (3) root surfaces, particularly near the cervical line; and (4) subgingival areas (Fig. 2-14). These sites correspond to the locations where caries lesions are most frequently found.

Pits and Fissures

Pits and fissures are particularly susceptible surfaces for caries initiation (see Fig. 2-12; Figs. 2-15 to 2-19; see also Fig. 2-12). The pits and fissures provide excellent mechanical shelter for organisms and harbor a community dominated by *S. sanguis* and other streptococci.⁷ The relative proportion of MS most probably determines the cariogenic potential of the pit-and-fissure community. The appearance of MS in pits and fissures is usually followed by caries 6 to 24 months later. In susceptible patients, sealing the pits and fissures just after tooth

eruption may be the most important event in their resistance to caries.

Smooth Enamel Surfaces

The proximal enamel surfaces immediately gingival to the contact area are the second most susceptible areas to caries (Figs. 2-20 and 2-21; see also Figs. 2-14 and 2-18). These areas are protected physically and are relatively free from the effects of mastication, tongue movement, and salivary flow. The types and numbers of organisms composing the proximal surface biofilm community vary. Important ecologic determinants for the biofilm community on the proximal surfaces are the topography of the tooth surface, the size and shape of the gingival papillae, and the oral hygiene of the patient. A rough surface (caused by caries, a poor-quality restoration, or a structural defect) restricts adequate biofilm removal. This situation favors the occurrence of caries or periodontal disease at the site.

Root Surfaces

The proximal root surface, particularly near the cemento-enamel junction (CEJ), often is unaffected by the action of hygiene procedures such as flossing because it may have concave anatomic surface contours (fluting) and occasional roughness at the termination of the enamel. These conditions, when coupled with exposure to the oral environment (as a result of gingival recession), favor the formation of mature, cariogenic biofilm and proximal root-surface caries. Likewise, the facial or lingual root surfaces (particularly near the CEJ), when exposed to the oral environment (because of gingival recession), are often both neglected in hygiene procedures and usually not rubbed by the bolus of food. Consequently, these root surfaces also frequently harbor cariogenic biofilm. Root-surface caries is more common in older patients because of niche availability and other factors sometimes associated with senescence, such as decreased salivary flow and poor oral hygiene as a result of lowered digital dexterity and decreased motivation. Caries originating on the root is alarming because (1) it has a comparatively rapid progression, (2) it is often asymptomatic, (3) it is closer to the pulp, and (4) it is more difficult to restore.

Oral Hygiene and Its Role in the Caries Process

Oral hygiene, accomplished primarily by proper tooth brushing and flossing, is another ecologic determinant of caries onset and activity. Careful mechanical cleaning of teeth disrupts the biofilm and leaves a clean enamel surface. The cleaning process does not destroy most of the oral bacteria but merely removes them from the surfaces of teeth. Large numbers of these bacteria subsequently are removed from the oral cavity during rinsing and swallowing after flossing and brushing, but sufficient numbers remain to recolonize teeth. Some fastidious organisms and obligate anaerobes may be killed by exposure to oxygen during tooth cleaning. No single species is likely to be entirely eliminated, however. Although all the species that compose mature biofilm continue to be present, most of these are unable to initiate colonization on the clean tooth surface.

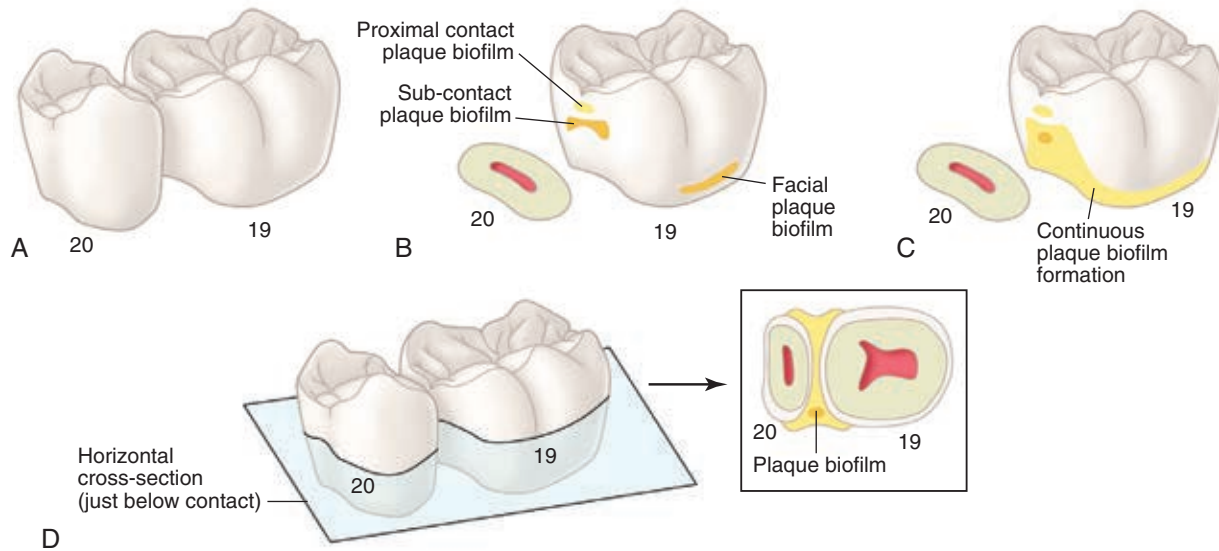


Fig. 2-13 Plaque biofilm formation on posterior teeth and associated caries lesions. **A**, Teeth No. 19 and No. 20 in contacting relationship. **B**, The crown of tooth No. 20 has been removed at the cervix. The proximal contact and subcontact plaque can be seen on the mesial surface of tooth No. 19. A facial plaque also is illustrated. **C**, During periods of unrestricted growth, the mesial and facial plaques become part of a continuous ring of plaque around teeth. **D**, A horizontal cross-section through teeth No. 19 and No. 20 with heavy plaque. Inset shows the interproximal space below the contact area filled with gelatinous plaque. This mass of interproximal plaque concentrates the effects of plaque metabolism on the adjacent tooth smooth surfaces. All interproximal surfaces are subject to plaque accumulation and acid demineralization. In patients exposed to fluoridated water, most interproximal lesions become arrested at a stage before cavitation.

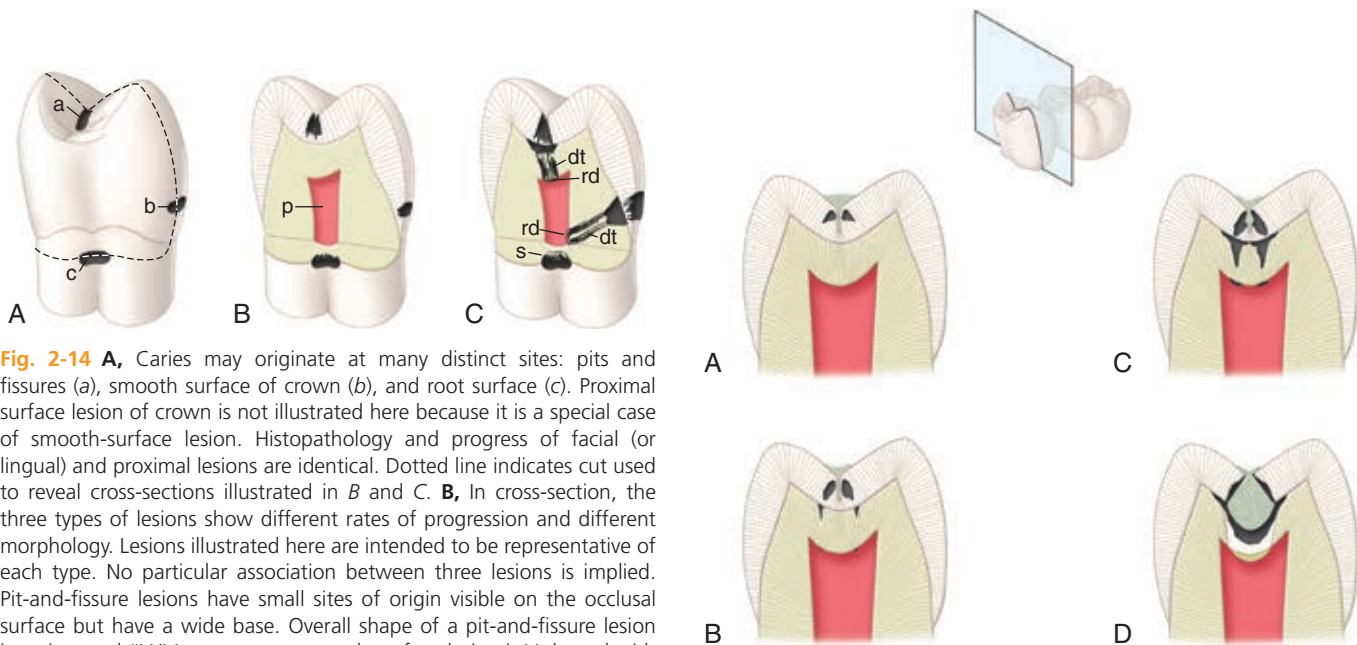


Fig. 2-14 **A**, Caries may originate at many distinct sites: pits and fissures (a), smooth surface of crown (b), and root surface (c). Proximal surface lesion of crown is not illustrated here because it is a special case of smooth-surface lesion. Histopathology and progress of facial (or lingual) and proximal lesions are identical. Dotted line indicates cut used to reveal cross-sections illustrated in B and C. **B**, In cross-section, the three types of lesions show different rates of progression and different morphology. Lesions illustrated here are intended to be representative of each type. No particular association between three lesions is implied. Pit-and-fissure lesions have small sites of origin visible on the occlusal surface but have a wide base. Overall shape of a pit-and-fissure lesion is an inverted "V." In contrast, a smooth-surface lesion is V-shaped with a wide area of origin and apex of the V directed toward pulp (p). Root caries begins directly on dentin. Root-surface lesions can progress rapidly because dentin is less resistant to caries attack. **C**, Advanced caries lesions produce considerable histologic change in enamel, dentin, and pulp. Bacterial invasion of lesion results in extensive demineralization and proteolysis of the dentin. Clinically, this necrotic dentin appears soft, wet, and mushy. Deeper pulpally, dentin is demineralized, but not invaded by bacteria, and is structurally intact. This tissue appears to be dry and leathery in texture. Two types of pulp-dentin response are illustrated. Under pit-and-fissure lesions and smooth-surface lesions, odontoblasts have died, leaving empty tubules called dead tracts (dt). New odontoblasts have been differentiated from pulp mesenchymal cells. These new odontoblasts have produced reparative dentin (rd), which seals off dead tracts. Another type of pulp-dentin reaction is sclerosis (s)—occlusion of the tubules by peritubular dentin. This is illustrated under root-caries lesion.

Fig. 2-15 Progression of caries in pits and fissures. **A**, The initial lesions develop on the lateral walls of the fissure. Demineralization follows the direction of the enamel rods, spreading laterally as it approaches the dentinoenamel junction (DEJ). **B**, Soon after the initial enamel lesion occurs, a reaction can be seen in the dentin and pulp. Forceful probing of the lesion at this stage can result in damage to the weakened porous enamel and accelerate the progression of the lesion. Clinical detection at this stage should be based on observation of discoloration and opacification of the enamel adjacent to the fissure. These changes can be observed by careful cleaning and drying of the fissure. **C**, Initial cavitation of the opposing walls of the fissure cannot be seen on the occlusal surface. Opacification can be seen that is similar to the previous stage. Remineralization of the enamel because of trace amounts of fluoride in the saliva may make progression of pit-and-fissure lesions more difficult to detect. **D**, Extensive cavitation of the dentin and undermining of the covering enamel darken the occlusal surface (see Fig. 2-16).

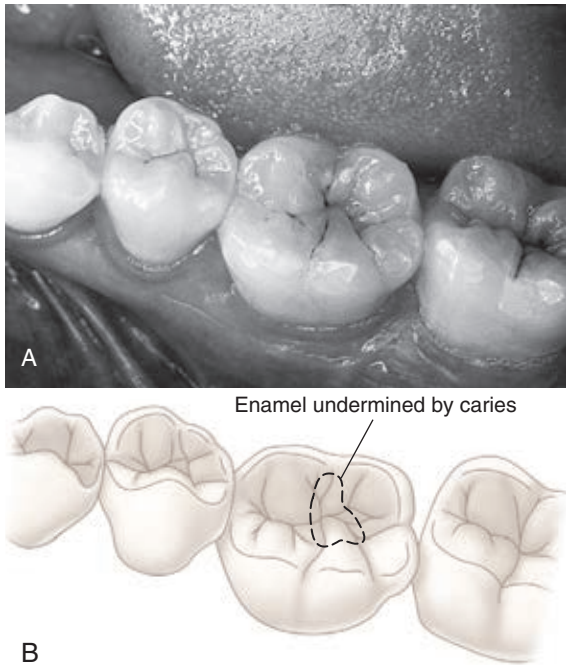


Fig. 2-16 **A**, Mandibular first molar has undermined discolored enamel owing to extensive pit-and-fissure caries. The lesion began as illustrated in Fig. 2-15 and has progressed to the stage illustrated in Fig. 2-15, **D**. **B**, Discolored enamel is outlined by broken line in the central fossa region.

Saliva: Nature’s Anticaries Agent

Saliva is an extremely important substance for the proper digestion of foods, and it also plays a key role as a natural anticaries agent (Table 2-3). Many medications are capable of reducing salivary flow and increasing caries risk (Table 2-4). The importance of saliva in the maintenance of the oral health is illustrated dramatically by observing changes in oral health after therapeutic radiation to the head and neck. After radiation, salivary glands become fibrotic and produce little or no saliva, leaving the patient with an extremely dry mouth, a condition termed *xerostomia* (*xero*, dry; *stoma*, mouth). Such patients may experience near-total destruction of the teeth in just a few months after radiation treatment.^{8,9} Salivary protective mechanisms that maintain the normal oral flora and tooth surface integrity include bacterial clearance, direct antibacterial activity, buffers, and remineralization.¹⁰

Bacterial Clearance

Secretions from various salivary glands pool in the mouth to form whole or mixed saliva. The amount of saliva secreted varies greatly over time. When secreted, saliva remains in the mouth for a short time before being swallowed. While in the mouth, saliva lubricates oral tissues and bathes teeth and the biofilm. The secretion rate of saliva may have a bearing on caries susceptibility and calculus formation. Adults produce 1-1.5 L of saliva a day, very little of which occurs during sleep. The flushing effect of this salivary flow is, by itself, adequate to remove virtually all microorganisms not adherent to an oral

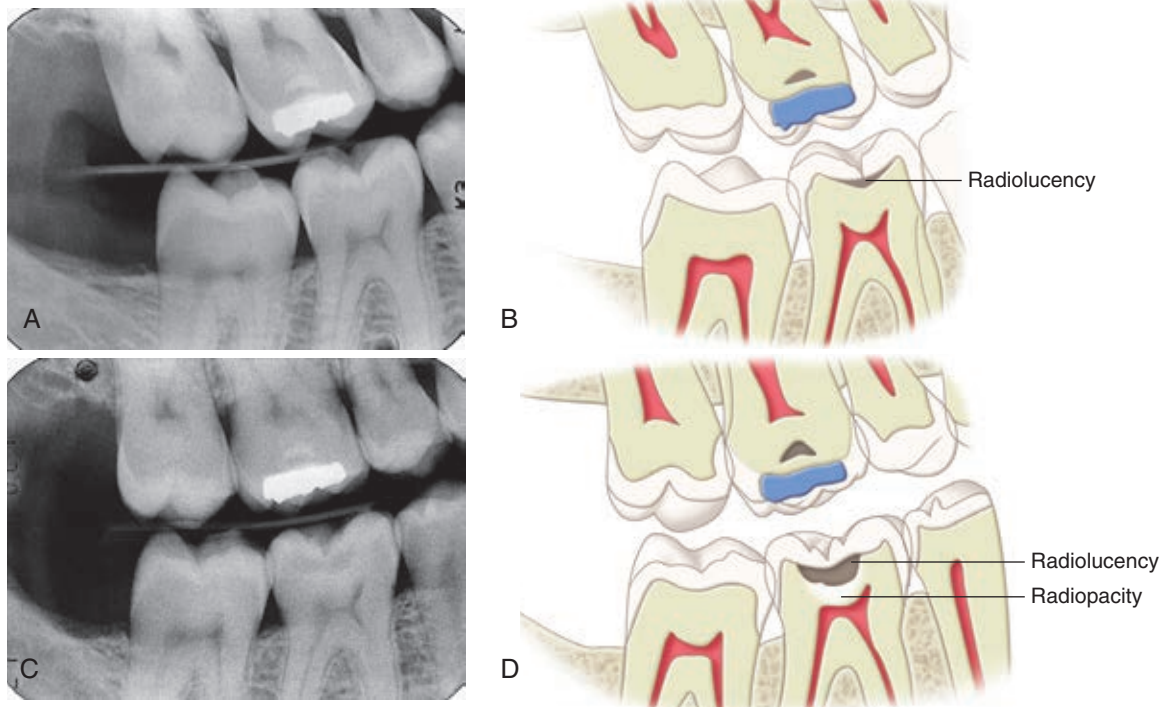


Fig. 2-17 Progression of pit-and-fissure caries. **A**, The mandibular right first molar (tooth No. 30) was sealed. Note radiolucent areas under the occlusal enamel in **A** and **B**. The sealant failed, and caries progressed slowly during the next 5 years; the only symptom was occasional biting-force pain. **C** and **D**, Note the extensive radiolucency under the enamel and an area of increased radiopacity below the lesion, suggesting sclerosis.

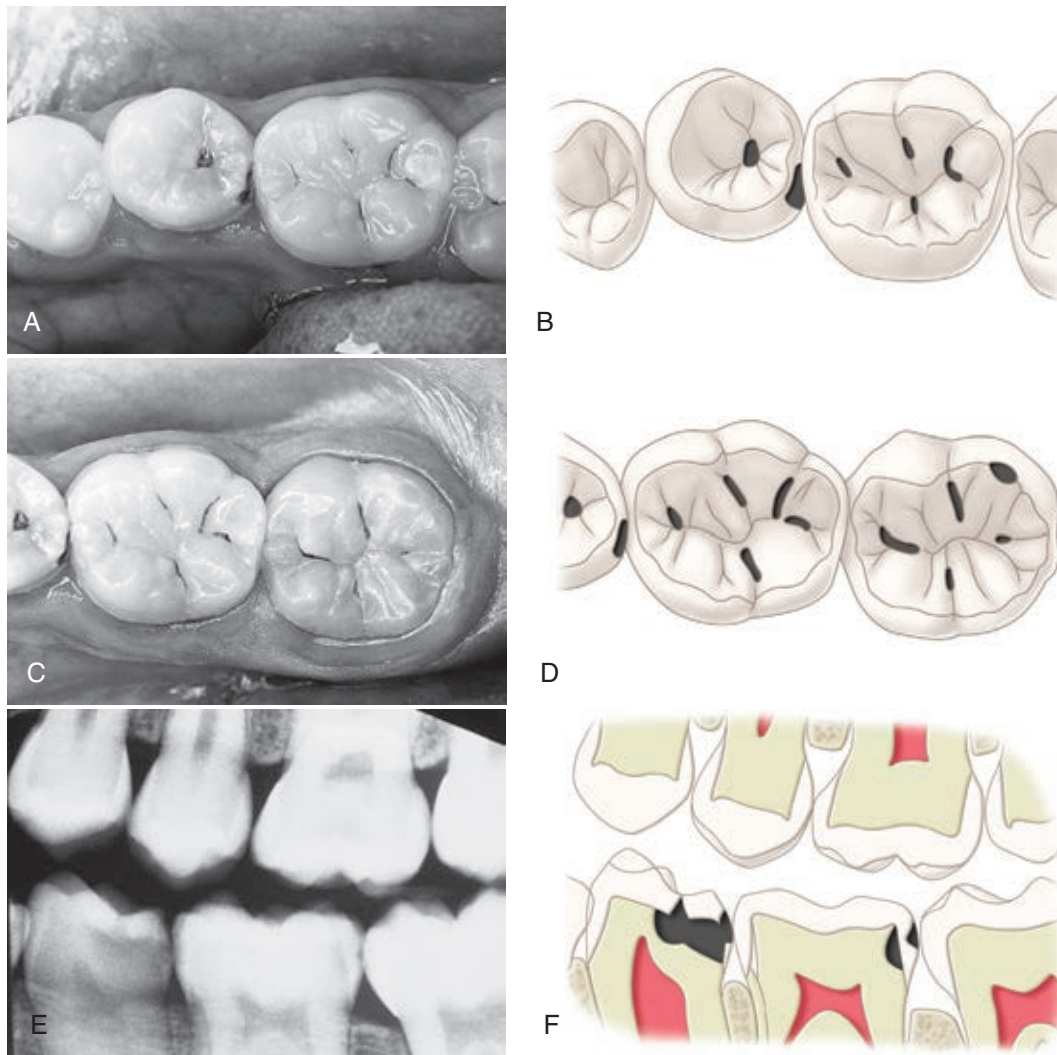


Fig. 2-18 A young patient with extensive caries. **A** and **B**, The occlusal pits of the first molar and second premolar are carious. An interproximal caries lesion is seen on the second premolar. The second premolar is rotated almost 90 degrees, bringing the lingual surface into contact with the mesial surface of the first molar. Normally, the lingual surfaces of mandibular teeth are rarely attacked by caries, but here, the tooth rotation makes the lingual surface a proximal contact and, consequently, produces an interproximal habitat, which increases the susceptibility of the surface to caries. **C** and **D**, The first and second molars have extensive caries in the pits and fissures. **E** and **F**, On the bitewing radiograph, not only can the extensive nature of the caries in the second premolar be seen but also seen is a lesion on the distal aspect of the first molar, which is not visible clinically. (Dark areas in **B**, **D**, and **F** indicate caries.)

Table 2-3 Elements of Saliva that Control Plaque Biofilm Communities

Names	Action	Effects on Plaque Biofilm Community
SALIVARY ENZYMES		
Amylase	Cleaves—1,4 glucoside bonds	Increases availability of oligosaccharides
Lactoperoxidase	Catalyzes hydrogen peroxide-mediated oxidation; adsorbs to hydroxyapatite in active form	Lethal to many organisms; suppresses plaque formation on tooth surfaces
Lysozyme	Lyses cells by degradation of cell walls, releasing peptidoglycans; binds to hydroxyapatite in active conformation	Lethal to many organisms; peptidoglycans activate complement; suppresses plaque formation on tooth surfaces
Lipases	Hydrolysis of triglycerides to free fatty acids and partial glycerides	Free fatty acids inhibit attachment and growth of some organisms
NON-ENZYME PROTEINS		
Lactoferrin	Ties up free iron	Inhibits growth of some iron-dependent microbes
Secretory immunoglobulin A(IgA) (smaller amounts of IgM, IgG)	Agglutination of bacteria inhibits bacterial enzymes	Reduces numbers in saliva by precipitation; slows bacterial growth
Glycoproteins (mucins)	Agglutination of bacteria	Reduces numbers in saliva by precipitation

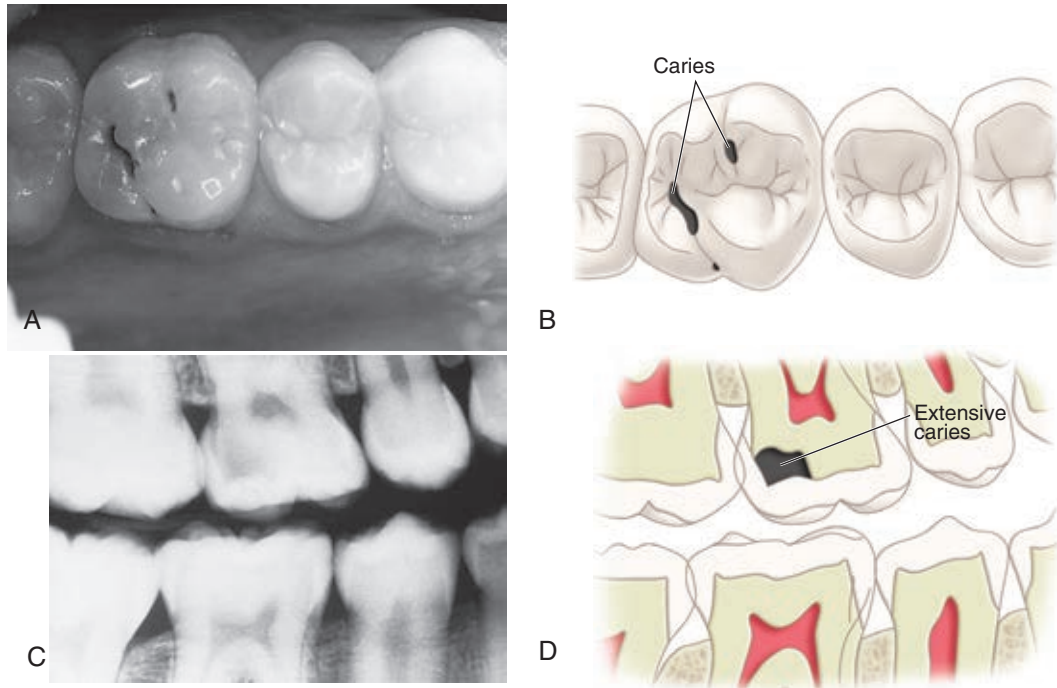


Fig. 2-19 Example of occlusal caries that is much more extensive than is apparent clinically. **A** and **B**, Clinical example. **C** and **D**, A bitewing radiograph further reveals an extensive area of demineralization undermining the distofacial cusp.

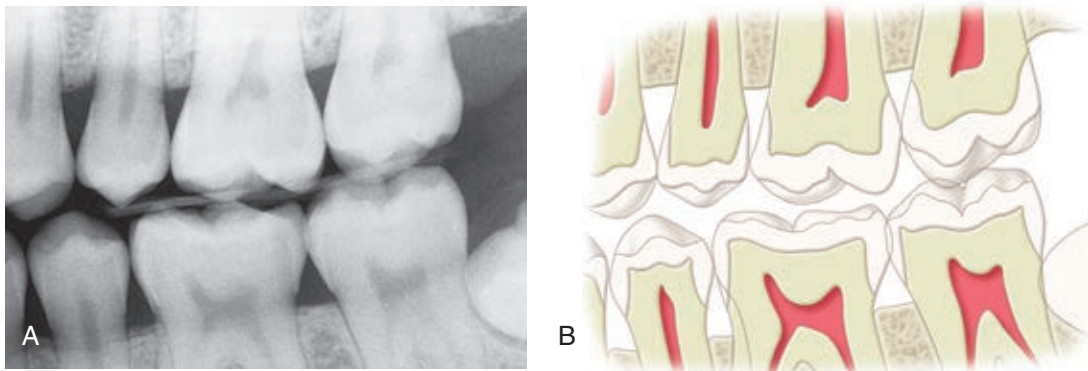


Fig. 2-20 Bitewing radiograph of normal teeth, free from caries. Note the uniform density of the enamel on the interproximal surfaces. A third molar is impacted on the distal aspect of the lower second molar. The interproximal bone levels are uniform and located slightly below the cemento enamel junctions, suggesting a healthy periodontium.

surface. The flushing is most effective during mastication or oral stimulation, both of which produce large volumes of saliva. Large volumes of saliva also can dilute and buffer biofilm acids.

Direct Antibacterial Activity

Salivary glands produce an impressive array of antimicrobial products (see [Table 2-3](#)). Lysozyme, lactoperoxidase, lactoferrin, and agglutinins possess antibacterial activity. These salivary proteins are not part of the immune system but are part of an overall protection scheme for mucous membranes that occurs in addition to immunologic control. These protective proteins are present continuously at relatively uniform levels,

have a broad spectrum of activity, and do not possess the “memory” of immunologic mechanisms. The normal resident oral flora apparently has developed resistance to most of these antibacterial mechanisms.

Although the antibacterial proteins in saliva play an important role in the protection of soft tissue in the oral cavity from infection by pathogens, they have little effect on caries because similar levels of antibacterial proteins can be found in caries-active and caries-free individuals.^{11,12} It is suggested that caries susceptibility in healthy individuals is not related to saliva composition. Individuals with decreased salivary production (owing to illness, medication, or irradiation) may have significantly higher caries susceptibility (see [Table 2-4](#)).

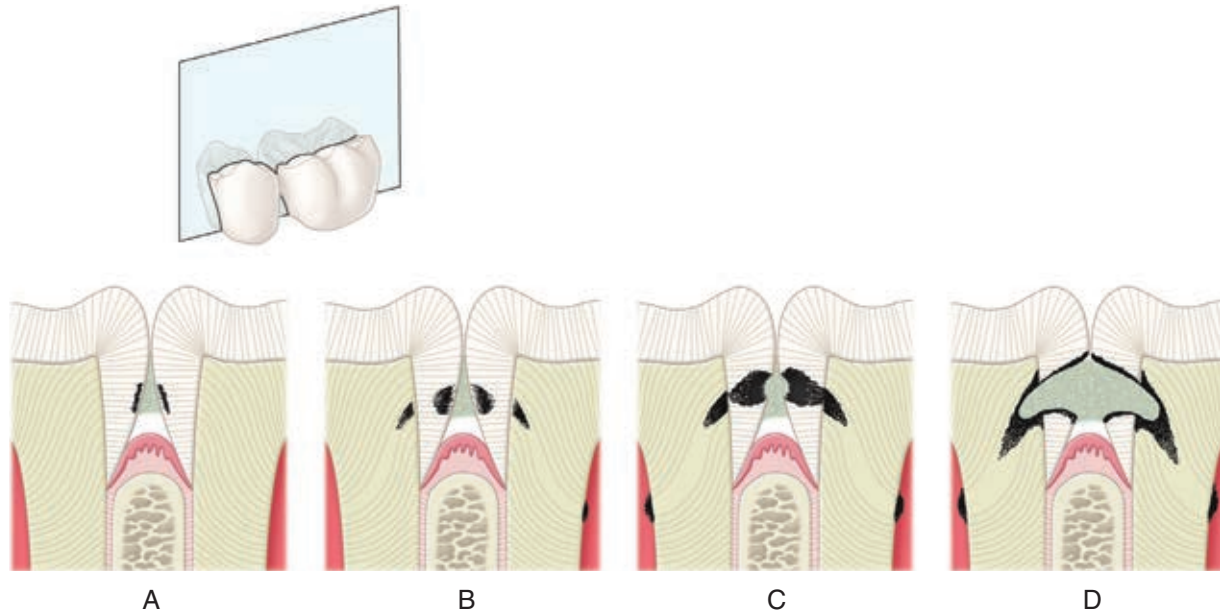


Fig. 2-21 Longitudinal sections (see inset for A) showing initiation and progression of caries on interproximal surfaces. **A**, Initial demineralization (indicated by the shading in the enamel) on the proximal surfaces is not detectable clinically or radiographically. All proximal surfaces are demineralized to some degree, but most are remineralized and become immune to further attack. The presence of small amounts of fluoride in the saliva virtually ensures that remineralization and immunity to further attack will occur. **B**, When proximal caries first becomes detectable radiographically, the enamel surface is likely still to be intact. An intact surface is essential for successful remineralization and arrest of the lesion. Demineralization of the dentin (indicated by the shading in the dentin) occurs before cavitation of the surface of the enamel. Treatment designed to promote remineralization can be effective up to this stage. **C**, Cavitation of the enamel surface is a critical event in the caries process in proximal surfaces. Cavitation is an irreversible process and requires restorative treatment and correction of the damaged tooth surface. Cavitation can be diagnosed only by clinical observation. The use of a sharp explorer to detect cavitation is problematic because excessive force in application of the explorer tip during inspection of the proximal surfaces can damage weakened enamel and accelerate the caries process by creating cavitation. Separation of the teeth can be used to provide more direct visual inspection of suspect surfaces. Fiberoptic illumination and dye absorption also are promising new evaluation procedures, but neither is specific for cavitation. **D**, Advanced cavitated lesions require prompt restorative intervention to prevent pulpal disease, limit tooth structure loss, and remove the nidus of infection of odontopathic organisms.

Buffer Capacity

The volume and buffering capacity of saliva available to tooth surfaces have major roles in caries protection.¹³ The buffering capacity of saliva is determined primarily by the concentration of bicarbonate ion. Buffering capacity can be estimated by titration techniques and may be a useful method for assessment of saliva in caries-active patients. The benefit of the buffering is to reduce the potential for acid formation.

In addition to buffers, saliva contains molecules that contribute to increasing biofilm pH. These include urea and sialin, which is a tetrapeptide that contains lysine and arginine. Hydrolysis of either of these basic compounds results in production of ammonia, causing the pH to increase.

Because saliva is crucial in controlling the oral flora and the mineral content of teeth, salivary testing should be done on patients with high caries activity. A portion of the salivary sample also may be used for bacteriologic testing, as will be described later in this chapter.

Remineralization

Saliva and biofilm fluid are supersaturated with calcium and phosphate ions. Without a means to control precipitation of these ions, the teeth literally would become encrusted with mineral deposits. Saliva contains statherin, a proline-rich

peptide that stabilizes calcium and phosphate ions and prevents excessive deposition of these ions on teeth.¹⁴ This supersaturated state of the saliva provides a constant opportunity for remineralizing enamel and can help protect teeth in times of cariogenic challenges.

Diet and Caries

High-frequency exposure of fermentable carbohydrates such as sucrose may be the most important factor in producing cariogenic biofilm and, ultimately, caries lesions. Frequent ingestion of fermentable carbohydrates begins a series of changes in the local tooth environment that promotes the growth of highly acidogenic bacteria and eventually leads to caries. In contrast, when ingestion of fermentable carbohydrates is severely restricted or absent, biofilm growth typically does not lead to caries. Dietary sucrose plays a leading role in the development of pathogenic biofilms and may be the most important factor in disruption of the normal healthy ecology of dental biofilm communities. Because the eventual metabolic product of cariogenic diet is acid, and the acid leads to the development of caries, the exposure to acidity from other sources (e.g., dried fruits, fruit drinks, or other acidic foods and drinks) also may result in caries. The dietary emphasis must include all intakes that result in acidity, not just sucrose.

Table 2-4 Medications with Potential to Cause Hyposalivation or Dry Mouth (Xerostomia)

Action/Medication Group	Medicaments	Action/Medication Group	Medicaments
SYMPATHOMIMETIC		ANTICHOLINERGIC, DEHYDRATION	
Antidepressants	Ventafaxine Duloxetine Reboxetine Bupropion	Diuretics	Furosemide Bumetanide Torsemide Ethacrynic acid
ANTICHOLINERGIC		SYMPATHOMIMETIC	
Tricyclic antidepressants	Amitriptyline Clomipramine Amoxapine Protriptyline Doxepin Imipramine Trimipramine Nortriptyline Desipramine	Antihypertensive agents	Metoprolol Monoxidine Rilmenidine
Muscarinic receptor antagonists	Oxybutynin	Appetite suppressants	Fenfluramine Sibutramine Phentermine
Alpha-receptor antagonists	Tamsulosin Terazosin	Decongestants	Pseudoephedrine
Antipsychotics	Promazine Triflupromazine Mesoridazine Thioridazine Clozapine Olanzapine	Bronchodilators	Tiotropium
Antihistamines	Azardine Brompheniramine Chlorpheniramine Cyproheptadine Dexchlorpheniramine Hydroxyzine Phenindamine Cetirizine Loratidine	Skeletal muscle relaxants	Tizanidine
		Antimigraine agents	Rizatriptan
		SYNERGISTIC MECHANISM	
		Opioids, hypnotics	Opium Cannabis Tramadol Diazepam
		UNKNOWN	
		H2 antagonists, proton pump inhibitors	Cimetidine Ranitidine Famotidine Nizatidine Omeprazole
		Cytotoxic drugs	Fluorouracil
		Anti-HIV drugs, protease inhibitors	Didanosine

(Adapted from the Kois Center, Support Materials, Always Pages, <http://koiscenter.com/store/supmatlist.aspx>, accessed January 13, 2012.)

Clinical Characteristics of the Caries Lesion

The caries lesion is the product of disequilibrium between the demineralization and remineralization processes discussed previously. When the tooth surface becomes cavitated, a more retentive surface area becomes available to the biofilm community. The cavitation of the tooth surface produces a synergistic acceleration of the growth of the cariogenic biofilm community and the expansion of the demineralization with ensuing expanded cavitation. This situation results in a rapid and progressive destruction of the tooth structure. When enamel caries penetrates to the dentinoenamel junction (DEJ), rapid lateral expansion of the caries lesion occurs because dentin is much less resistant to acid demineralization. This sheltered, highly acidic, and anaerobic environment provides an ideal niche for cariogenic bacteria.

Clinical Sites for Caries Initiation

The characteristics of a caries lesion vary with the nature of the surface on which the lesion develops. There are three distinctly different clinical sites for caries initiation: (1)

developmental pits and fissures of enamel, which are the most susceptible sites; (2) smooth enamel surfaces that shelter cariogenic biofilm; and (3) the root surface (see Fig. 2-14). Each of these areas has distinct surface topography and environmental conditions. Consequently, each area has a distinct biofilm population. The diagnosis, treatment, and prevention of these different lesion types should take into account the different etiologic factors operating at each site.

Pits and Fissures

Bacteria rapidly colonize the pits and fissures of newly erupted teeth. The type and nature of the organisms prevalent in the oral cavity determine the type of organisms colonizing pits and fissures and are instrumental in determining the outcome of the colonization. Large variations exist in the microflora found in pits and fissures, suggesting that each site can be considered a separate ecologic system. Numerous gram-positive cocci, especially *S. sanguis*, are found in the pits and fissures of newly erupted teeth, whereas large numbers of MS usually are found in carious pits and fissures.

The shape of the pits and fissures contributes to their high susceptibility to caries. The long, narrow fissure prevents

adequate biofilm removal (see Fig. 2-12). Considerable morphologic variation exists in these structures. Some pits and fissures end blindly, others open near the dentin, and others penetrate entirely through the enamel.

Pit-and-fissure caries expands as it penetrates into the enamel. The entry site may appear much smaller than the actual lesion, making clinical diagnosis difficult. Caries lesions of pits and fissures develop from attack on their walls (see Fig. 2-15, A through C). Progression of the dissolution of the walls of a pit-and-fissure lesion is similar in principle to that of the smooth-surface lesion because a wide area of surface attack extends inward, paralleling the enamel rods. A lesion originating in a pit or fissure affects a greater area of the DEJ than does a comparable smooth-surface lesion. In cross-section, the gross appearance of a pit-and-fissure lesion is an inverted “V” with a narrow entrance and a progressively wider area of involvement closer to the DEJ (see Fig. 2-15, D).

Smooth Enamel Surfaces

The smooth enamel surfaces of teeth present a less favorable site for cariogenic biofilm attachment. Cariogenic biofilm usually develops only on the smooth surfaces that are near the gingiva or are under proximal contacts. The proximal surfaces are particularly susceptible to caries because of the extra shelter provided to resident cariogenic biofilm owing to the proximal contact area immediately occlusal to it (Fig. 2-22). Lesions starting on smooth enamel surfaces have a broad area of origin and a conical, or pointed, extension toward the DEJ. The path of ingress of the lesion is roughly parallel to the long axis of the enamel rods in the region. A cross-section of the enamel portion of a smooth-surface lesion shows a V-shape, with a wide area of origin and the apex of the V directed toward the DEJ. After caries penetrates the DEJ, softening of dentin spreads rapidly laterally and pulpally (see Fig. 2-21).



Fig. 2-22 Extracted tooth showing extensive caries lesion just gingival to the proximal contact area. (Note the slightly “flat” contact area adjacent to marginal ridge.)

Root Surfaces

The root surface is rougher than enamel and readily allows cariogenic biofilm formation in the absence of good oral hygiene. The cementum covering the root surface is extremely thin and provides little resistance to caries attack. In addition, the critical pH for dentin is higher than for enamel, so demineralization is likely to start even before the pH reaches the critical level for enamel (pH = 5.5). Root caries lesions have less well-defined margins, tend to be U-shaped in cross-section, and progress more rapidly because of the lack of protection from an enamel covering. In recent years, the prevalence of root caries has increased significantly because of the increasing number of older persons who retain more teeth, experience gingival recession, and usually have cariogenic biofilm on the exposed root surfaces.¹⁵⁻¹⁸

Progression of Caries Lesions

The progression and morphology of the caries lesion vary, depending on the site of origin and the conditions in the mouth (see Figs. 2-14, 2-15, and 2-21). The time for progression from non-cavitated caries to clinical caries (*cavitation*) on smooth surfaces is estimated to be 18 months \pm 6 months.¹⁹ Peak rates for the incidence of new lesions occur 3 years after the eruption of the tooth. Occlusal pit-and-fissure lesions develop in less time than smooth-surface caries. Poor oral hygiene and frequent exposures to sucrose-containing or acidic food can produce noncavitated (“white spot”) lesions (first clinical evidence of demineralization) in 3 weeks. Radiation-induced *xerostomia* (dry mouth) can lead to clinical caries development in 3 months from the onset of the radiation. Caries development in healthy individuals is usually slow compared with the rate possible in compromised persons.

Enamel Caries

An understanding of the enamel composition and histology is helpful to understand enamel caries histopathology (see Chapter 1 (Figs. 2-23 to 2-25)). On clean, dry teeth, the earliest evidence of caries on the smooth enamel surface of a crown is a white spot (Fig. 2-26; see also Figs. 2-2 and 2-3). These lesions usually are observed on the facial and lingual surfaces of teeth. White spots are chalky white, opaque areas that are revealed only when the tooth surface is desiccated and are termed *noncavitated enamel caries lesions*. These areas of enamel lose their translucency because of the extensive subsurface porosity caused by demineralization. Care must be exercised in distinguishing white spots of noncavitated caries from developmental white spot hypocalcifications of enamel. Noncavitated (white spot) caries partially or totally disappears visually when the enamel is hydrated (wet), whereas hypocalcified enamel is affected less by drying and wetting (Table 2-5). Hypocalcified enamel does not represent a clinical problem except for its esthetically objectionable appearance. The surface texture of a non-cavitated lesion is unaltered and is undetectable by tactile examination with an explorer. A more advanced lesion develops a rough surface that is softer than the unaffected, normal enamel. Softened chalky enamel that can be chipped away with an explorer is a sign of active caries. Injudicious use of an explorer tip can cause actual cavitation

Table 2-5 Clinical Characteristics of Normal and Altered Enamel

	Hydrated	Desiccated	Surface Texture	Surface Hardness
Normal enamel	Translucent	Translucent	Smooth	Hard
Hypocalcified enamel	Opaque	Opaque	Smooth	Hard
Noncavitated caries	Translucent	Opaque	Smooth	Softened
Active caries	Opaque	Opaque	Cavitated	Very soft
Inactive caries	Opaque, dark	Opaque, dark	Roughened	Hard

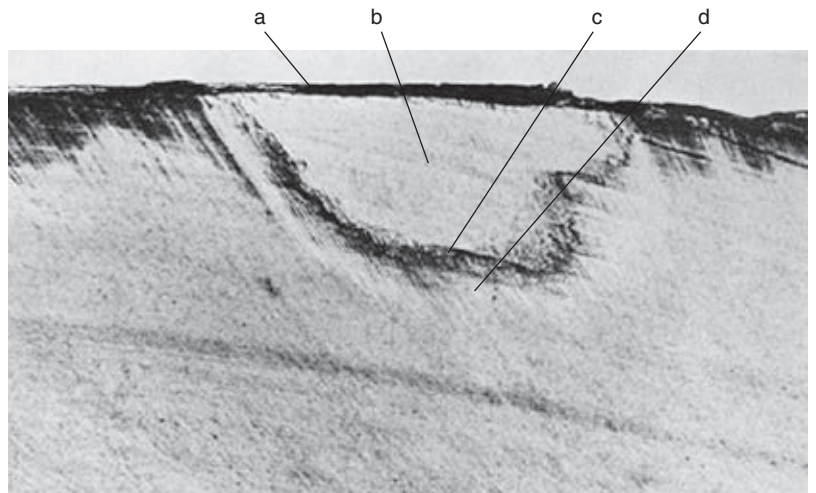


Fig. 2-23 Cross-section of small caries lesion in enamel examined in quinoline by transmitted light (×100). Surface (a) appears to be intact. Body of lesion (b) shows enhancement of striae of Retzius. Dark zone (c) surrounds body of lesion, whereas translucent zone (d) is evident over entire advancing front of lesion. (From Silverstone LM et al, editors: Dental caries, London and Basingstoke, 1981, Macmillan, Ltd.)

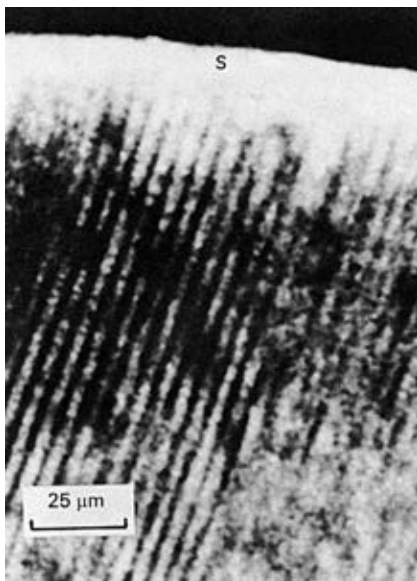


Fig. 2-24 Microradiograph (×150) of cross-section of small caries lesion in enamel. Well-mineralized surface (s) is evident. Alternating radiolucent and radiopaque lines indicate demineralization between enamel rods. (From Silverstone LM et al, editors: Dental caries, London and Basingstoke, 1981, Macmillan, Ltd.)

in a previously noncavitated area, requiring, in most cases, restorative intervention. Similar noncavitated lesions occur on the proximal smooth surfaces, but usually are undetectable by visual or judicious tactile (explorer) examination. Noncavitated enamel lesions sometimes can be seen on radiographs as a faint radiolucency that is limited to the superficial enamel. When a proximal lesion is clearly visible radiographically, the lesion may have advanced significantly, and histologic alteration of the underlying dentin probably already has occurred, whether the lesion is cavitated or not (Fig. 2-27).

It has been shown experimentally and clinically that noncavitated caries of enamel can remineralize.²⁰⁻²¹ Table 2-5 and Table 2-6 list the characteristics of enamel at various stages of demineralization. Noncavitated enamel lesions retain most of the original crystalline framework of the enamel rods, and the etched crystallites serve as nucleating agents for remineralization. Calcium and phosphate ions from saliva can penetrate the enamel surface and precipitate on the highly reactive crystalline surfaces in the enamel lesion. The supersaturation of saliva with calcium and phosphate ions serves as the driving force for the remineralization process. Artificial and natural caries lesions of human enamel have been shown to regress to earlier histologic stages after exposure to conditions that promote remineralization. The presence of trace amounts of fluoride ions during this remineralization process greatly enhances the precipitation of calcium and phosphate, resulting in the remineralized enamel becoming more

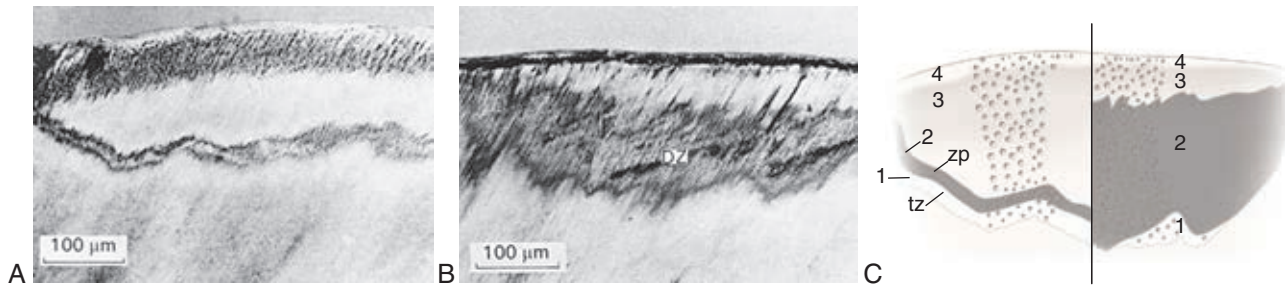


Fig. 2-25 **A**, Cross-section of small caries lesion in enamel examined in quinoline with polarized light (×100). Advancing front of lesion appears as a dark band below body of lesion. **B**, Same section after exposure to artificial calcifying solution examined in quinoline and polarized light. Dark zone (DZ) covers a much greater area after remineralization has occurred (×100). **C**, Schematic diagram of Figs. 2-25, **A** and **B**. Left side indicates small extent of zones 1 and 2 before remineralization. Small circles indicate relative sizes of pores in each zone. Right side indicates increase in zone 2, the dark zone, after remineralization. This micropore system must have been created where previously the pores were much larger. (Redrawn from Silverstone LM et al, editors: Dental caries, London and Basingstoke, 1981, Macmillan, Ltd., C was redrawn)

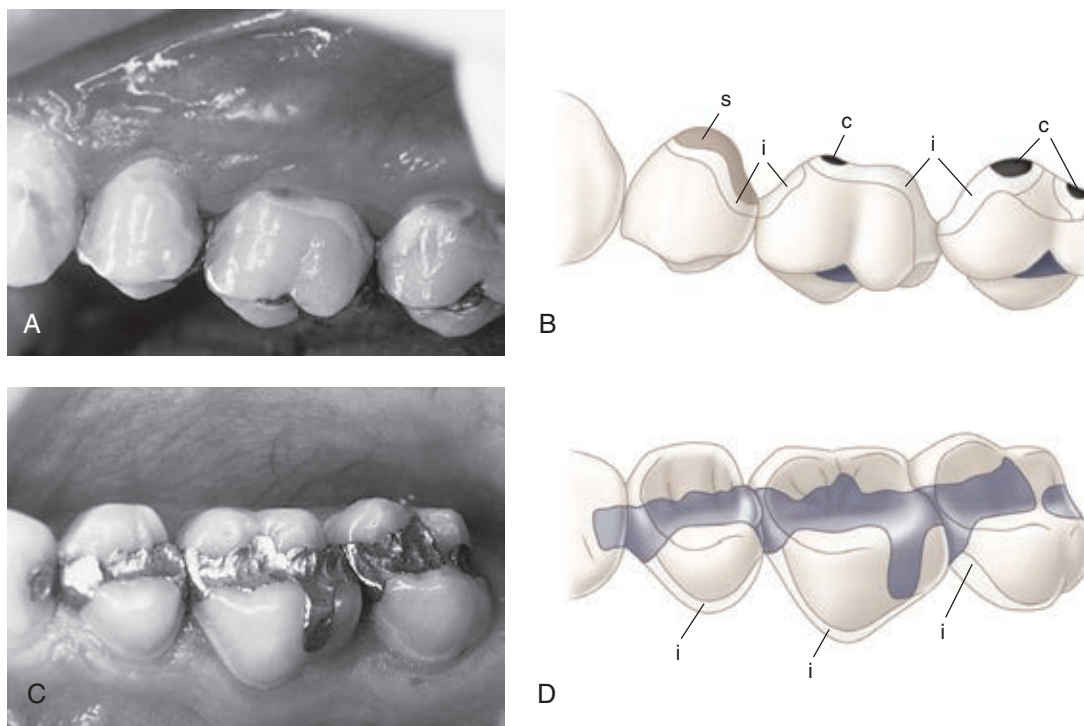


Fig. 2-26 Facial and lingual smooth-surface caries. This patient has high caries activity with rapidly advancing caries lesions. Plaque, containing mutans streptococci (MS), extends entirely around the cervical areas of the posterior teeth. Several levels of caries involvement can be seen, including cavitation (c); non-cavitated white spot lesions (i); and stained, roughened, partially remineralized non-cavitated lesions (s).

Table 2-6 Clinical Significance of Enamel Lesions

	Plaque Biofilm	Enamel Structure	Non-restorative, Therapeutic Treatment (e.g., remineralization, antimicrobial, pH control)	Restorative Treatment
Normal enamel	Normal	Normal	Not indicated	Not indicated
Hypocalcified enamel	Normal	Abnormal, but not weakened	Not indicated	Only for esthetics
Noncavitated caries	Cariogenic	Porous, weakened	Yes	Not indicated
Active caries	Cariogenic	Cavitated, very weak	Yes	Yes
Inactive caries	Normal	Remineralized, strong	Not indicated	Only for esthetics

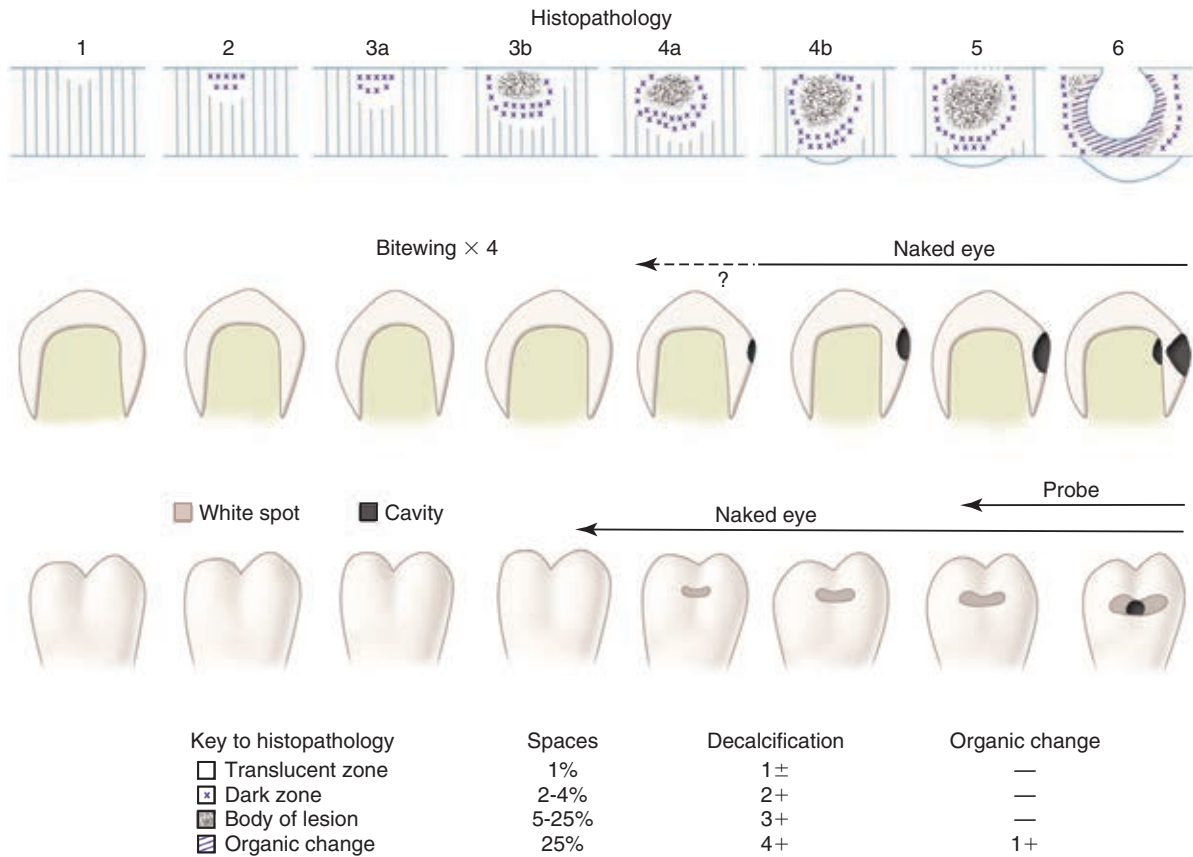


Fig. 2-27 Schematic representation of developmental stages of enamel caries lesion correlated with radiographic and clinical examination. Cavitation occurs late in development of the lesion and before cavitation remineralization is possible. (Redrawn from Darling AI: *The pathology and prevention of caries*, Br Dent J 107:287-302, 1959.)

resistant to subsequent caries attack because of the incorporation of more acid-resistant fluorapatite (Fig. 2-28). Remineralized (arrested) lesions can be observed clinically as intact, but discolored, usually brown or black, spots (Fig. 2-29). The change in color is presumably caused by trapped organic debris and metallic ions within the enamel. These discolored, remineralized, arrested caries areas are intact and are more resistant to subsequent caries attack than the adjacent unaffected enamel. They should not be restored unless they are esthetically objectionable.

Cavitated enamel lesions can be initially detected as subtle breakdown of the enamel surface. These lesions are very sensitive to probing, and can be easily enlarged by using sharp explorers and excessive probing force. More advanced cavitated enamel lesions are more obviously detected as enamel breakdown. Although some cavitated enamel lesions can be arrested and may not progress to larger lesions, most cavitated caries lesions require restorative treatment.

Dentin Caries

An understanding of the dentin composition and histology is helpful to understand the histopathology of dentin caries (see Chapter 1 (Fig. 2-30). Progression of caries in dentin is different from progression in the overlying enamel because of the structural differences of dentin (Figs. 2-31 to 2-33; see also

Local mechanism of enamel adaptation to the cariogenic challenge

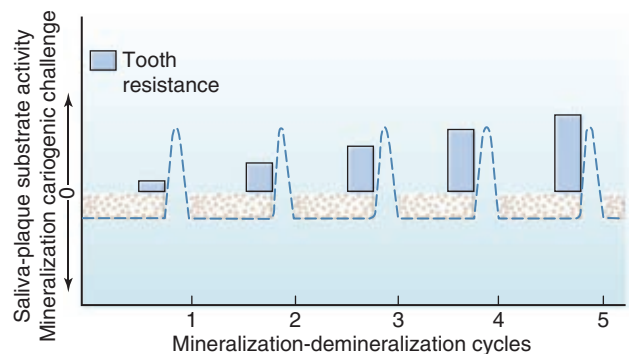


Fig. 2-28 Diagrammatic representation of enamel adaptation reaction. Enamel interacts with its fluid environment in periods of undersaturation and supersaturation, presented here as periodic cycles. Undersaturation periods dissolve most soluble mineral at the site of cariogenic attack, whereas periods of supersaturation deposit most insoluble minerals if their ionic components are present in immediate fluid environment. As a result, under favorable conditions of remineralization, each cycle could lead toward higher enamel resistance to a subsequent challenge. (Redrawn from Koulouirides T: In Menaker L, editor: *The biologic basis of dental caries*, New York, 1980, Harper & Row.)

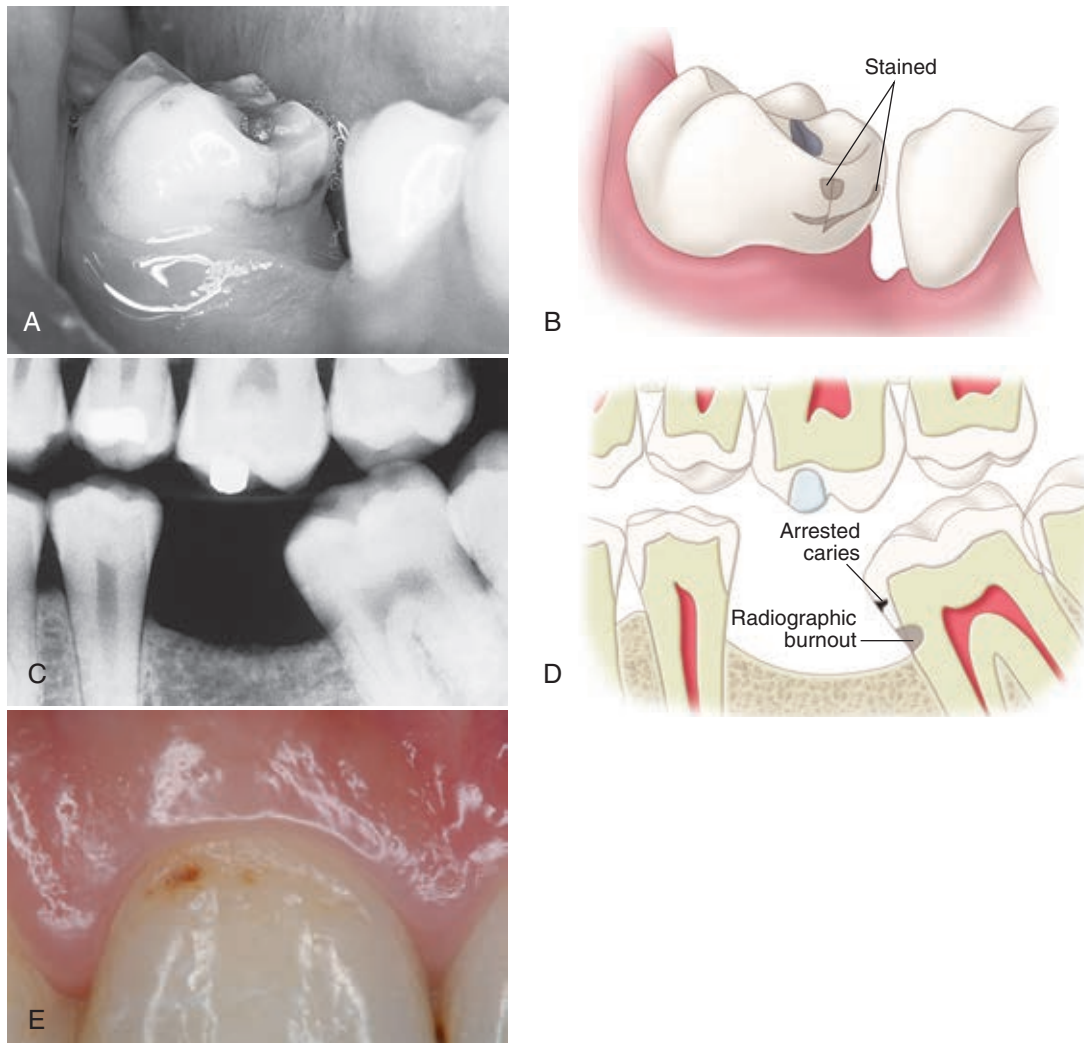


Fig. 2-29 **A** and **B**, Example of arrested caries on the mesial surface of a mandibular second molar. The area below the proximal contact (**A** and **B**, mirror view of tooth No. 18) is partly opaque and stained. Clinically the surface is hard and intact, yet the area is more radiolucent than the enamel above or below the stain. **C** and **D**, In a different clinical case, caries diagnosis based only on the radiograph would lead to a false-positive diagnosis (i.e., caries present when it is not). The radiolucency is caused by the broad area of subsurface demineralization that extends from the facial to the lingual line angles. The x-ray beam was directed parallel to the long axis of demineralization and consequently produced a sharply demarcated zone of radiolucency in the enamel. This example illustrates the shortcomings of radiographic diagnosis. Were there not visual access to the mesial surface of the second molar, it would be easy to diagnose active caries incorrectly and consequently restore the tooth. **E**, Cavitated inactive (arrested) enamel caries lesion on the cervical one third of a central incisor of a 27-year-old patient with low caries risk. This lesion, if not esthetically offensive, does not require a restoration and should be monitored.

Fig. 2-30). Dentin contains much less mineral and possesses microscopic tubules that provide a pathway for the ingress of bacteria and egress of minerals. The DEJ has the least resistance to caries attack and allows rapid lateral spreading when caries has penetrated the enamel (see **Figs. 2-15** and **2-21**). Because of these characteristics, dentinal caries is V-shaped in cross-section with a wide base at the DEJ and the apex directed pulpally. Caries advances more rapidly in dentin than in enamel because dentin provides much less resistance to acid attack owing to less mineralized content. Caries produces a variety of responses in dentin, including pain, sensitivity, demineralization, and remineralization.

Often, pain is not reported even when caries invades dentin except when deep lesions bring the bacterial infection close to the pulp. Episodes of short-duration pain may be felt occasionally during earlier stages of dentin caries. The pain is

caused by stimulation of pulp tissue by the movement of fluid through the dentinal tubules that have been opened to the oral environment by cavitation. When bacterial invasion of the dentin is close to the pulp, toxins and possibly a few bacteria enter the pulp, resulting in inflammation of the pulpal tissues and, thus, pulpal pain.

The pulp–dentin complex reacts to caries attacks by attempting to initiate remineralization and blocking off the open tubules. These reactions result from odontoblastic activity and the physical process of demineralization and remineralization. Three levels of dentinal reaction to caries can be recognized: (1) reaction to a long-term, low-level acid demineralization associated with a slowly advancing lesion; (2) reaction to a moderate-intensity attack; and (3) reaction to severe, rapidly advancing caries characterized by very high acid levels. Dentin can react defensively (by repair) to low-intensity and

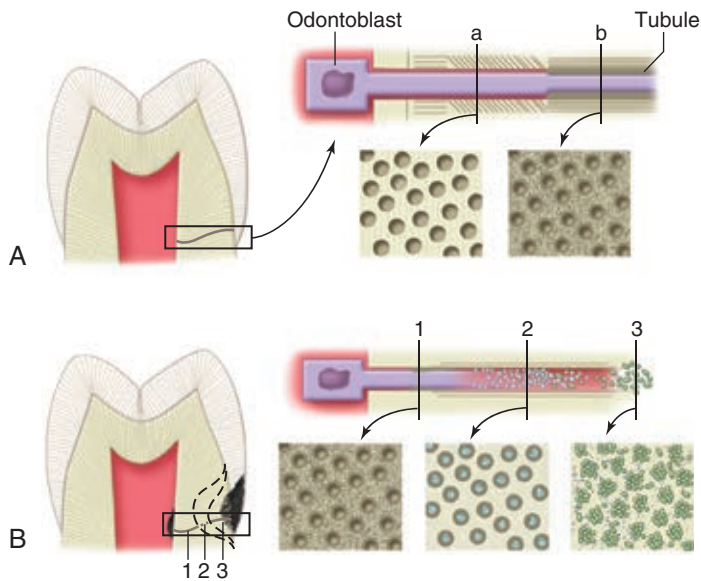


Fig. 2-30 Normal and carious dentin. **A**, Normal dentin has characteristic tubules that follow a wavy path from the external surface of dentin, below enamel or cementum, to the inner surface of dentin in the pulp tissue of the pulp chamber or pulp canal. Dentin is formed from the external surface and grows inward. As dentin grows, odontoblasts become increasingly compressed in the shrinking pulp chamber, and the number of associated tubules becomes more concentrated per unit area. The more recently formed dentin near the pulp (*a*) has large tubules with little or no peritubular dentin and calcified intertubular dentin filled with collagen fibers. Older dentin, closer to the external surface (*b*), is characterized by smaller, more widely separated tubules and a greater mineral content in intertubular dentin. The older dentin tubules are lined by a uniform layer of mineral termed *peritubular dentin*. These changes occur gradually from the inner surface to the external surface of the dentin. Horizontal lines indicate predentin; diagonal lines indicate increasing density of minerals; darker horizontal lines indicate densely mineralized dentin and increased thickness of peritubular dentin. The transition in mineral content is gradual, as indicated in Fig. 2-25. **B**, Carious dentin undergoes several changes. The most superficial infected zone of carious dentin (3) is characterized by bacteria filling the tubules and granular material in the intertubular space. The granular material contains very little mineral and lacks characteristic cross-banding of collagen. As bacteria invade dentinal tubules, if carbohydrates are available, they can produce enough lactic acid to remove peritubular dentin. This doubles or triples the outer diameter of the tubules in infected dentin zone. Pulpal to (below) the infected dentin is a zone where the dentin appears transparent in mounted whole specimens. This zone (2) is affected (not infected) carious dentin and is characterized by loss of mineral in the intertubular and peritubular dentin. Many crystals can be detected in the lumen of the tubules in this zone. The crystals in the tubule lumen render the refractive index of the lumen similar to that of the intertubular dentin, making the zone transparent. Normal dentin (1) is found pulpal to (below) transparent dentin.

moderate-intensity caries attacks as long as the pulp remains vital and has an adequate blood circulation.

In slowly advancing caries, a vital pulp can repair demineralized dentin by remineralization of the intertubular dentin and by apposition of peritubular dentin. Early stages of caries or mild caries attacks produce long-term, low-level acid demineralization of dentin. Direct exposure of the pulp tissue to microorganisms is not a prerequisite for an inflammatory response. Toxins and other metabolic byproducts, especially



Fig. 2-31 Cross-section of demineralized specimen of advanced caries in dentin. Reparative dentin (*A*) can be seen adjacent to most advanced portion of lesion. (From Boyle P: *Kornfeld's histopathology of the teeth and their surrounding structures*, Philadelphia, 1955, Lea & Febiger.)



Fig. 2-32 Rampant caries in a preschool child. (From Dean JA, Avery DR, McDonald RE: *McDonald and Avery's dentistry for the child and adolescent*, ed 9, St Louis, 2011, Mosby.)

hydrogen ion, can penetrate via the dentinal tubules to the pulp. Even when the lesion is limited to enamel, the pulp can be shown to respond with inflammatory cells.^{22,23} Dentin responds to the stimulus of its first caries demineralization episode by deposition of crystalline material in the lumen of the tubules and the intertubular dentin of affected dentin in front of the advancing infected dentin portion of the lesion (see Fig. 2-30, *B*). Hypermineralized areas may be seen on radiographs as zones of increased radiopacity (often S-shaped following the course of the tubules) ahead of the advancing, infected portion of the lesion. This repair occurs only if the tooth pulp is vital.

Dentin that has more mineral content than normal dentin is termed *sclerotic dentin*. Sclerotic dentin formation occurs ahead of the demineralization front of a slowly advancing lesion and may be seen under an old restoration. Sclerotic dentin is usually shiny and darker in color but feels hard to the explorer tip. By contrast, normal, freshly cut dentin lacks

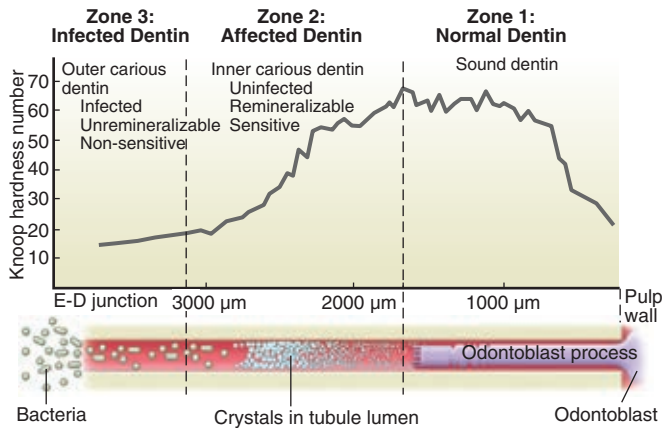


Fig. 2-33 Schematic illustration of the relationship of dentin hardness, crystal deposition, condition of the odontoblastic process, and zones of dentin caries. During caries excavation, the goal is to remove only infected dentin, while affected dentin is remineralizable and can be maintained. For orientation of layers on tooth, see Fig 2-34. (Courtesy of Dr. T. Fusayama. Copyright Ishiyaku EuroAmerica, Inc, Tokyo, 1993.)

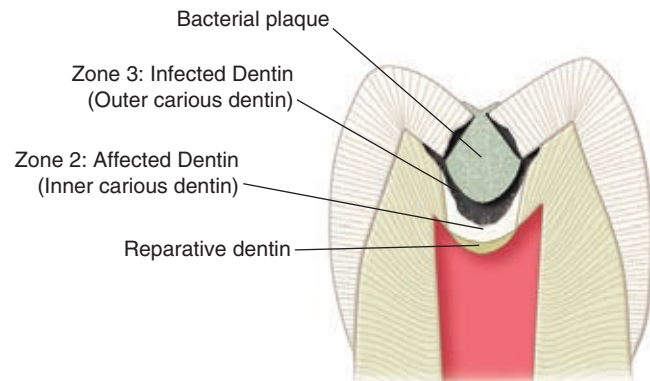


Fig. 2-34 Cross-section of occlusal caries. The occlusal enamel appears intact, with a small opening in the occlusal fissure. Enamel is darkened where it is undermined by demineralization. The surface of enamel is unaffected. The lesion is filled with a bacterial plug containing high numbers of mutans streptococci (MS) and lactobacilli. Dentin is infected below the plug. Deeper dentin is not infected but is extensively demineralized. Reparative dentin is being formed below the lesion.

a shiny, reflective surface and allows some penetration from a sharp explorer tip. The apparent function of sclerotic dentin is to wall off a lesion by blocking (sealing) the tubules. The permeability of sclerotic dentin is greatly reduced compared with normal dentin because of the decrease in the tubule lumen diameter.²⁴

Crystalline precipitates form in the lumen of the dentinal tubules in the advancing front of a demineralization zone (affected dentin). When these affected tubules become completely occluded by the mineral precipitate, they appear clear when a section of the tooth is evaluated. This portion of dentin has been termed *affected zone of dentin* (see next section on zones of dentinal caries) and is the result of mineral loss in the intertubular dentin and precipitation of this mineral in the tubule lumen. Consequently, affected dentin is softer than normal dentin (Fig. 2-34).²⁵

The second level of dentinal response is to moderate-intensity irritants. More intense caries activity results in bacterial invasion of dentin. Infected dentin contains a wide variety of pathogenic materials or irritants, including high acid levels, hydrolytic enzymes, bacteria, and bacterial cellular debris. These materials can cause the degeneration and death of odontoblasts and their tubular extensions below the lesion and a mild inflammation of the pulp. The pulp may be irritated sufficiently from high acid levels or bacterial enzyme production to cause the formation (from undifferentiated mesenchymal cells) of replacement odontoblasts (secondary odontoblasts). These cells produce reparative dentin (reactionary dentin) on the affected portion of the pulp chamber wall (see Figs. 2-30, B, and 2-34). This dentin is different from the normal dentinal apposition that occurs throughout the life of the tooth by primary (original) odontoblasts. The structure of reparative dentin varies from well-organized tubular dentin (less often) to very irregular atubular dentin (more often), depending on the severity of the stimulus. Reparative dentin is an effective barrier to diffusion of material through the tubules and is an important step in the repair of dentin. Severe stimuli also can result in the formation within the pulp chamber of unattached dentin, termed *pulp stones*, in addition to reparative dentin.

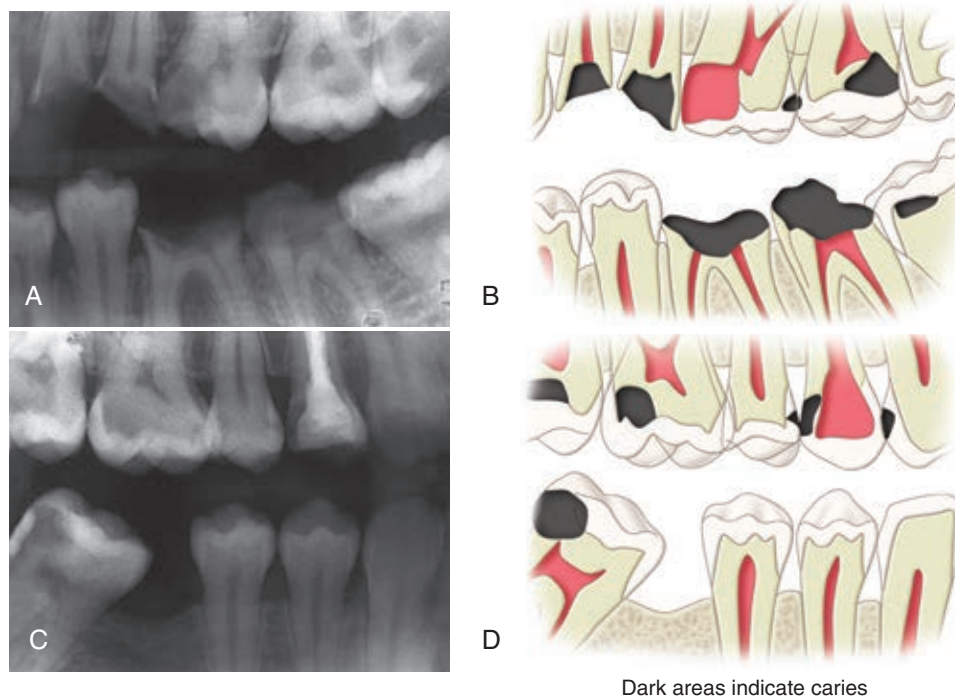
The success of dentinal reparative responses, either by remineralization of intertubular dentin and apposition of peritubular dentin or by reparative dentin, depends on the severity of the caries attack and the ability of the pulp to respond. The pulpal blood supply may be the most important limiting factor to the pulpal responses.

The third level of dentinal response is to severe irritation. Acute, rapidly advancing caries with high levels of acid production overpowers dentinal defenses and results in infection, abscess, and death of the pulp. Compared with other oral tissues, the pulp is poorly tolerant of inflammation. Small, localized infections in the pulp produce an inflammatory response involving capillary dilation, local edema, and stagnation of blood flow. Because the pulp is contained in a sealed chamber, and its blood is supplied through narrow root canals, any stagnation of blood flow can result in local anoxia and necrosis. The local necrosis leads to more inflammation, edema, and stagnation of blood flow in the immediately adjacent pulp tissue, which becomes necrotic in a cascading process that rapidly spreads to involve the entire pulp.

Maintenance of pulp vitality depends on the adequacy of pulpal blood supply. Recently erupted teeth with large pulp chambers and short, wide canals with large apical foramina have a much more favorable prognosis for surviving pulpal inflammation than fully formed teeth with small pulp chambers and small apical foramina.

Zones of Dentin Caries

Caries advancement in dentin proceeds through three changes: (1) weak organic acids demineralize dentin; (2) the organic material of dentin, particularly collagen, degenerates and dissolves; and (3) the loss of structural integrity is followed by invasion of bacteria. Three different zones have been described in carious dentin (see Figs. 2-33 and 2-34). The zones are most clearly distinguished in slowly advancing lesions. In rapidly progressing caries, the difference between the zones becomes less distinct.



Dark areas indicate caries

Fig. 2-35 Rampant caries in a 21-year-old man. Although occlusal and interproximal lesions exist in the patient, the progress of the occlusal lesions produced the most tooth destruction. The potential for developing occlusal lesions could have been reduced by earlier application of sealants. This extensive amount of caries was the result of the patient's excessive fear of bad breath. In an attempt to keep his breath smelling fresh, he kept sugar-containing breath mints in his mouth most of the day. (Dark areas in *B* and *D* indicate caries.)

ZONE 1: NORMAL DENTIN

The deepest area is *normal dentin*, which has tubules with odontoblastic processes that are smooth, and no crystals are present in the lumens. The intertubular dentin has normal cross-banded collagen and normal dense apatite crystals. No bacteria are present in the tubules. Stimulation of dentin (e.g., by osmotic gradient [from applied sucrose or salt], a bur, a dragging instrument, or desiccation from heat or air) produces a sharp pain.

ZONE 2: AFFECTED DENTIN

Also called *inner carious dentin*, affected dentin is a zone of demineralization of intertubular dentin and of initial formation of fine crystals in the tubule lumen at the advancing front. Damage to the odontoblastic process is evident. Affected dentin is softer than normal dentin and shows loss of mineral from intertubular dentin and many large crystals in the lumen of the dentinal tubules. Stimulation of affected dentin produces pain. Although organic acids attack the mineral and organic contents of dentin, the collagen cross-linking remains intact in this zone. The intact collagen can serve as a template for remineralization of intertubular dentin, and this region remains capable of self-repair, provided that the pulp remains vital. The affected dentin zone can also be subclassified in three sub-zones: (1) *subtransparent dentin* (2) *transparent dentin* (3) and *turbid dentin*.

ZONE 3: INFECTED DENTIN

Also called *outer carious dentin*, this is the outermost carious layer, the layer that the clinician would encounter first when opening a lesion. The infected dentin is the zone of bacterial

invasion and is marked by widening and distortion of the dentinal tubules, which are filled with bacteria. Little mineral is present, and the collagen in this zone is irreversibly denatured. The dentin in this zone does not self-repair. This zone cannot be remineralized, and its removal is essential to sound, successful restorative procedures and the prevention of spreading the infection.

In slowly advancing lesions, it is expedient to remove softened dentin until the readily identifiable zone of sclerotic dentin is reached. In rapidly advancing lesions (Fig. 2-35 and 2-36), little clinical evidence (as determined by texture or color change) exists to indicate the extent of infected dentin. For deep lesions, this lack of clinical evidence may result in an excavation that risks pulp exposure. In a tooth with a deep caries lesion, no history of spontaneous pain, normal responses to thermal stimuli, and a vital pulp, a deliberate, incomplete caries excavation may be indicated. This procedure is termed *indirect pulp capping* (also referred to as *stepwise caries excavation* or *partial caries excavation*) and is supported by a large body of evidence.²⁶⁻³⁴ Partial caries excavation will be covered later in this chapter. In brief, indirect pulp capping consists of complete caries excavation peripherally to a sound, caries-free DEJ; axially and pulpally, caries is excavated to within approximately 1 mm of the pulp; a glass ionomer (e.g., Fuji IX, GC America, Alsip, IL) sedative restoration or a definitive restoration is then placed. The glass ionomer is used when the clinician anticipates a follow-up appointment will be needed to re-enter the preparation and complete the caries excavation. Growing evidence suggests that re-entry does not contribute to improved clinical outcomes, but current research supports the placement of a definitive restoration.^{26-29,33,34} A calcium



Fig. 2-36 Acute, rampant caries in both anterior (A) and posterior (B) teeth.

hydroxide liner can be used on the deepest portions of the excavation to enhance the formation of reparative dentin.

Advanced Caries Lesions

Increasing demineralization of the body of the enamel lesion results in the weakening and eventual collapse of the surface enamel. The resulting cavitation provides an even more protective and retentive habitat for the cariogenic biofilm, accelerating the progression of the lesion. The DEJ provides less resistance to the carious process than either enamel or dentin. The resultant lateral spread of the lesion at the DEJ produces the characteristic second cone of caries activity in dentin. Figures 2-30, 2-32, and 2-36 and Figure 2-37 illustrate advanced lesions with infected dentin.

Necrotic dentin is recognized clinically as a wet, mushy, easily removable mass. This material is structureless or granular in histologic appearance and contains masses of bacteria. Occasionally, remnants of dentinal tubules may be seen in histologic preparations. Removal of the necrotic material uncovers deeper infected dentin (turbid dentin), which appears dry and leathery. Leathery dentin is easily removed by hand instruments and flakes off in layers parallel to the



Fig. 2-37 Advance cavitated active caries lesions on a 35-year-old patient with high caries risk. (Courtesy of Dr. Ayesha Swarn, DDS, Operative Dentistry Graduate Program at UNC School of Dentistry.)

DEJ. Microscopic examination of this material reveals distorted dentinal tubules engorged with bacteria. Clefs coursing perpendicular to the tubules also are seen in leathery dentin. Apparently, these clefs represent the rest lines formed during the original deposition of dentin and are more susceptible to caries attack. Further excavation uncovers increasingly harder dentin. If the lesion is progressing slowly, a zone of hard, hypermineralized sclerotic dentin may be present, as a result of remineralization of what formerly was affected (or transparent) dentin (zone 2). When sclerotic dentin is encountered, it represents the ideal final excavation depth because it is a natural barrier that blocks the penetration of toxins and acids.

Removal of the bacterial infection is an essential part of all operative procedures. Because bacteria never penetrate as far as the advancing front of the lesion, it is not necessary to remove all of the dentin that has been affected by the caries process. In operative procedures, it is convenient to term dentin as either *infected*, which requires removal, or *affected*, which does not require removal. Affected dentin is softened, demineralized dentin that is not yet invaded by bacteria. Infected dentin is softened and contaminated with bacteria. It includes superficial, granular necrotic tissue and softened, dry, leathery dentin. The outer layer (infected dentin) can be selectively stained in vivo by caries detection solutions such as 1% acid red 52 (acid rhodamine B or food red 106) in propylene glycol.³⁵ This solution stains the irreversibly denatured collagen in the outer carious layer but not the reversibly denatured collagen in the inner carious layer.³⁶ Clinical use of this staining technique may provide a more conservative tooth preparation because the boundary between the two layers differentiated by this technique cannot easily be detected in a tactile manner.

Caries Risk Assessment and Management

In Chapter 3, the clinical examination process for diagnosis and detection of caries lesions is discussed in detail. Although it is very important to detect caries lesions, this

is a tooth-centered process. It is critical to remember that clinicians treat the entire patient and not just individual teeth and caries lesions. As noted earlier in this chapter, dental caries is a multi-factorial medical disease process, and the caries lesions are the expression of that disease process involving the patient as a whole. Equally important in the management of caries as a disease entity is the ability to individualize caries diagnosis and treatment or interventions for each patient. To do this, the clinician must formulate a caries risk assessment profile that is based on the patient's risk factors and risk indicators currently present. A *risk factor* is defined as an environmental, behavioral, or biologic factor that directly increases the probability that a disease will occur and, the absence or removal of which reduces the possibility of disease.^{37,38} Risk factors are part of the causal chain of the disease process, or they expose the host to the causal chain; but once the disease occurs, removal of a risk factor may not always result in the disease process being halted. Any definition of risk factor must clearly establish that the exposure has occurred before the outcome or before the conditions are established that make the outcome likely. This means that longitudinal studies are necessary to demonstrate risk factors. Terms such as *risk indicators* and *risk markers* are also used in the caries literature to refer to risk factors, putative risk factors, or something else entirely. For example, *risk indicators* can refer to existing signs of the disease process, or signs that the disease process has occurred, but are not part of the disease causal chain. For example, existing caries lesions would be risk indicators, as they indicate a risk status, but are not per se part of the causal chain. Multiple risk factors (and indicators) have been studied, reviewed, and validated in the assessment of risk for development of future caries disease, but caries risk assessment is not an exact science. Because caries is a complex multi-factorial disease, no single risk factor (or indicator, or marker) is highly predictive of future caries. However, caries risk assessment is necessary to inform what (if any) interventions are needed to lower the patient's caries risk and activity—which is the ultimate goal of caries management in a medical model.^{39,40} A discussion of different risk factors will be included in this section of this chapter.

Caries risk assessments are specific for adults and adolescents older than 6 years and children under 6 years of age. It is very important to spend the time with the patient to uncover all relevant risk factors and indicators currently present. Some risk factors and protective factors can be adjusted and modified by either the patient or the clinician, such as sucrose intake and fluoride exposure; other risk factors are not modifiable, such as xerostomia as the result of a needed medication. Understanding and controlling risk factors and protective factors can be very important in the prevention of new caries lesions and to slow down or arrest the progression of existing caries lesions.

No consensus exists on exactly how to define the risk categories for caries risk assessments. Terms used are “at risk,” “low risk,” “medium risk,” “high risk,” and so on. Assignment of these terms is typically based on the subjective judgment of the clinician with general rules applied, based on the clinician's previous clinical experiences and training. If a clinician finds no detectable or active caries lesions and minimum or no identifiable risk factors, that patient would be assigned a *low caries risk*. In this situation, in the current state of the patient's health, the protective factors for not developing

caries lesions outweigh the risk factors that could lead to new caries lesions. The strongest predictor for caries risk for patients in the *at risk* and *high risk* categories are the number of caries lesions being detected for the patient over the last 2 to 3 years along with past history of caries lesions in the patient's lifetime.³⁹

Historically, dentistry has used a surgical model for the management of dental caries, which mainly contemplated the biomechanical excision of caries lesions and the restoration of the resultant *tooth preparation* to form and function with a restorative material. Management of caries disease by a surgical model consisted of waiting until cavitations were detected and treating the cavitations with restorations. Eventually, it became apparent that dealing only with the end result of the disease and not addressing its etiology for each individual patient was not successful in controlling the caries disease process. Since surgical management alone was not successful, a system has been developed using caries management strategies. This system looks at individualized caries risk assessments and uses this information to design treatment plans according to the risk assessment findings. These assessments look at each patient's unique set of pathologic factors and protective factors. Caries management by risk assessment represents a management philosophy that manages the caries disease process using a medical model. This process provides an individualized evaluation of a patient's pathologic factors and protective factors and assesses the patient's risk for developing future disease. The risk assessment is then used to develop an *individualized* evidence-based caries management plan that would involve all aspects of nonsurgical therapeutics and dental surgical interventions. Both risk assessment and patient-centered interventions are based on the concept of caries balance as discussed earlier in this chapter (see Fig. 2-1). The caries balance model is based on minimizing pathologic factors while maximizing protective factors to attain a balance that favors no disease occurring, or health. With the use of caries management by risk assessment for patient management, mounting evidence suggests that early damage to teeth may be reversed and that the incidences of disease manifestations can be significantly reduced or prevented. Caries management by risk assessment is evolving into the standard of care in caries management. In the United States, one of the most widely used systems is CAMBRA (*caries management by risk assessment*).^{4,41}

Caries Risk Assessment

In Chapter 3, the examination process and formulation of the diagnosis, prognosis, and treatment planning related to caries management and operative dentistry interventions are reviewed. The caries risk assessment is an important part of this overall process of patient care. The clinician must gather all appropriate data from both the interview with the patient and the clinical examination for caries detection to formulate an individualized caries risk assessment. Part of the caries risk assessment identifies the causative factors, called *risk factors*, but does not predict the caries outcome. Risk factors can exist for a patient without the disease being expressed at the current point in time. The predictive model part of the risk assessment looks at the assessment of caries progression in the future. The term *risk factor* is associated with the variables studied that have value for prediction purposes, which means that the risk

factor is present *before* the disease occurs. As discussed above, risk indicators are existing signs of the disease process. They are examples of what is happening with the patient's current state of oral health, not how disease occurred. They are clinical observations and detection modalities used to identify risk-level status. Examples include visible cavitations in pits and fissures or in proximal surfaces of teeth, brown spots, active white spots, or cavitated lesions on free smooth surfaces, as well as any restorations in the past 3 years. The ideal caries risk assessment model should be inexpensive and easy to use but at the same time have high degrees of accuracy in predictive value. It should be valuable in decision making for caries management in the use of nonsurgical therapeutics and surgical interventions that serve the patient in a cost-effective and health-promoting manner.

One of the roles of caries risk assessments in caries management is to assist in determining the current caries lesion activity. Caries lesions can be detected much before frank cavitation occurs. The diagnosis of caries lesions should include whether they are actively progressing. An inactive lesion may be visible clinically or radiographically. However, an inactive caries lesion does not progress over time. With a positive shift in protective factors, change in oral hygiene, reduction of negative risk factors, it is possible for caries lesions to change in density, size, hardness and show increased sheen compared with the previous matte surface texture. These inactive lesions may remineralize and not require operative intervention. Assessment by the clinician of all the risk factors and protective factors in the patient's current history can greatly aid in the decision regarding current activity. Looking at all the possible risk factors with a thorough risk assessment allows for a more predictive analysis of current and future disease activity and assists in deciding on nonsurgical or surgical interventions. Caries risk assessments help the clinician to identify the etiologic causes of the disease for a specific patient at a specific point in time. Risk assessments are important in determining the frequency of recare visits and the treatment protocols for follow-up visits. Restorative decisions in terms of material used and cavity preparation design are also influenced by the information gathered in the risk assessments. The data gathered establish an important baseline for use in future reassessments to help the clinician and the patient measure the effectiveness of the caries management treatment protocol used for the patient. The systematic use of risk assessment profiles is essential in uncovering risk factors that are present before expression of the disease. This information can be useful in the prevention of caries lesions in patients who have risk factors present but no disease expression and then experience a lifestyle change that adds additional risk factors. This new risk factor then becomes a tipping point for the caries balance equation toward disease expression. For instance, a patient who has the risk factor of frequent consumption of high-sugar soft drinks during the day suddenly is prescribed a xerostomia-inducing medication that increases his caries risk. The informed patient would have the option of making the decision to eliminate a modifiable risk factor (soft drinks) before expression of the disease and before the introduction of the xerostomia-producing medication to his risk assessment.

The incorporation of risk assessments in routine patient care and in each patient's caries management program is necessary because of the multi-factorial nature of caries. No one

factor can be used to predict the probability of a patient developing caries lesions. Looking at the whole patient in developing a preventive and restorative caries management plan is essential to successful outcomes. In addition, having recorded specific risk assessment profiles provides patients with an educational tool that empowers them to be an important part of managing their disease. Finally, risk assessments provide a means for both the clinician and the patient to monitor and measure the proposed caries management protocols over time and evaluate and adjust the protocols as needed. Risk assessments lead to better treatment outcomes for patients.

Knowing certain factors pertaining to the patient's history are key in establishing a caries risk assessment. Such factors that have been identified as contributing to caries risk include age, gender, fluoride exposure, home care, smoking habits, alcohol intake, medications, dietary habits, economic and educational status, and general health. Increased smoking, alcohol consumption, use of medications, and sucrose intake result in increased risks for caries development.⁴² Children and older adults have increased risks. Decreased fluoride exposure, lower economic status, and lower educational attainment also increase risk. Poor general health also increases the risk. A strong body of evidence suggests that past caries experience is the best predictor of future caries activity.⁴³ Information that is important and obtained in the patient history interview would be biologic and environmental factors that include, but are not limited to, medical history including current and past diseases, current medications, and history of xerostomia from medications or conditions; dental history including past history of dental caries, dental phobias, and history of dental conditions; current home care practices and how well this is done; current diet and exposure to sucrose and other fermentable carbohydrates; and current exposure to topical fluoride products in toothpaste, mouth rinses, and fluoridated water supply. Some of these factors are explored in more detail in the following sections.

Figure 2-38, A and B, present two examples of Caries Risk Assessment forms that can be used as part of the initial caries diagnosis process, and Figure 2-38, C, is an example of a Caries Assessment form that can be used to facilitate communication of the findings with patients; this Caries Assessment form is a useful tool to measure changes and determine the effectiveness of caries management procedures. All of these forms can be incorporated into an electronic patient management system for increased efficiency.

Social, Economic, and Education Status

Social status and economic status are not directly involved in the disease process but are important because they affect the expression and management of the caries disease. The socioeconomic status and educational status of the patient have implications on the necessary compliance and behavioral changes that can decrease risk for caries in patients. These are predictive at the population level but are generally inaccurate at the individual level.

Dietary Analysis

Sugar intake in the form of fermentable carbohydrates and increased frequency of intake are conditions that increase risk for caries. The use of candies and lozenges frequently during

Caries Risk Assessment Form (Age >6)

Patient Name:

Score:

Birth Date:

Date:

Age:

Initials:

		Low Risk (0)	Moderate Risk (1)	High Risk (10)	Patient Risk
Contributing Conditions					
I.	Fluoride Exposure (through drinking water, supplements, professional applications, toothpaste)	Yes	No		
II.	Sugary Foods or Drinks (including juice, carbonated or non-carbonated soft drinks, energy drinks, medicinal syrups)	Primarily at mealtimes		Frequent or prolonged between meal exposures/day	
III.	Caries Experience of Mother, Caregiver and/or other Siblings (for patients ages 6-14)	No carious lesions in last 24 months	Carious lesions in last 7-23 months	Carious lesions in last 6 months	
IV.	Dental Home: established patient of record, receiving regular dental care in a dental office	Yes	No		
General Health Conditions					
I.	Special Health Care Needs*	No	Yes (over age 14)	Yes (ages 6-14)	
II.	Chemo/Radiation Therapy	No		Yes	
III.	Eating Disorders	No	Yes		
IV.	Medications that Reduce Salivary Flow	No	Yes		
V.	Drug/Alcohol Abuse	No	Yes		
Clinical Conditions					
I.	Cavitated or Non-Cavitated (incipient) Carious Lesions or Restorations (visually or radiographically evident)	No new carious lesions or restorations in last 36 months	1 or 2 new carious lesions or restorations in last 36 months	3 or more carious lesions or restorations in last 36 months	
II.	Teeth Missing Due to Caries in past 36 months	No		Yes	
III.	Visible Plaque	No	Yes		
IV.	Unusual Tooth Morphology that compromises oral hygiene	No	Yes		
V.	Interproximal Restorations - 1 or more	No	Yes		
VI.	Exposed Root Surfaces Present	No	Yes		
VII.	Restorations with Overhangs and/or Open Margins; Open Contacts with Food Impaction	No	Yes		
VIII.	Dental/Orthodontic Appliances (fixed or removable)	No	Yes		
IX.	Severe Dry Mouth (Xerostomia)	No		Yes	
TOTAL:					

Patient Instructions:

*Patients with developmental, physical, medical or mental disabilities that prevent or limit performance of adequate oral health care by themselves or caregivers. © American Dental Association, 2009, 2011. All rights reserved.

A

Fig. 2-38 A, Example of a Caries Risk Assessment form recommended by the American Dental Association.

Caries Risk Initial Assessment

Name _____

Date _____

Risk Low Risk At Risk High Risk

Risk Rating Score ≤ 3 ≥4 and ≤8 ≥9

Patient Interview Assessment

Dental History

1. Had non emergency dental care in last year	yes	no	-1
2. Brushes teeth at least twice daily	yes	no	-3
3. Uses fluoridated toothpaste or product daily	yes	no	-3
4. New caries lesions within the last 3 years	yes	no	8
5. Patient has teeth sensitive to hot, cold, sweets	yes	no	3
6. Patient avoids brushing any part of mouth	yes	no	3

Supplemental notes for dental history

Dietary Assessment

1. Water supply currently fluoridated	yes	no	-2
2. Frequent snacking with sugary foods, acidic foods, fermentable carb foods	yes	no	8
3. Sugary drinks including soft drinks, juice, sports drinks, medicinal syrups	yes	no	8
4. Tobacco use of any kind	yes	no	3
5. Excessive alcohol or recreational drug use	yes	no	8
6. Eating disorders	yes	no	5

Supplemental notes for dietary assessment

Xerostomia Assessment

1. Patient is aware of dry mouth or reduced saliva	yes	no	10
2. Medications taken that reduce salivary flow	yes	no	8
3. Medical conditions affecting salivary flow/content	yes	no	8
4. Saliva flow or content visibly abnormal	yes	no	10

Xerostomia Assessments with scores of 8-10 indicate baseline salivary testing is required

Patient Clinical Assessment

Clinical Oral Findings

1. Readily visible biofilm/plaque	yes	no	5
2. Visible cavitated lesions	yes	no	10
3. Interproximal enamel lesions or radiolucencies	yes	no	10
4. Visible white spots	yes	no	5
5. Visible brown spots or non cavitated caries lesions	yes	no	3
6. Deep pits or grooves	yes	no	5
7. Radiographic cavitated lesions	yes	no	10
8. Restorations with overhangs and/or margin concerns or open contacts	yes	no	3
9. Prosthesis ortho, fixed, or removable	yes	no	3

Clinical Assessments with scores of 10 indicate that baseline bacterial testing is required

Risk Rating Total =

10. Clinician's impression of patient's risk	low	at risk	high
--	-----	---------	------

This is clinician's impression of patient's risk if different than would be indicated by risk factors marked. Describe in box below.

Patient Compliance Assessment

Patient's attitude and general assessment of patient's ability to comply for each of the following categories:

Oral hygiene compliance patient limitations	yes	no
Dietary recommendation patient limitations	yes	no
Therapeutic homecare products limitations	yes	no
Special needs health care (physical or mental compliance issues)	yes	no

This is clinician's assessment of any perceived limitations for the patient to comply with oral hygiene, dietary, or using home care products. Could be lifestyle, physical, or economic reasons. Describe in box below.

Patient Clinical In Office Tests Indicated From Risk Score

Cariscreen Meter	completed	at risk	low risk	reading _____
GC America Saliva Check	completed	at risk	low risk	
GC America Strep Mutans	completed	at risk	low risk	
GC America Plaque Indicator	completed	at risk	low risk	
UNC Biologic Testing Lab	completed	at risk	low risk	

Notes from oral findings, patient's attitude, office tests, special circumstances that would influence caries risk or management

B

Fig. 2-38, cont'd B, Example of a Caries Risk Assessment form used by the University of North Carolina, Department of Operative Dentistry.

Caries Assessment Testing Results

PREPARED FOR

PREPARED BY

Name _____

Date _____

Your Risk Scores:

Risk predicts your likelihood of developing future disease. Green is low risk and means you are unlikely to develop a cavity whereas red means you are very likely to develop a cavity unless your risk factors are managed. We will use these results to work with you to develop an individualized plan to control your disease.

Existing Dental Conditions



Your dental condition score is based on current areas of decay, number of cavities in the last three years, exposed root surfaces, crowns and fillings that are defective. Your score will also be higher if you wear partial dentures or other appliances.

Saliva Assessment Testing

Saliva pH Testing



>6.8 6.0-6.6 <5.8

Saliva Flow and Buffering



Normal Abnormal

Your saliva is the main protective factor in the caries risk disease state equation. Yellow and Red results can produce an increased incidence of cavities. If the pH of the saliva is low, it sets the stage for the bacteria to grow that cause cavities to form in your mouth. If the quantity of the saliva is below normal, the healing ability of the saliva to remineralize your teeth after acidic food and beverages is greatly reduced. This can, in most incidences, result in a dry mouth that is uncomfortable when eating and lead to an increase in cavities on the roots and other surfaces of your teeth. Any change in saliva content, amount, or pH can increase your risk for cavities to form even if you have not had cavities in the past. New medications and medical conditions can cause your saliva to change rapidly.

Plaque Assessment Testing

Plaque pH Testing



>6.8 6.0-6.6 <5.8

Biofilm Activity



<1500 1500-2000 >2000

Visible Plaque



Low High

Plaque or biofilm is the mass of bacteria that is always changing and clings to the surfaces of your teeth. Plaque is one of the main risk factors that result in cavities. For plaque to produce the acid that dissolves your teeth and form cavities, it has to be in an acidic state, or in other words, have a low pH. The more acidic, the more damage that can result. The type of bacteria in the plaque also influences how easy it is for the damage to occur. The biofilm activity measures the amount of the "bad" bacteria present in the plaque. The higher the number, the more bacteria are present that cause the cavities to form. The amount of plaque on your teeth means more bacteria are present in your mouth. More bacteria produce higher amounts of acid to demineralize your teeth and cause them to decay.

Dietary Habits

Frequency of Snacking



< 1 2-3 >3

Frequency of sweetened beverages and sport drinks



< 1 2-3 >3

A key factor in how you control your disease and prevent cavities is how you eat and what beverages you consume. Snacking with sweet foods or high carbohydrate foods that can form sugars causes the plaque to become acidic. This results in more bacteria forming that produce even more acid. All of this acid dissolves your teeth and forms the cavities. Sweetened drinks or drinks high in acid content also produce low pH plaque and more bacteria. Soft drinks and sports drinks like Gatorade are very low in pH. The more you drink, the more acid the plaque and bacteria produce to cause the cavities in your teeth.

C

Fig. 2-38, cont'd C, Another caries Assessment form used by the University of North Carolina, Department of Operative Dentistry. This form is very useful for patient communication and compliance. (A, Copyright 2009, 2011 the American Dental Association.)

the day or night increases the risk. Acidic beverages, including sport drinks, fruit juices, and soft drinks, all contribute to increasing risk by providing energy to the acidogenic and aciduric bacteria and by influencing the pH of the biofilm to support cariogenic bacteria. Frequency of snacking and the frequency of consuming these foods and beverages all support an increase in biologic caries risk factors by modifying the biofilm to support a lower pH environment.

Salivary Analysis

Salivary flow rate, buffering capacity, and pH all can be measured by different tests and means. The predictive value for these tests for caries is not supported by the highest evidence in all circumstances. Patients with good saliva flow and adequate buffering can still have caries. In cases of dry mouth, or xerostomia, a salivary analysis is a predictive risk factor for root caries in older patients with recession and for increased caries in general in other populations. As discussed previously, saliva has numerous effects in protection against caries, including inhibition of bacteria, diluting and eliminating bacteria and their substrates, buffering bacterial acids, and offering a reparative environment with necessary calcium and phosphate minerals after bacteria-induced demineralization. Since all of these benefits are missing when patients have salivary hypofunction, patients with dry mouth are at higher risk for caries. These patients are more susceptible to dietary changes that are associated with lower pH foods and beverages or foods and beverages containing fermentable carbohydrates, since the protective factors of saliva are diminished in patients with xerostomia.

Dental Clinical Analysis (Dental Exam)

The dental examination determines risk indicators more than risk factors. This is also important as many of the indicators are directly related to the current caries activity. The indicators and current caries activity drive the decision making process for the type of intervention that the clinician would prescribe. Visible cavitated caries lesions, white spots on teeth, and brown spots on teeth are all indicators for caries risk. Visible plaque or biofilm can be considered a risk factor for caries development. Other examination findings that would influence increased risk for caries are exposed root surfaces, deep pits or grooves, fixed, removable prosthesis, or orthodontic appliances used, poor quality existing restorations with open contacts, open margins, or overhangs.

Bacterial Biofilm Analysis

Use of supplemental tests to analyze the bacterial component of the biofilm can help determine the patient's risk level. However, the evidence is weaker with some potential for bias by the examiners for these tests being predictive of future caries. For example, the presence of *S. mutans* or lactobacilli in saliva or plaque as a sole predictor for caries in primary teeth was shown to have low sensitivity but high specificity. Other means of bacterial testing still being evaluated is the measurement of adenosine triphosphate (ATP) activity of the biofilm bacteria as a surrogate measure of caries activity. Although these bacterial tests can be useful for communication with the patient and can provide insight into the type of

bacteria present and the type of biofilm environment present, predictive evidence for caries from these tests need to be further studied and improved.

Risk Considerations for Children Under 6 Years Old

In addition to all the above risk factors for adults and adolescents, age-specific risk factors and indicators that should be considered for children under 6 years old include presence of active caries in the primary caregiver in the past year; feeding on demand past 1 year of age; bedtime bottle or sippy cup with anything other than water; no supervised brushing; and severe enamel hypoplasia.

Caries risk assessment is only effective if used in conjunction with a corresponding caries management program. The caries prevention or management program should comprise a menu of prevention therapies and interventions that should be recommended on the basis of the level of caries risk (Table 2-7 and Box 2-2). However, as was discussed in the previous section, no caries risk assessment system is perfect. Therefore, in addition to the outcome of the caries risk assessment tool, the clinician needs to use the best clinical judgment, coupled with the best available research evidence, to design a preventive or therapeutic program that works for the patient. Needless to say, this is a dynamic process, so monitoring and periodic reassessment and re-evaluation of the disease activity and prevention or management program are critical.

Caries Management and Protocols or Strategies for Prevention

Management of dental caries and its consequences remains the predominant activity of dentists. Preventive and diagnostic services are, however, increasing.^{44,45} Although these activities relate to a variety of dental problems, diagnosis and prevention of caries are major parts of these increases. In a modern practice model, the restoration of a caries lesion should no longer be considered a cure for dental caries. Rather, the practitioner must identify patients who have active caries lesions and patients at high risk for caries and institute appropriate preventive and treatment measures. This section presents some measures that can reduce the likelihood of a patient developing caries lesions. Depending on the risk status of the patient, the dentist must decide which of these to institute. In the future, dentistry will focus increasing effort on limiting the need for restorative treatment.

Preventive treatment methods are designed to limit tooth demineralization caused by cariogenic bacteria, preventing cavitated lesions. These methods include (1) limiting pathogen growth and altering metabolism, (2) increasing the resistance of the tooth surface to demineralization, and (3) increasing biofilm pH. A caries prevention and management program is a complex process involving multiple interrelated factors (Table 2-7; Tables 2-8, 2-9, 2-10 and 2-11; see also Table 2-7 and Box 2-2). The primary goals of a caries prevention program are to reduce the numbers of cariogenic bacteria and to create an environment conducive to remineralization. Prevention should start with a consideration of the overall resistance of the patient to infection by the cariogenic bacteria. Although the general health of the patient, fluoride exposure

Table 2-7 Suggested Risk-Based Interventions for Adults*

Caries Risk Category	Office-Based Interventions	Home-Based Interventions
HIGH	3-month recare examination and oral prophylaxis Fluoride varnish at each recare visit Individualized oral hygiene instructions and use of specialized cleaning aids (e.g., powered toothbrush, Waterpik) Dietary counseling Bitewing radiographs every 6–12 months [†]	Brush with prescription fluoride dentifrice, e.g. 1/1%/5000 ppm NaF Use sugar substitutes (e.g., xylitol, sorbitol) Apply calcium-phosphate compounds (e.g., MI Paste) Use antimicrobial agents (e.g., xylitol gum or lozenge, chlorhexidine rinse) If xerostomic, increase salivary function (e.g., xylitol gum, rinses, oral moisturizers)
MODERATE	4–6 month recare examination and oral prophylaxis Fluoride varnish at each recall Reinforce proper oral hygiene Dietary counseling	Brush with fluoride dentifrice (e.g., 1450 ppm fluoride) OTC fluoride rinse (e.g., 0.05% NaF)
LOW	9-12 month recare examination and oral prophylaxis Reinforce good oral hygiene	Brush with fluoride dentifrice

*These are general guidelines, and should be customized based on the specific patient's needs and on weight of individual risk factors uncovered with a caries risk assessment instrument.

[†]Data from U.S. Department of Health and Human Services, Public Health Service, Food and Drug Administration; and American Dental Association, Council on Dental Benefit Programs, Council on Scientific Affairs. The selection of patients for dental radiographic examinations. Rev. ed. 2004. Available at: "www.ada.org/prof/resources/topics/radiography.asp". Accessed January 20, 2012.

NaF, sodium fluoride; OTC, over the counter; ppm, parts per million.

(Modified from Shugars DA, Bader JD: *MetLife Quality Resource Guide: Risk-based management of dental caries in adults*, *MetLife Quality Resource Guide*, ed 3, Metropolitan Life Insurance, Co., Bridgewater NJ; 2009-2012, p. 6)

Box 2.2 Sample Preventive Protocol for a High-Risk Patient with Cavitated Caries Lesions

1. A comprehensive oral and radiographic evaluation is conducted charting caries lesions, periodontal pocket probing, existing restorations, and oral cancer exam; the medical and dental histories are reviewed. In this hypothetical patient, multiple caries lesions, poor oral hygiene, and generalized marginal gingivitis are noted.
2. A caries risk assessment is completed with emphasis on discovering the risk factors that are contributing to the causative aspect of the caries problem and discovering the risk factors for the patient that are predictors of future caries risk. A discussion of these risk factors with the patient is essential for understanding of the caries disease process and the patient's role and the provider's role in controlling the disease.
3. Diagnosis and treatment planning procedures are completed and discussed with the patient.
4. Nonoperative and operative treatments will be completed in three phases: (i) A control phase, (ii) a definitive treatment phase, (iii) a maintenance re-assessment phase.
5. CONTROL PHASE (2–4 weeks):
 - a. Oral hygiene procedures are explained and reviewed at each patient visit. The frequency of the visits in this initial phase is determined by severity of the disease. This could be weekly or more frequent, depending on the provider's evaluation. When attempting behavior modification, repetition is essential. Review of patient's current home care techniques and frequency of home care are reviewed along with lifestyle issues that might impede compliance. Use of a powered toothbrush and an oral irrigator for possibly improving patient compliance and technique are discussed. Evaluation of the patient's motivation along with the person's mental and physical capacity to comply with recommendations for home care must be noted and considered by the provider.

Specific recommendations are listed for the patient to use at home, and the patient agrees that this is practical for his or her life situation.
 - b. Prescription fluoride toothpaste is prescribed (5000 parts per million [ppm]) and the patient is instructed to brush with it three times per day and to use according to given instructions (do not rinse after use, only expectorate excess). Any products used for home care should be carefully reviewed for the pH of the product. Products with pH lower than 6.0 should be carefully considered whether their use would contribute to the pH shift of the biofilm to pathologic for caries lesion formation.
 - c. A diet analysis is completed, analyzed, and reviewed with the patient. Cariogenic foods and beverages are identified and alternatives suggested. Also, acidic foods and beverages that are contributing to the pH shift to a lower oral pH environment are identified and discussed. Options for foods that have impact to raise the oral pH are suggested, such as foods rich in arginine. Again the patient's motivation and abilities to fit the necessary diet modifications into his or her lifestyle must be evaluated and discussed.
 - d. A microbiologic survey is completed, using either the adenosine triphosphate (ATP) chairside device or formal saliva samples to identify specific mutans streptococci (MS) and lactobacilli counts. This will serve as baseline data to determine the effectiveness of the prevention protocol for both the provider and the patient and can serve as a motivation for the patient.
 - e. A saliva analysis is conducted to determine stimulated flow rate, salivary pH and buffering capacity, and viscosity. Treatment protocols for xerostomia are recommended for patients with an analysis that indicates deficiencies in the above

Continued

Box 2.2 Sample Preventive Protocol for a High-Risk Patient with Cavitated Caries Lesions, cont'd

areas. Patients with low salivary pH would need to use baking soda rinses during the day and use xylitol gum or other recommended products to raise pH levels, increase flow, and increase buffering capacity.

- f. Caries control (described elsewhere in this chapter) is completed. This involves partial caries removal and sealing of all cavitated caries lesions, usually during one appointment and sealing the cavities with glass ionomer. This is critical to prevent re-inoculation of the oral cavity with MS from the caries lesions.
 - g. The patient is instructed to rinse twice a day with either a chlorhexidine (CHX) mouth rinse preferably without alcohol or sodium hypochlorite mouth rinse. If CHX is used, an SLS free prescription toothpaste should be used. The goal is to substantially reduce the numbers of MS in saliva.
 - h. A prophylaxis is performed and 5% sodium fluoride (NaF) varnish is applied to all teeth.
 - i. The microbiologic testing is repeated 2 to 4 weeks after initiation of treatment. If the numbers of circulating MS are significantly reduced, the patient will then receive definitive restorative treatment. If the numbers are not reduced, use of the therapeutic mouth rinses is continued until the counts are lowered. Diet analysis is followed up and reviewed again. Successes in diet modifications are positively reinforced. Shortcomings in diet modifications are discussed and options explored with the patient to rectify diet issues, where needed. Home care regimens are reviewed again with patients and refined. It is important to listen to the patient and work to incorporate diet and home care into the patient's lifestyle and abilities to mentally and physically comply with the recommendations.
6. DEFINITIVE TREATMENT PHASE:
- a. The glass ionomer provisional restorations are replaced (usually by quadrants) with definitive restorations.
 - b. Oral hygiene procedures are reinforced at each visit. Flossing and brushing three times per day with prescription toothpaste is recommended.
 - c. The patient is instructed to chew xylitol chewing gum with at least one gram of xylitol per piece three to six times per day, preferably after meals and snacks.
 - d. The patient is instructed to apply casein phosphopeptide–amorphous calcium phosphates (CPP-ACP) to teeth after brushing and flossing prior to retiring to bed.
 - e. If reduced salivary flow rates are considered to be a major etiologic factor, the patient should be instructed to chew sugar-free mints several times a day or use other recommended products for xerostomia treatment. Prescribing pilocarpine or other salivary stimulant should be considered.
 - f. When all definitive restorations are completed, the patient then enters the maintenance reassessment phase.
7. MAINTENANCE REASSESSMENT PHASE:
- a. The patient should be recalled every 3 months. Oral hygiene and home care procedures are reviewed and evaluated. Recommendations for improvement and modifications to home care are evaluated and discussed.
 - b. Prophylaxis followed by fluoride varnish application is accomplished.
 - c. Caries risk assessment is completed again; changes are noted in risk factors that have been controlled and those risk factors still listed as causative and predictive factors.
 - d. Diet analysis and recommendations from previous visits are reviewed and evaluated.
 - e. Patient continues use of prescription 5000 ppm toothpaste, CPP-ACP paste, and xylitol chewing gum. Any other recommendations to changes or additions to the product protocols are reviewed, discussed, and implemented.
 - f. Every 6 months, salivary and microbiologic evaluations are repeated.
 - g. Bitewing radiographs are taken on an annual basis or more frequently if new lesions continue to be detected.
 - h. It is critical for the patient to understand that caries is a disease that is only controlled and not “cured.” The protocol that is determined to be currently successful may have to be periodically reviewed, updated, and changed. More importantly, the patient will be much like a patient with diabetes, requiring lifetime medication and therapy, diet control, and lifestyle management for disease stability, and will need to be dedicated to a lifetime of careful management of caries risk factors to keep the disease controlled.

Table 2-8 Health History Factors Associated with Increased Caries Risk

History Factor	Risk-Increasing Observations
Age	Childhood, adolescence, senescence
Fluoride exposure	No fluoride in public water supply No fluoride toothpaste
Smoking	Risk increases with amount smoked
Alcohol	Risk increases with amount consumed
General health	Chronic illness and debilitation decreases ability to give self-care
Medication	Medications that reduce salivary flow

history, and function of the immune system and salivary glands have a significant impact on the patient's caries risk, the patient may have little control over these factors. The patient usually is capable of controlling other factors such as diet, oral hygiene, use of antimicrobial agents, and dental care (which may include use of sealants and restorations). This section presents a variety of factors that may have an impact on the prevention of caries.

General Health

The patient's general health has a significant impact on overall caries risk. Declining health signals the need for increased preventive measures, including more frequent recalls. Every patient has an effective surveillance and destruction system for

Table 2-9 Clinical Examination Findings Associated with Increased Caries Risk

Clinical Examination	Risk-Increasing Findings
General appearance	Appearance: sick, obese, or malnourished
Mental or physical disability	Inability or unwillingness to comply with dietary and oral hygiene instruction
Mucosal membranes	Dry, red, glossy mucosa, suggesting decreased salivary flow
Active caries lesions	Cavitation and softening of enamel and dentin; circumferential chalky opacity at gingival margins
Plaque biofilm	High plaque scores
Gingiva	Puffy, swollen, and inflamed gingiva; bleeds easily
Existing restorations	Large numbers, indicating past high caries rate; poor quality, indicating increased habitat for cariogenic organisms

Table 2-10 Methods of Caries Treatment by the Medical Model

Method and Indications	Rationale	Techniques or Material
A. LIMIT CARIOGENIC SUBSTRATE		
Indications: Frequent sucrose exposure Poor-quality diet	Reduce number, duration, and intensity of acid attacks Reduce selection pressure for mutans streptococci (MS)	Diet diary Eliminate sucrose from between meal snacks Substantially reduce or eliminate sucrose from meals
B. MODIFY MICROFLORA		
Indications: High MS counts High lactobacilli counts	Intensive antimicrobial treatment to eliminate cariogenic bacteria from biofilm Select against reinfection by MS	Bactericidal mouth rinse (chlorhexidine) Topical fluoride treatments
C. DISORGANIZE PLAQUE BIOFILM		
Indications: High plaque biofilm scores Puffy red gingiva High bleeding point score	Prevents plaque biofilm succession Decreases plaque biofilm mass Promotes buffering	Brushing Flossing Other oral hygiene aids as necessary (e.g., electric toothbrush)
D. MODIFY TOOTH SURFACE		
Indications: Non-cavitated lesions Surface roughening	Increase resistance to demineralization Decrease plaque biofilm retention	Systemic fluorides Topical fluorides Smooth surface
E. STIMULATE SALIVA FLOW		
Indications: Dry mouth with little saliva Red mucosa Medication that reduces salivary flow	Increases clearance of substrate and acids Promotes buffering	Eat noncariogenic foods that require lots of chewing Sugarless chewing gum Medications to stimulate salivary flow Use dry mouth topical agents, oral lubricants, etc.
F. SEAL SUSCEPTIBLE SURFACES		
Indications: Moderate and high caries risk individuals Teeth with susceptible anatomy (deep grooves) Initial non-cavitated enamel lesions in high-risk patients (smooth-surface sealants)	Prevents colonization (infection) of pit-and-fissure system with cariogenic plaque biofilm Inhibits progression of smooth-surface lesion	Use pit-and-fissure and smooth-surface resin sealants
G. RESTORE ACTIVE CAVITATED SURFACES		
Indications: Cavitated lesions Defective restorations	Eliminate nidus of MS and lactobacilli infection Deny habitat for MS re-infection	Restore all cavitated lesions Correct all defects (e.g., marginal crevices, proximal overhangs)

Table 2-11 Treatment Strategies

Examination Findings	Nonrestorative, Therapeutic Treatment	Restorative Treatment	Follow-Up*
Normal (no lesions)	None	None	1-year clinical examination
Hypocalcified enamel (developmental white spot)	None for non-hereditary lesions; hereditary lesions (dentinogenesis imperfecta) may require special management	Treatment is elective; esthetics (restore defects)	1-year clinical examination
Non-cavitated enamel lesions only; bitewing radiographs indicated (demineralized white spot)	Techniques A–E in Table 2-9, as indicated	Seal defective pits and fissures as indicated	3 months; evaluate: oral flora, mutans streptococci (MS) counts, progression of white spots, presence of cavitations
Possible cavitated lesions (active caries) and other non-cavitated lesions present; bitewing radiographs indicated	Techniques A–E in Table 2-9, as indicated	Techniques F and G (restorations, sealants) in Table 2-9 as indicated	3 months; evaluate: oral flora, MS counts, progression of white spots, presence of new cavitations, pulpal response
Inactive caries; no active (new cavitations) or non-cavitated lesions	None	Treatment is elective; esthetics (restore defects)	1-year clinical examination

*These are only generalized follow-up times. Particular circumstances may dictate shorter or longer follow-up intervals, depending on presence of primary and secondary modifying risk factors (see Fig. 2-1).

“foreign” bacteria. The effectiveness of a patient’s immune system depends on overall health status. Patients undergoing radiation or chemotherapy treatment have significantly decreased immunocompetence and are at risk for increased caries.

Medically compromised patients should be examined for changes in the following: plaque index, salivary analysis, oral mucosa, gingiva, and teeth. Early signs of increased risk include increased plaque biofilm; puffy, bleeding gingiva; dry mouth with red, glossy mucosa; and demineralization of teeth. Decreased saliva flow is common during acute and chronic systemic illnesses and is responsible for the dramatic increase in plaque biofilm. Ambulatory patients with chronic illnesses often take multiple medications, which individually or in combination may reduce salivary flow significantly (see Table 2-4). Saliva should be tested for flow and buffering capacities when changes are detected from an oral examination.

Diet

Dietary sucrose has two important detrimental effects on how plaque biofilm affects caries. First, frequent ingestion of foods containing sucrose provides a stronger potential for colonization by MS, enhancing the caries potential of the biofilm. Second, mature plaque biofilm exposed frequently to sucrose rapidly metabolizes it into organic acids, resulting in a profound and prolonged decline in pH. Caries activity is most strongly stimulated by the frequency, rather than the quantity, of sucrose ingested. The message that excessive and frequent sucrose intake can cause caries has been widely disseminated and is well known by laypeople. Despite this knowledge, dietary modification for the purpose of caries control has failed as a public health measure. For an individual patient, dietary modification can be effective if the patient is properly motivated and supervised. Evidence of new caries activity in adolescent and adult patients indicates the need for dietary counseling. The goals of dietary counseling should be to

identify the sources of sucrose and acidic foods in the diet and to reduce the frequency of ingestion of both. Minor dietary changes such as substitution of sugar-free foods for snacks are more likely to be accepted than more dramatic changes. Rampant (or acute) caries (a rapidly invading infectious process usually involving several teeth) is a sign of gross dietary inadequacy, a complete absence of oral hygiene practice, or systemic illness. Rampant caries that is present primarily on interproximal surfaces may point more to diet as the main causative factor, whereas rampant caries in the cervical and interproximal areas may point to diet and hygiene as the causative factors. The presence of rampant caries indicates the need for comprehensive patient evaluation. Textbooks on nutrition and medicine should be consulted, as needed.

For high-risk patients, a formal diet analysis should routinely be undertaken to identify cariogenic foods and beverages that are frequently ingested. This analysis should be conducted over a 4-day period with 2 of the days surveyed being weekend days. Patients’ diets frequently change considerably on weekends. A form should be provided that divides each day into six segments (breakfast, morning, lunch, afternoon, dinner, and evening) and the patient should be instructed to write down everything ingested, including medications and the amount. The diary is then analyzed by the dentist, and a discussion is held with the patient to suggest appropriate alternatives.⁴⁶

Oral Hygiene

Biofilm-free tooth surfaces do not decay. Daily removal of plaque biofilm by dental flossing, tooth brushing, and rinsing is the best patient based measure for preventing caries and periodontal disease (Figs. 2-39 and 2-40). Loe established supragingival plaque as the etiologic agent of gingivitis.⁴⁷ Longstanding gingivitis can lead to damage of the epithelial attachment and progression to more serious periodontal

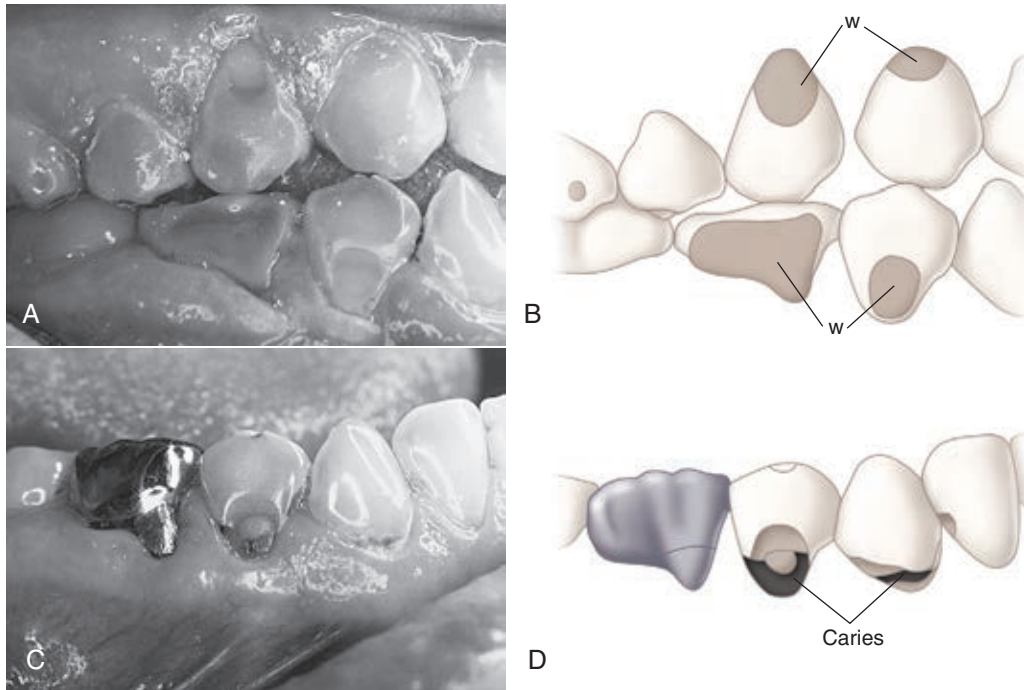


Fig. 2-39 Erosion wear and poor home care leading to caries. A young female patient with severe wear on the facial surfaces of posterior teeth. This patient subsequently was found to have a hiatal hernia with frequent regurgitation of stomach acids. Too vigorous brushing and acid demineralization of teeth accelerated the loss of tooth structure (A and B). Areas of severe wear (w) exhibit dentin hypersensitivity. Dentin pain was the symptom that caused the patient to seek dental care. Advising the patient to reduce vigorous tooth brushing resulted in cessation of all brushing. Caries activity rapidly occurred (C and D).

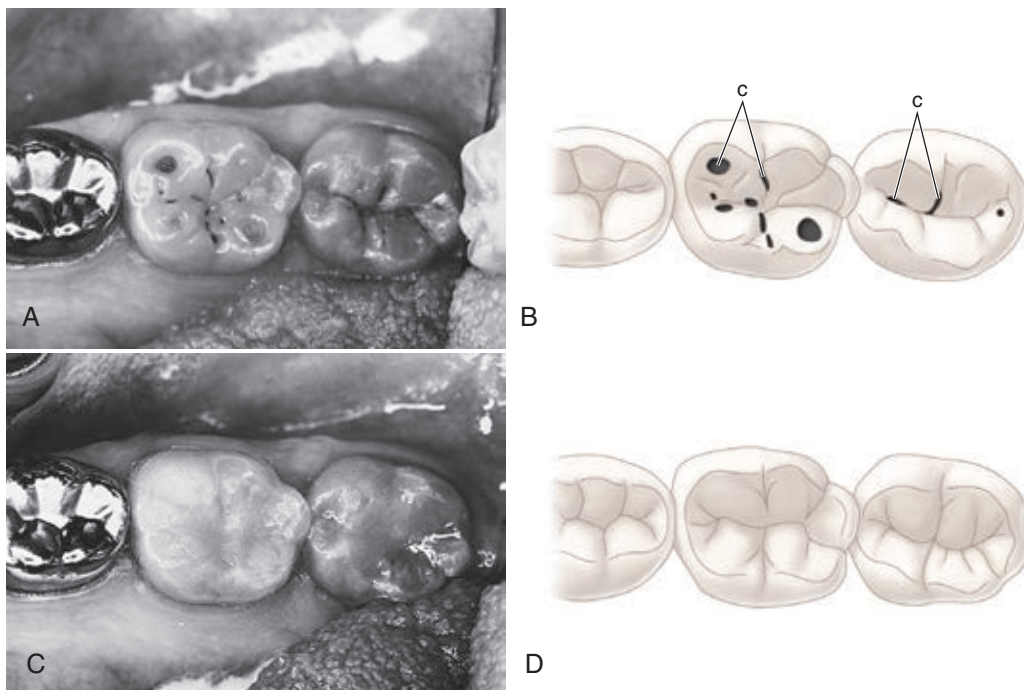


Fig. 2-40 A and B, Photograph of the occlusal surfaces of the teeth illustrated in Figure 2-39. C and D, After cessation of oral hygiene procedures, caries (c) rapidly developed in the exposed dentin and fissures on the occlusal surfaces. Caries was treated conservatively by excavation of softened dentin and restoration of the excavations and fissures with composite.

disease. Effective plaque control by oral hygiene measures results in resolution of the gingival inflammation and remineralization of any initially demineralized enamel surface. Pits and fissures are not accessible to toothbrush bristles because of the small diameter of their orifices, and these areas are highly susceptible to caries. Obturation of pits and fissures by sealants is a highly effective method for caries prevention.

Mechanical plaque biofilm disorganization by brushing and flossing has the advantage of not eliminating the normal oral flora. Topical antibiotics can control plaque biofilm, but long-term use predisposes the host to infection by antibiotic-resistant pathogens such as *Candida albicans*. Frequent mechanical plaque removal does not engender the risk of infection by opportunistic organisms. It does change the species composition of plaque in the selection for pioneering organisms and the denial of habitat to potential pathogens. The oral flora on the teeth of patients with good plaque control has a high percentage of *S. sanguis* or *S. mitis* and is much less cariogenic than older, mature plaque communities, which have a significantly higher percentage of MS.

Krasse showed that a combination of oral hygiene and diet counseling is effective in children.⁴⁸ In this classic study, children in two schools were monitored for *Lactobacillus* levels. The children in one school were given feedback about the results of the studies and proper preventive oral hygiene and dietary instruction. After 18 months, the children in the school receiving preventive counseling had an average of 3.3 new restorations, whereas the control school children, who received no counseling, averaged 8.2 new restorations. This study is an excellent demonstration that good oral hygiene and dietary improvements can be effective when using microbiologic testing as a motivational tool.

Rigid oral hygiene programs should be prescribed only to high-risk persons with evidence of active disease. Overzealous, universal application of oral hygiene training programs is frustrating to dentists and their patients. High-risk patients should receive intensive oral hygiene training, dietary instruction, and preventive dental treatment, as necessary, to control the progress of disease. Adults with a low caries experience probably require less frequency of daily flossing and brushing.

Plaque control requires a little dexterity and a lot of motivation. Some knowledge of tooth contours, embrasure form, proximal contacts, and tooth alignment is helpful in optimal plaque control. Instruction should include the selection and use of mechanical aids, based on the patient's needs. Professional tooth cleaning also has an important effect on caries reduction. One study divided grade school students into three treatment groups: control, monthly professional cleaning, and twice-a-month professional cleaning.⁴⁹ In students with low MS levels, the once-a-month cleaning group had half as many new carious surfaces (0.8 surfaces/student) as did the control group (1.8 surfaces/student). In the high MS group, the control group had the most new caries (2.5 surfaces/student), whereas the once-a-month cleaning group had similar levels (0.96 surfaces/student) to the low MS group, and the twice-a-month cleaning group had almost one tenth the number of new lesions (0.34 surfaces/student) as the control group. This study showed that professional plaque removal on grade school students, even only once every 2 weeks, dramatically reduces the development of new caries lesions. Equal or

greater reductions can be expected in patients who practice proper oral hygiene methods for plaque removal.

Another adjunct to regular brushing and flossing is the regular use of electric toothbrushes and oral irrigation devices. A recent study has demonstrated these devices can effectively remove biofilm and more importantly change the composition of the biofilm in the favorable direction when used regularly.⁵⁰

Fluoride Exposure

Fluoride in trace amounts increases the resistance of tooth structure to demineralization and is particularly important for caries prevention (Fig. 2-41). When fluoride is available during cycles of tooth demineralization, it is a major factor in reduced caries activity.⁵¹ Fluoride seems to be an essential nutrient for humans and is required only in very small quantities. Laboratory animals fed a completely fluoride-free diet develop anemia and reduced reproduction after four generations. When available to humans, fluoride produces spectacular decreases in caries incidence. The availability of fluoride to reduce caries risk is thought to be primarily achieved by fluoridated community water systems but also may occur from fluoride in the diet, toothpastes, mouth rinses, and professional topical applications. The optimal fluoride level for public water supplies is 0.7 milligrams of fluoride per liter of water.⁵² The percentage of the U.S. population with public fluoridated community water systems has increased from 62% (140 million) in 1999 to 66% (162 million) in 2000, to 69% (184 million) in 2006.^{23,54} Public water fluoridation has been one of the most successful public health measures instituted in the United States. For communities that have fluoridated water systems, the annual cost averages about \$0.70 per person.⁵³ For every \$1 spent on water fluoridation, \$6 of health savings are realized. At 0.1 ppm (parts per million) and less, the preventive effect is lost, and the caries rate is higher for such populations lacking sufficient fluoride exposure. Excessive fluoride exposure (≥ 10 ppm) results in fluorosis, which initially causes enamel to become white but may eventually cause a brownish discoloration, a condition termed *mottled enamel*.

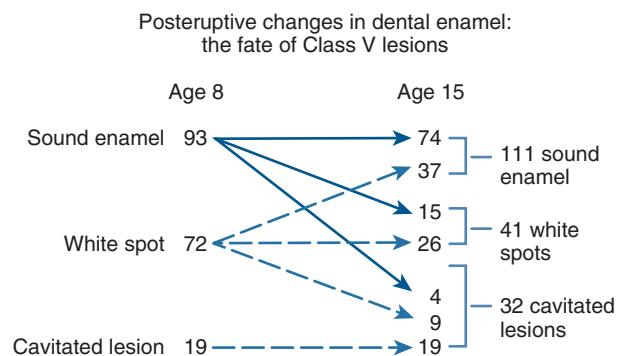


Fig. 2-41 White spot lesions of enamel (stage 3 in Fig. 2-27) may remineralize, remain unchanged, or progress to cavitated lesions. In this study, done in a community with a fluoridated public water supply, only 9 of 72 noncavitated lesions became cavitated. More than half of noncavitated lesions (37 of 72) regressed to become indistinguishable from normal enamel. (Redrawn from Backer Dirks O. Posteruptive changes in dental enamel. *J Dent Res* 45:503-511, 1966)

Fluoride exerts its anticaries effect by three different mechanisms. First, the presence of fluoride ion greatly enhances the precipitation into tooth structure of fluorapatite from calcium and phosphate ions present in saliva. This insoluble precipitate replaces the soluble salts containing manganese and carbonate that were lost because of bacteria-mediated demineralization. This exchange process results in the enamel becoming more acid resistant (see Fig. 2-28). Second, noncavitated caries lesions are remineralized by the same process. Third, fluoride has antimicrobial activity. In low concentrations, fluoride ion inhibits the enzymatic production of glucosyltransferase. Glucosyltransferase promotes glucose to form extracellular polysaccharides, and this increases bacterial adhesion. Intracellular polysaccharide formation also is inhibited, preventing storage of carbohydrates by limiting microbial metabolism between the host's meals. The duration of caries attack is limited to periods during and immediately after eating. In high concentrations (12,000 ppm) used in topical fluoride treatments, fluoride ion is directly toxic to some oral microorganisms, including MS. Suppression of growth of MS after a single topical fluoride treatment may last several weeks.⁵⁵ It is possible to lengthen this suppression greatly by a change in dietary habits (especially eliminating sucrose) and by the patient's conscientious application of a good oral hygiene program.

All of the methods for fluoride exposure (Table 2-12) are effective to some degree. The clinician's goal is to choose the most effective combination for each patient. This choice must be based on the patient's age, caries experience, general health, and oral hygiene. Children with developing permanent teeth benefit most from systemic fluoride treatments via the public water supply. In regions without adequate fluoride in the water supply, dietary supplementation of fluoride is indicated for children and sometimes for adults. The amount of fluoride supplement must be determined individually. This is of particular importance in rural areas with individual wells because the fluoride content of well water can vary greatly within short distances.

Topical application of fluoride should be done periodically for children and adults who are at high risk for caries development. The periodicity varies with the case. Teeth should be

cleaned free of plaque before the application of topical fluorides. Flossing followed by tooth brushing is recommended for this purpose. Pumicing of teeth (professional prophylaxis) can remove a considerable amount of the fluoride-rich surface layer of enamel and can be counterproductive. Acidulated phosphate fluoride is effective, but the potential risk of swallowing excessive amounts of fluoride exists, particularly in young children. Acidulated phosphate fluoride is available in thixotropic gels and has a long shelf life. Stannous fluoride (8% F), another option, has a bitter, metallic taste; may burn the mucosa; and has a short shelf life. Although the tin ion in stannous fluoride may be responsible for staining the teeth, it may be beneficial in arresting root caries. Topical fluoride agents should be applied according to the manufacturer's recommendations and always under supervision to prevent swallowing.

Various fluoride varnishes are available and are successful in preventing caries. Varnishes provide a high uptake of the fluoride ion into enamel and are rapidly becoming widely accepted as the vehicle of choice for fluoride delivery to young adults and older adults alike. Fluoride varnishes are professionally applied and yet may provide the most cost-effective means of delivery of fluoride to teeth. These varnishes are effective bactericidal and caries-preventive agents. Fluoride varnishes were developed several decades ago in an attempt to improve fluoride application techniques and benefits. European countries have used fluoride varnishes for many years. Numerous randomized clinical trials conducted outside the United States point to the efficacy and safety of fluoride varnishes as caries-preventive agents.⁵⁶⁻⁶⁴

The fluoride varnish deposits large amounts of fluoride on an enamel surface, especially on a demineralized enamel surface. Calcium fluoride precipitates on the surface, and often fluorapatite is formed. The high concentration of surface fluoride also may provide a reservoir for fluoride, which promotes remineralization. Although additional research on fluoride varnishes is needed, the use of a fluoride varnish as a caries-preventive agent should be expanded because it has advantages over other topical fluoride vehicles in terms of safety, ease of application, and fluoride concentration at the enamel surface.⁶ The American Dental Association (ADA)

Table 2-12 Fluoride Treatment Modalities*

Route	Method of Delivery	Concentration (ppm)	Caries Reduction (%)
Systemic Topical	Public water supply	1	50-60
	<i>Self-application</i>		
	Low-dose/high-frequency rinses (0.05% sodium fluoride daily)	225	30-40
	High-potency-low-frequency rinses (0.2% sodium fluoride weekly)	900	30-40 after 2 years
	Fluoridated dentifrices (daily)	1000-1450	20
	Prescription-strength fluoridated dentifrices (daily)	4950	32
	<i>Professional application</i>		
	Acidulated phosphate fluoride gel (1.23%) annually or semiannually	12,300	40-50
	Sodium fluoride solution (2%)	20,000	40-50
	Sodium fluoride varnish (5%)	22,500	30
Stannous fluoride solution (8%)	80,000	40-50	

*Caries reduction estimates for topically administered fluorides indicate their effectiveness when used individually. When they are combined with systemic fluoride treatment, they can provide some additional caries protection.
ppm, parts per million.

Council on Scientific Affairs recently endorsed the use of fluoride containing varnishes as caries prevention agents.⁶⁵

Current evidence indicates that fluoride varnishes with the concentration of 5% sodium fluoride are the most efficacious of all topically applied fluoride products.^{58,66} For patients with a high risk of caries, fluoride varnish should be applied every 3 months. For moderate-risk patients, application every 6 months is indicated. Fluoride varnish is not needed for low-risk patients.

When applying fluoride varnish, the clinician dries off saliva from teeth and applies a thin layer of fluoride varnish directly onto teeth. Because the fluoride varnish sets when contacting moisture, thorough isolation of the area is not required. Only toothbrushing, rather than prophylaxis, is necessary before application. The main disadvantage of fluoride varnish is that a temporary change in tooth color may occur. Patients should avoid eating for several hours and avoid brushing until the next morning after the varnish has been applied.

Self-administered fluoride rinses have an additive effect (about 20% reduction) when used in conjunction with topical or systemic fluoride treatment. Fluoride rinses are indicated in high-risk patients and patients exhibiting a recent increase in caries activity. Two varieties of fluoride rinses have similar effectiveness: (1) high dose–low frequency and (2) low dose–high frequency. High-dose (0.2% F)–low-frequency rinses are best used in supervised weekly rinsing programs based in public schools. Low-dose (0.05% F)–high-frequency rinses are best used by individual patients at home. A high-risk or caries-active patient should be advised to use the rinse daily. The optimal application time is in the evening. The rinse should be forced between teeth many times and then expectorated, not swallowed. Eating and drinking should be avoided after the rinse.

Routine use of over-the-counter fluoride containing dentifrice three times per day is recommended for all patients. These toothpastes generally contain 0.32% sodium fluoride (1450 ppm). For moderate-risk and high-risk patients 6 years or older, prescription dentifrices containing higher concentrations of fluoride are recommended. These products typically contain 1.1% sodium fluoride (5000 ppm) and can be safely used up to three times per day in this age group.⁶⁷

Immunization

For many years, investigators have been trying to develop an effective anti-caries vaccine. Several prototypes have been tested in animals, but at this time, neither the safety nor efficacy of such vaccines has been demonstrated in humans.^{68,69}

Even if an anti-caries vaccine were developed, some concerns remain, which may affect its widespread use. First, the potential adverse effects of a vaccine must be identified. The safety of such a vaccine has not yet been shown; concerns about a possible cross-reaction with human heart tissue remain. Second, its cost must be compared with that of public water fluoridation, which is inexpensive and already effective at reducing caries. Vaccination may be no more effective than fluoride therapy, which has a proven safety record. It may, however, be practical to use a caries vaccine when public water fluoridation is impractical in developed countries, and it may be useful in developing countries. Third, limitations imposed by governmental regulatory agencies may affect the widespread use of an anti-caries vaccine.

Function of Saliva

Saliva is nature's first line of defense against dental caries. Saliva works by diluting acid produced in plaque biofilm, washing the acid away (swallowing), buffering the produced acid (biocarbonate + phosphate), and assisting in remineralization (calcium + phosphate) and by forming a pellicle. When normal salivary flow rates are compromised, patients are usually at high risk for developing caries.

Normal aging does not result in reduced salivary flow rates. However, many older patients have compromised salivary flow rates as a result of medications taken for systemic conditions. Many commonly prescribed medications are xerogenic, and a recent publication has indicated that 63% of the 200 most commonly prescribed drugs in the United States have the adverse effect of reduced salivary flow rates.⁷⁰

One important strategy for the prevention of caries in such patients is increasing the salivary flow rates and concomitant buffering capacity. For these patients, gathering initial baseline data on salivary flow rates is critical. Commercial kits are available for this. These kits will provide data on simulated flow rates, the pH of saliva, and the level of buffering capacity. If saliva samples are sent for microbiologic testing, specific MS and lactobacilli counts can be determined. Specific strategies for improving flow rates and reducing bacterial counts can then be initiated, and subsequent re-testing will yield results concerning the efficacy of the strategies.

When attempting to improve salivary flow rates, a consultation with the patient's physician may be in order. A less xerogenic drug may then be prescribed or the dose of a current drug reduced. Changing the time of taking the medication(s) may be useful. Prescribing salivary stimulants such as pilocarpine or cevimeline can be very beneficial in patients with functioning salivary glands but who have xerostomia because of medications.

Other strategies to improve salivary flow rates include chewing sugar-free candies or mints several times a day and the use of xylitol chewing gum. Xylitol will be discussed in the next section.

Antimicrobial Agents

Prior to initiating procedures to reduce the numbers of cariogenic bacteria in the oral cavity, bacterial testing should be conducted to determine baseline microbiologic variables. Saliva samples can be tested for specific MS and lactobacilli levels; commercial devices can help evaluate the level of ATP in the biofilm. This seems to have moderate correlation with MS levels.⁷¹

A variety of antimicrobial agents are available to help prevent caries (Table 2-13). In rare cases, antibiotics might be considered, but the systemic effects must be considered. As already discussed, fluoride has antimicrobial effects. Two differing strategies have been suggested for reducing bacterial counts. The traditional approach is the use of chlorhexidine (CHX) mouthwash, varnish, or both, along with prescription fluoride toothpaste. When using this approach, it may be prudent to use toothpaste free from sodium laurel sulfate (SLS), which causes the foaming action in dentifrices. Although data are equivocal, evidence demonstrates that SLS reduces the ability of CHX to reduce plaque formation.⁷² The other approach is to use a twice-daily mouth rinse containing

Table 2-13 Antimicrobial Agents

	Mechanism of Action	Spectrum of Antibacterial Activity	Persistence in Mouth	Adverse Effects
ANTIBIOTICS				
Vancomycin	Blocks cell wall synthesis	Narrow	Short	Increases gram-negative flora
Kanamycin	Blocks protein synthesis	Broad	Short	Can increase caries activity
Actinobolin	Blocks protein synthesis	Streptococci	Long	Unknown
BIS BIGUANIDES				
Alexidine	Antiseptic; prevents bacterial adherence	Broad	Long	Bitter taste; stains teeth and tongue brown; mucosal irritation
Chlorhexidine	Antiseptic; prevents bacterial adherence	Broad	Long	Bitter taste; stains teeth and tongue brown; mucosal irritation
HALOGENS				
Iodine	Bactericidal	Broad	Short	Metallic taste
Fluoride	1–10 parts per million (ppm) reduces acid production; 250 ppm bacteriostatic; 1000 ppm bactericidal	Broad	Long	Increases enamel resistance to caries attack; fluorosis in developing teeth with chronic high doses

sodium hypochlorite and xylitol. Both approaches have been shown to substantially reduce bacterial counts, but the superiority of neither has been demonstrated.

Chlorhexidine was first available in the United States as a rinse and was first used for periodontal therapy. It was prescribed as a 0.12% rinse to high-risk patients for short-term use. In other countries, it is used as a varnish, and the most effective mode of varnish use is as a professionally applied material.⁷³ Chlorhexidine varnish enhances remineralization and decreases MS presence. Emilson concluded that chlorhexidine varnishes provide effective reduction in MS, although recent evidence is not as conclusive in favor of chlorhexidine.^{74,75}

Chlorhexidine is prescribed for home use at bedtime as a 30-second rinse. Used at this time, when the salivary flow rate is decreased, the agent has a better opportunity to interact with MS organisms while tenaciously adhering to oral structures. It is used for approximately 2 weeks and results in a reduction of MS counts to below caries-potential levels. This decrease is sustained for 12 to 26 weeks. The agent also can be applied professionally once a week for several weeks, with monitoring of microbial counts to determine effectiveness. Chlorhexidine may be used in combination with other preventive measures in high-risk patients. A popular mouthwash (Listerine; McNeil-PPC, Inc., Fort Washington, PA) has been reported to be effective in plaque reduction when used specifically as directed.^{76,77} Although this report has been challenged, it initially reported a plaque-reducing benefit equivalent to flossing.

Xylitol is a natural five-carbon sugar obtained from birch trees. It seems to have several mechanisms of action to reduce the incidence of caries. Xylitol keeps the sucrose molecule from binding with MS. MS cannot ferment (metabolize) xylitol, so no acid is produced. Xylitol reduces MS by altering the metabolic pathways. Finally there is some suggestion that xylitol may enhance remineralization and help arrest dental caries.^{78,79} It is usually recommended that a patient chew a piece of xylitol gum for 5 to 30 minutes after

eating or snacking. Chewing any sugar-free gum after meals reduces the acidogenicity of plaque because chewing stimulates salivary flow, which improves the buffering of the pH drop that occurs after eating.⁸⁰ Reductions in caries rates are greater, however, when xylitol is used as the sugar substitute.⁸¹

Xylitol chewing gum has been shown to be effective in reducing caries rate.⁸² Its efficacy is dose related, so care must be taken to recommend products with adequate dose levels. Current protocols suggest chewing two pieces of gum containing a total of 1 gram of xylitol three to six times per day, preferably after meals and snacks.

Calcium and Phosphate Compounds

A relatively new group of products, called amorphous calcium-phosphates (ACP), have become commercially available and have the potential to remineralize tooth structure.⁸³ ACP is a reactive and soluble calcium phosphate compound that releases calcium and phosphate ions to convert to apatite and remineralize the enamel when it comes in contact with saliva. Forming on the tooth enamel and within the dentinal tubules, ACP provides a reservoir of calcium and phosphate ions in the saliva.⁸⁴ Casein phosphopeptide (CPP) is a milk-derived protein that binds to the tooth's biofilm and is used to stabilize ACP. Remineralization products that use CPP as a vehicle to deliver and maintain a supersaturation state of ACP at or near the tooth surface have recently been introduced. Some of these products contain other caries-preventive agents such as fluoride and xylitol (e.g., MI Paste Plus, GC America, Alsip, IL). Gum, lozenges, and topically applied solutions containing CPP-ACP have also been reported to remineralize white spots.^{85,86} Mounting evidence indicates that CPP-ACP complexes, when used regularly, are effective in enamel remineralization.⁸⁷⁻⁹⁰

The evidence base for ACP is not as strong as that for xylitol, but extensive clinical trials are ongoing, and the evidence that is available is supportive.

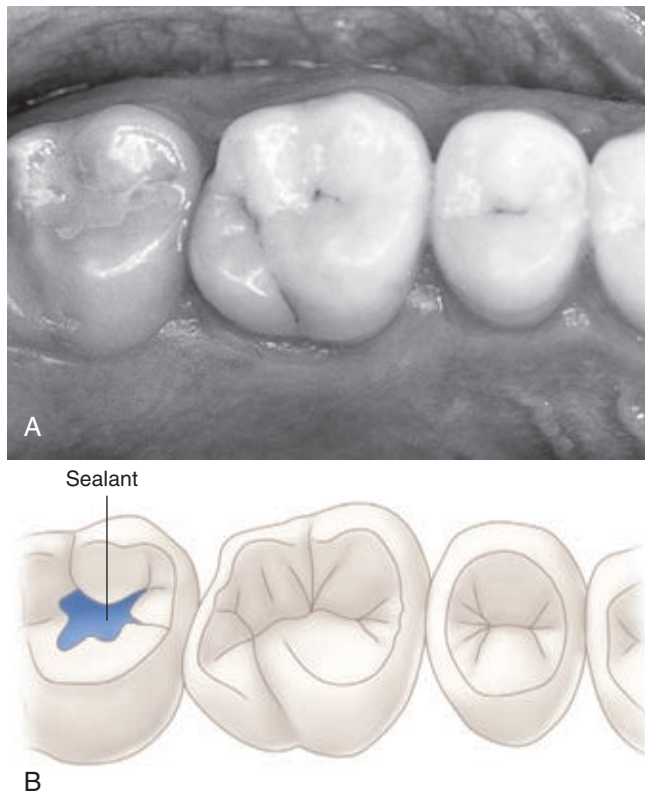


Fig. 2-42 **A** and **B**, Sealant applied to the central fossa of a maxillary second molar. This tooth was treated because of the appearance of chalky enamel and softening in the central fossa. A highly filled sealant was used (see Fig. 2-43).

Probiotics

One novel approach for reducing dental caries that has emerged in recent years is that of probiotics. The fundamental concept is to inoculate the oral cavity with bacteria that will compete with cariogenic bacteria and eventually replace them. Obviously, the probiotic bacteria must not produce significant adverse effects.

A number of commercial products have been introduced and have been demonstrated to be safe in short-term studies. However, their relative level of efficacy remains unknown. It has been speculated that for the probiotic microorganisms to gain dominance, existing pathogens must first be eliminated. The concept of probiotics holds significant promise but considerably more research is required.

Sealants

Although fluoride treatments are most effective in preventing smooth-surface caries, they are less effective in preventing pit-and-fissure caries. The use of sealants is an effective preventive treatment for caries.⁹¹ Sealants have three important preventive effects. First, sealants mechanically fill pits and fissures with an acid-resistant resin. Second, because the pits and fissures are filled, sealants deny MS and other cariogenic organisms their preferred habitat. Third, sealants render the pits and fissures easier to clean by toothbrushing and mastication (Figs. 2-42 and 2-43).

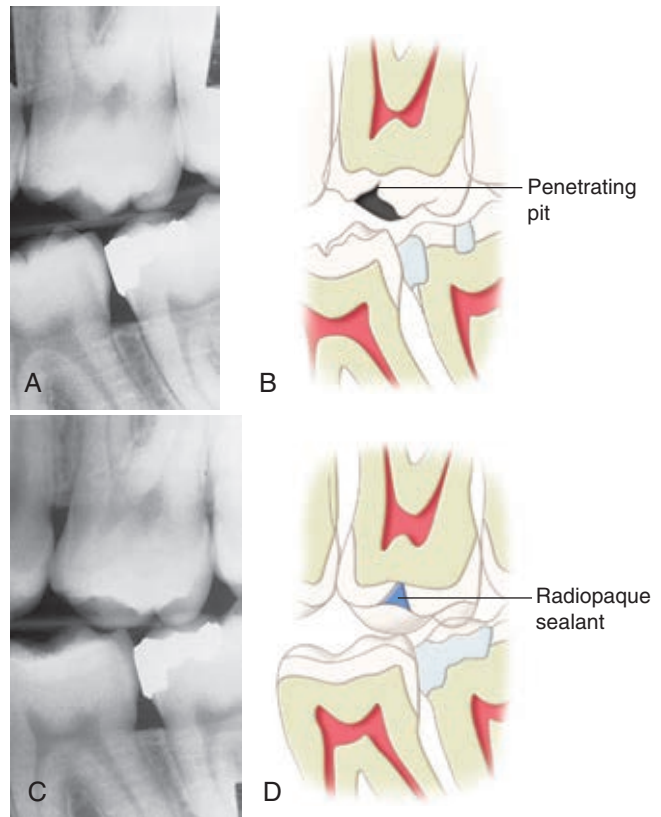


Fig. 2-43 **A** and **B**, Radiograph of a maxillary first molar with a deep central fossa pit that appears to penetrate to the dentin. **C** and **D**, The central pit was sealed with a highly filled, radiopaque sealant. The sealant is readily visible on the radiograph.

Based on the available scientific literature, pit-and-fissure sealants are appropriate for prevention of caries in susceptible teeth and patients and, within limits, for arresting and managing early caries lesions.⁹²⁻⁹⁶ No consensus exists with regard to placing sealants over known caries, and this text does not advocate the intentional use of sealants over active caries lesions.

Another strategy that has been recently introduced is the use of extremely low-viscosity resin sealants for the infiltration of white-spot caries lesions on smooth surfaces.⁹⁷ In situ studies demonstrate the ability of resin sealants, also called *infiltrants*, to prevent further demineralization under cariogenic conditions.⁹⁸ This technique can reportedly be used in free (i.e., facial and lingual) as well as in interproximal surfaces, but similar to the occlusal sealant technique, it is highly subject to technique sensitivity. In addition virtually no clinical data on the performance of the technique are available as yet.

Restorations

The status of a patient's existing restorations may have an important bearing on the outcome of preventive measures and caries treatment. Old restorations that are rough and plaque retentive could be smoothed and polished or replaced. Restoration defects such as overhangs, open proximal contacts, and defective contours contribute to plaque formation and retention. These defects should be corrected, usually by replacement of the defective restoration. Detection of

secondary caries can be difficult around old restorations. Discoloration of the enamel adjacent to a restoration suggests secondary caries. This condition appears as a localized opalescent area next to the restoration margins. (*Exception:* A bluish color of facial or lingual enamel that directly overlies an old, otherwise acceptable, amalgam restoration does not indicate replacement unless for improvement of esthetics. Such a discoloration may be caused by the amalgam itself.) Because metallic restorations are radiopaque, the radiolucency of secondary caries may be masked. The placement of restorations is preventive only in the sense of removing large numbers of cariogenic organisms and some of the sites in which they may be protected. The placement of a restoration into a cavitated carious tooth does not cure the carious process.

Although diagnostic and preventive measures have been improved and are more widely used, the repair of destruction caused by the carious process still is necessary for many patients. The treatment regimen is dictated by the patient's caries status. If the patient is at high risk for caries development, treatment should consist of restorative procedures and many of the preventive measures described previously. The damage done by caries can be repaired, and the patient's risk status for further caries attacks can be reduced. Sometimes, patients present with acute caries lesions in numerous teeth. Because these teeth may be in jeopardy and because of the large numbers and sites of cariogenic bacteria, restorative treatment for caries control may be indicated, as described later in this section. This procedure rapidly gets rid of the caries lesions, providing better assessment of the pulpal responses of some teeth and greater success of the preventive measures instituted. Later, teeth can be restored with placement of more definitive restorations.

Once caries has produced cavitation of the tooth surface, preventive measures usually are inadequate to prevent further progression of the lesion because it is impossible to adequately remove cariogenic biofilm from a cavitated caries lesion. Excision of the lesion (tooth preparation) and proper tooth restoration is the most effective method to control the progression of active, cavitated lesions.

Caries-Control Restorations

The term *caries control* refers to an operative procedure in which multiple teeth with acute threatening caries are treated quickly by (1) removing the infected tooth structure, (2) medicating the pulp, if necessary, and (3) restoring the defect(s) with a temporary material. With this technique, most of the infecting organisms and their protecting sites are removed, limiting further acute spread of caries throughout the mouth. The caries-control procedure must be accompanied by other preventive measures (Table 2-14). Teeth rapidly treated by caries-control procedures subsequently are treated by using routine restorative techniques, if appropriate pulpal responses are obtained. Also, the intent of caries-control procedures is immediate, corrective intervention in advanced caries lesions to prevent and assess pulpal disease and avoid possible sequelae such as toothache, root canal therapy, or more complex ultimate restorations.

OBJECTIVES AND INDICATIONS

Active, rapidly progressing caries requires urgent clinical treatment when dentin softening has progressed at least half the

Table 2-14 Caries-Control Restoration

Initial treatment	<ul style="list-style-type: none"> Caries risk assessment Education and motivation Thorough evaluation and documentation of lesions Temporization of all large cavitated lesions by caries-control restorations Specific non-restorative, therapeutic treatment (see Table 2-10) Plaque control (see Table 2-10, technique C) Dietary control (see Table 2-10, technique A)
Preliminary assessment	<ul style="list-style-type: none"> Gingival response as a marker of plaque biofilm control effectiveness Pulpal response of teeth with caries-control restorations Assessment of patient compliance with medications, oral hygiene, and dietary control measures
Follow-up care	<ul style="list-style-type: none"> Careful clinical evaluation of teeth Replacement of caries-control restorations with permanent restorations Monitoring of plaque biofilm and mutans streptococci (MS) levels Further antimicrobial treatment and dietary reassessment as indicated by new cavitations, non-cavitated lesions, or high MS levels

distance from the DEJ to the pulp. Acute caries may progress rapidly without operative intervention. Conventional restorative treatment techniques may not address acute problems with sufficient rapidity to prevent pulpal infection or death of the pulp.

The treatment objective for caries control is to remove the infected tooth matter from all of the advanced caries lesions, place appropriate pulpal medication (if needed), and restore the tooth in the most expedient manner. Provisional restorative materials (intermediate restorative material, a strong glass-ionomer material such as Fuji IX, or amalgam) are usually the treatment materials of choice. Caries control is an intermediate step in restorative treatment and has several other indications. Teeth with questionable pulpal prognosis should be treated with a caries-control approach. In this way, the progression of demineralization of the dentin is stopped, and the response of the pulp can be determined before making a commitment to a permanent restoration. Another clinical situation in which caries control is a useful approach is during an operative procedure when a tooth is unexpectedly found to have extensive caries. Caries-control technique provides the busy practitioner the flexibility to respond rapidly to stop the carious process in that tooth without causing major changes in the daily schedule. The caries-control procedure allows quick removal of the caries, placement of a temporary restoration, and the rescheduling of the patient for a more time-consuming, permanent restoration. Before placement of a permanent restoration, a caries-control procedure also provides a suitable delay that gives the pulp some time to recover, allowing a better assessment of the pulpal status. A caries-control procedure is indicated when (1) the caries is extensive enough that adverse pulpal sequelae are likely to occur soon, (2) the goal of treatment is to remove the nidus of caries infection in the patient's mouth, or (3) a tooth has extensive carious

involvement that cannot or should not be permanently restored because of inadequate time or questionable pulpal prognosis.

CARIES-CONTROL TECHNIQUE

The following description involves only a single tooth, for the sake of simplicity. Caries control of multiple teeth in a single sitting is a practical clinical procedure and is simply an extension of the procedure for a single tooth. Figure 2-44 is a schematic representation of the caries-control procedure, and Figure 2-45, A, is a preoperative radiograph of the tooth described in the following sections.

Anesthesia for the affected area is usually indicated, unless a test preparation for pulpal vitality is to be performed. Because pulpal necrosis may occur when oral fluids contaminate exposure sites during excavation of advanced caries lesions, the operating site must be isolated. The rubber dam provides an excellent means of isolation and protection of the

excavation site from contamination by oral fluids during the operative procedure and should be used routinely in most caries-control procedures.

The primary objective of the caries-control tooth procedure is to provide adequate visual and mechanical access to

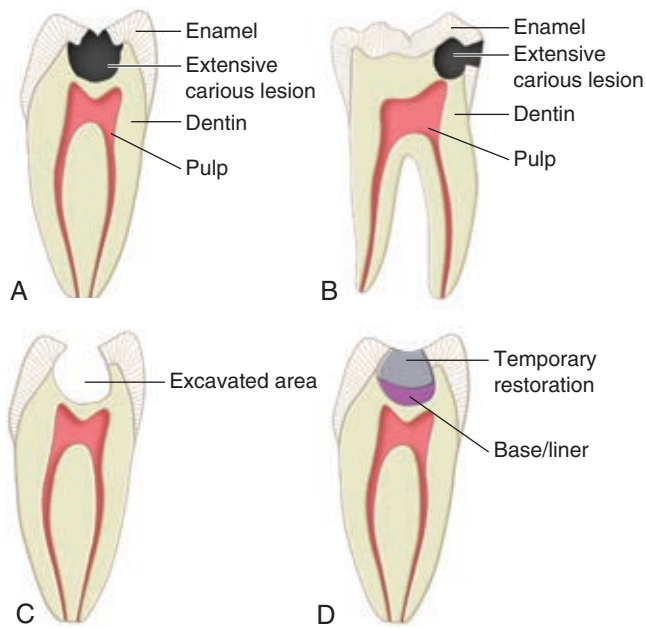
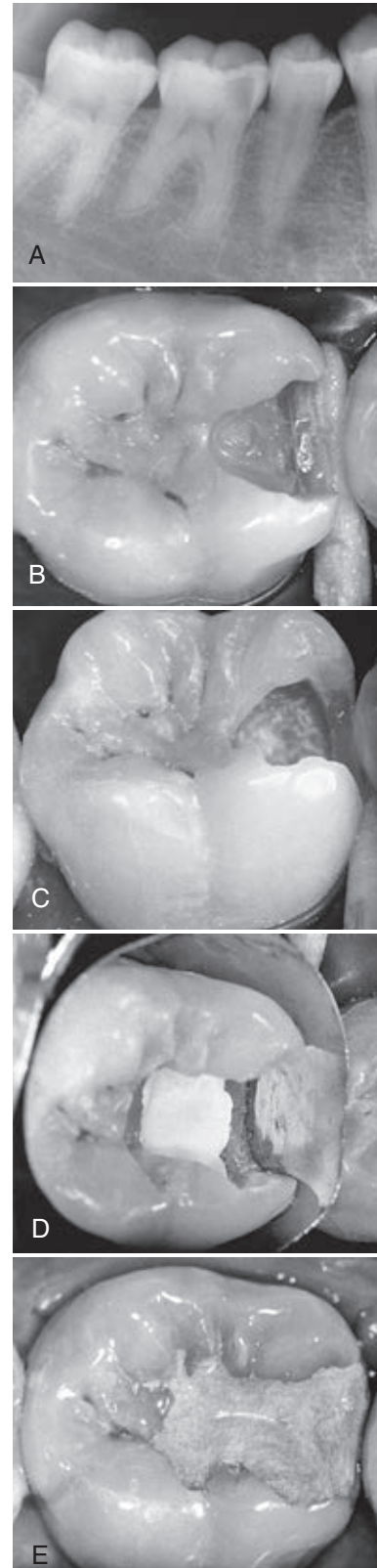


Fig. 2-44 Schematic representation of caries-control procedure. **A** and **B**, Faciolingual (**A**) and mesiodistal (**B**) cross-sections of mandibular first molar show extensive preoperative occlusal and proximal caries lesions. **C**, Tooth after excavation of extensive caries. Note remaining unsupported enamel. **D**, Temporary amalgam restoration inserted after appropriate liner or base.

Fig. 2-45 **A**, Preoperative clinical radiograph illustrating extensive caries lesion in the proximal and occlusal regions of the mandibular right first molar. Initial caries excavation of tooth. **B**, Remaining caries requires further excavation. Also, note the wedge in place, protecting rubber dam and soft tissue; it has been lightly shaved by a bur. **C**, Remaining unsupported enamel under mesiolingual cusp. **D**, Tooth ready for placement of temporary restoration. Carious involvement required further extension than that seen in **B** and **C**. Liner or base material has been applied to deepest excavated areas, and matrix, appropriately wedged, has been placed. **E**, Temporary restoration completed for caries-control procedure. Caries has been eliminated, the pulp adequately protected, and interarch and intra-arch positions of tooth maintained by caries-control procedure.



facilitate the removal of infected dentin. The initial opening of the tooth is made with the largest carbide bur that can be used. A high-speed handpiece with an air-water spray is the most practical instrument for this procedure (see Fig. 2-45, B and C). Retaining unsupported enamel is permissible in caries-control procedures because this tooth structure, although undermined, assists in the retention of the restorative material. Removal of unsupported enamel occurs when the final restoration is placed at a later date. Retaining sound portions of old restorative material also may enhance the temporary restoration and reduce the risk of pulpal exposure. Care must be exercised, however, when deciding not to remove all old restorative material because it may mask residual infected dentin.

When access has been gained, the identification and removal of caries depends primarily on the dentist's interpretation of tactile stimuli. Color differences cannot be used as a reliable index for complete caries removal, although caries-indicating solutions may provide color guides. In rapidly advancing lesions, softened dentin shows little or no color change, whereas more slowly advancing lesions have more discoloration. Dentin that appears leathery, peels off in small flakes, or can be judiciously penetrated by a sharp explorer should be removed.

Because fine tactile discrimination is required for complete removal of caries, the use of a high-speed handpiece at full speed is contraindicated for the removal of deep caries. Effective caries removal can be accomplished with (1) hand instrumentation using spoon excavators, (2) a slow-speed handpiece with a large round bur, or (3) a high-speed handpiece using a round bur operated just above stall-out speed (low speed). The use of spoon excavators may result in larger amounts of softened dentin being peeled off than intended and may result in inadvertent pulpal exposure. Hand excavation requires great skill and sharp instruments. Rotary instruments provide good control and require less skill. The high-speed handpiece, when running just above stalling speed, provides good control. A simple technique is to run the handpiece slowly enough that the bur stalls shortly after contacting dentin. Repeated applications of the bur remove dentin in small increments and allow the operator to monitor carefully changes in hardness and color. After removal of softened dentin, it is helpful to evaluate the excavated area carefully with a sharp explorer to determine if the remaining dentin is hard and sound. Extreme care must be used with the explorer to prevent penetration into the pulp. Penetration of the explorer into the pulp may cause pulpal infection, increasing the possibility of pulpal death.

Usually, all softened, infected dentin is removed during caries-control procedures. In asymptomatic teeth that have deep lesions (in which complete excavation of softened dentin is anticipated to produce pulpal exposure), softened, affected dentin nearest the pulp may be left. The deliberate retention of softened dentin near the tooth pulp and medication of the remaining dentin is termed *indirect pulp capping* and will be discussed in the next section. The goals of the caries-control and indirect pulp capping procedures are to prevent pulp exposure and aid pulpal recovery by medication.

If the pulp is penetrated by an instrument during the operative procedure, a decision must be made whether to proceed with root canal therapy or do a direct pulp capping. Direct pulp capping is a technique for treating a pulp exposure with

a material that seals over the exposure site and promotes reparative dentin formation. If the exposure site is the consequence of infected dentin extending into the pulp, termed *carious pulpal exposure*, infection of the pulp already has occurred, and removal of the tooth pulp is indicated. If, however, the pulp exposure occurs in an area of normal dentin (usually as a result of operator error or misjudgment), termed *mechanical pulpal exposure*, and bacterial contamination from salivary exposure does not occur, the potential success of the direct pulp capping procedure is enhanced. With either type of exposure, a more favorable prognosis for the pulp after direct pulp capping may be expected if any of the following findings are present:

1. The tooth has been asymptomatic (no spontaneous pain, normal response to thermal testing, and vital) before the operative procedure.
2. The exposure is small (<0.5mm in diameter).
3. The hemorrhage from the exposure site is easily controlled.
4. The exposure occurred in a clean, uncontaminated field (such as that provided by rubber dam isolation).
5. The exposure was relatively atraumatic, and little desiccation of the tooth occurred, with no evidence of aspiration of blood into dentin (dentin blushing).

A deep caries excavation close to the pulp, which may result in either an undetected pulpal exposure or a visible pulpal exposure, should be covered with a calcium hydroxide liner that can stimulate formation of dentin bridges (reparative dentin) over the exposure.⁹⁹ If used, the calcium hydroxide liner should always be covered with a glass ionomer or resin-modified glass ionomer liner before the tooth is restored. Deep excavations not encroaching on the pulp should be covered with a glass-ionomer material and then restored with either a definitive or a temporary restorative material. Alternatively, a reinforced glass ionomer material (such as Fuji IX) can be used for caries-control restorations, which eliminates the need for liners or bases in cases where no pulp exposure has occurred. The selection of a caries-control restorative material depends on the amount of missing tooth structure and the expected length of service anticipated for this temporary restoration. Amalgam, Fuji IX, and intermediate restorative material are the most frequently used materials for caries-control procedures.

If a long interval is anticipated between the caries-control procedure and the permanent restoration, amalgam ensures better maintenance of tooth position and proper contour. If significant portions of the proximal or occlusal surfaces are missing, an amalgam temporary restoration maintains the adjacent and occlusal tooth contact better than other weaker restorative materials. The extent of the access preparation and tooth structure loss indicates the need for a matrix application before placement of the restorative material (see Fig. 2-45, D). Matrix choice and application are described in subsequent chapters. Condensation and carving should be accomplished in the conventional manner. Precise anatomic form is unnecessary for temporary restorations. Proper proximal contacts and contours should be established, however, to maintain satisfactory dimension of the embrasures to foster interdental papilla health (see Fig. 2-45, E). Teeth lacking interproximal contacts may drift, making subsequent

restoration more difficult. Also, a condensation technique that exerts less pressure (i.e., using a spherical amalgam) reduces the chance of pulpal perforation.

Different opinions exist concerning various aspects of the caries-control technique. Some practitioners advocate removal of all caries in all teeth initially, regardless of the size of the lesion. This approach is undoubtedly the most effective for controlling the infection from dental caries. This approach has disadvantages, however, because it necessitates the excavation of all lesions, which is very laborious. Limiting caries-control procedures to pulp-threatening advanced caries lesions is advocated in this text as a more practical procedure. Caries-control restorations can be replaced after the remaining small- to moderate-sized lesions are completely restored. The interval between the caries-control restoration and its replacement with a permanent restoration provides time to complete the following: assessment of the pulpal response to excavation and medication, treatment of the cariogenic infection with prescribed anti-caries measures, assessment of the patient's ability to perform oral hygiene procedures, assessment of the patient's compliance with dietary changes, and assessment of caries activity elsewhere in the mouth. The outcome of these factors may have an important bearing on the choice of materials and techniques for the final restoration of teeth. Regardless of the caries-control concept endorsed, advanced caries lesions should be treated without delay to minimize the potential for adverse pulpal reaction and to provide time for assessment of the pulpal response to therapy.

Some controversy exists concerning the medication material to place over deeply excavated areas. Although most practitioners recognize the potential for stimulating reparative dentin formation with the use of calcium hydroxide materials, this is not universally accepted. More importantly, no consensus exists with regard to the mechanism of action of calcium hydroxide liners. One group of practitioners supports the concept that a calcium hydroxide liner must be in direct contact with pulpal tissue to cause reparative dentin formation. These practitioners believe that the use of calcium hydroxide liners in any situation other than a direct pulpal exposure would not stimulate reparative dentin formation. Other practitioners believe, however, that the calcium hydroxide material is soluble and is transmitted by the fluid in the dentinal tubules to the pulp and, consequently, causes reparative dentin formation.

Finally, minor controversy, or at least confusion, exists about the terminology related to this procedure. Although this section has termed the procedure *caries-control restorative treatment*, other terms such as *interim restoration*, *treatment restoration*, or *temporary restoration* may be used. All of these descriptions have validity when applied to the technique of removing acute caries without delay and temporarily restoring the involved tooth or teeth.

Partial Caries Excavation and Indirect Pulp Capping

Teeth that have large caries lesions but no overt pulpal or periapical pathology should be managed conservatively. It is generally not advisable to initiate definitive root canal therapy for asymptomatic teeth with a healthy pulp and healthy periapical area. Growing clinical and scientific evidence indicates

that large carious lesions with healthy pulpal and periapical tissues should be managed via *partial caries excavation* and *indirect pulp capping*. Aggressive complete caries removal that invades the pulp space and forces a decision of definitive root canal treatment or extraction in the context of caries control is to be avoided. Partial caries excavation followed by indirect pulp capping via placement of a sedative restoration has significant benefits. For the individual patient, it might allow retention of the tooth through the control phase without root canal therapy—thereby avoiding the time, expense, and necessary deferral of treatment for other teeth (including those with a better prognosis)—and it also avoids the problem of performing endodontic therapy on a tooth that might be recommended for extraction in the definitive phase of treatment. The complexity and cost of treatment increase several-fold once the pulp is exposed. For many patients, this can mean a death sentence for the tooth. From a public health perspective, teeth should not be extracted merely for financial reasons but should be maintained to provide some level of esthetics, function, and preservation of oral health, especially in patients with limited financial resources.

One of the major motivations in performing partial caries excavation and indirect pulp capping is to ensure that large caries lesions are treated as a priority, thus reducing the overall bacterial load and arresting or stopping lesion progression, which, in effect, is caries control as described in the preceding section. The philosophy behind this approach is that when the tooth is vital and no signs or symptoms of irreversible pulpitis are present, it is better to simply seal partially demineralized dentin from the oral environment and arrest the decay process than to engage in more complex and expensive procedures. When successful, the benefits in reduced cost and postoperative pain are obvious. Ample literature exists to support this approach as being more successful than the removal of all caries even if it means pulp exposure.^{28-34,100-123}

It is appropriate to use partial caries excavation and indirect pulp capping in the context of caries control on any tooth with a large caries lesion (or multiple teeth with moderately large lesions) that is deemed restorable and for which the pulpal and periapical areas are deemed healthy (no irreversible pulpitis or pulpal necrosis). Teeth that are restorable only with full-coverage restoration generally are not appropriate for this approach because of the difficulty of evaluating the tooth for possible failures such as continuing caries activity under the full-coverage restoration. Another concern is the cost of rectifying failures.

The following four steps summarize the partial caries excavation clinical protocol:

1. Preliminary assessment of pulpal and periapical health and restorability of teeth being considered for partial caries excavation and indirect pulp capping should be done. (*At the subsequent restorative steps, pulpal diagnosis and restorability may be reassessed.*) Partial caries excavation and indirect pulp capping are used only for teeth determined to be vital and to have a healthy periapical area. At worst, these teeth would have symptoms consistent with reversible pulpitis. If the tooth is found to be nonvital, if symptoms are consistent with irreversible pulpitis, or if apical periodontitis of endodontic origin is present, partial caries excavation and indirect pulp capping are contraindicated.

2. The restorability of the tooth is assessed at the beginning of the restorative appointment. Restorability must be definitively confirmed after completion of all peripheral caries removal (i.e., a caries-free DEJ should be established around the entire periphery of the cavity preparation). Partial caries excavation and indirect pulp capping are used only for teeth that are restorable with a direct restoration (glass ionomer, resin-modified glass ionomer, composite, amalgam, foundation) and teeth that have a fair to good restorative prognosis. A treatment plan should be made for the extraction of teeth that are found to be nonrestorable.
3. Caries is completely excavated peripherally to a sound, caries-free DEJ. Axially and pulpally, caries will be excavated to within approximately 1 mm of the pulp. The goal is to stop removing caries when the first of either of these two situations occurs: (1) All caries has been removed; or (2) all caries has been removed from all the walls except the axial or pulpal walls, where demineralized dentin still remains and approximately 1 mm of dentin thickness remains. If all caries has been removed (option 1), a definitive direct restoration may be placed, if recommended. If all caries has not been removed (option 2), a glass ionomer (e.g., Fuji IX) sedative restoration is placed. The sedative restoration is left in place for approximately 12 weeks.
 - a. Use of calcium hydroxide or other liner or base material after caries excavation and before use of the sedative restoration is not required, but it is permitted.
 - b. Use of a definitive restoration when all caries has not been removed (option 2) can be considered as well. The rationale behind this approach is that subsequent appointments, which require patient compliance, would not be necessarily required, and therefore, the tooth is more properly restored should the patient not follow up with subsequent appointments. Additionally, the placement of a definitive restoration at the time of the partial caries excavation may eliminate the need for a subsequent intervention in the tooth.
4. The treated tooth is re-evaluated approximately 12 weeks after the restorative appointment. Teeth that are vital and asymptomatic at this visit are restored with a direct restoration (either amalgam or composite). *The glass ionomer caries control restoration is not removed to facilitate the removal of caries left at the first appointment.* Rather, it is cut back pulpally and axially to serve as a base, and a definitive direct restoration (e.g., amalgam, composite resin) is placed. Strong evidence indicates that re-entering an asymptomatic, vital tooth significantly increases the likelihood of pulp exposure without increasing favorable outcomes.^{26,27,29,31,34,122} Re-evaluation of the remaining tooth structure prior to placement of a definitive direct restoration may sometimes result in a decision to place a full-coverage restoration. If that is the case, the glass ionomer may be removed, at the discretion of the operator, to facilitate the removal of any residual partially demineralized dentin and a foundation for a crown is placed. If pulp exposure occurs, the tooth should be treated endodontically. At the follow-up appointment, teeth that still

have symptoms consistent with a reversible pulpitis or are found to be necrotic are recommended for endodontic therapy or extraction. The dentist does have flexibility to extend the observation period and schedule one additional re-evaluation, but this is discouraged unless it is strongly believed that the status of the pulp will change dramatically.

The pulpal diagnoses outlined as part of the partial caries excavation and indirect pulp capping protocol rely on signs and symptoms of pulp pathology determined by using the best diagnostic tools available. However, actual pulpal status is difficult to determine clinically—bacteria and toxins progressing ahead of caries can cause areas of undetectable pulp necrosis or irreversible pulpitis.⁹⁹ This protocol calls for the use of glass ionomer (e.g., Fuji IX) as the indirect pulp capping or sedative restoration material because evidence indicates that it provides a good seal, which is critical to arresting the decay. Use of a material other than glass ionomer for the sedative restoration is permitted at the discretion of the dentist.

Root Caries Management

It is clear that the “baby boom” generation of North America is aging. In the year 1900, 3% of the U.S. population was over 60 years of age, whereas in the year 2000, 13% of the population was over 60 years old.¹²⁴ In the year 2030, it is estimated that at least 20% of the population will be 60 years or older. Root caries is a pervasive problem in a high percentage of older patients.^{125,126} Many of these patients have had extensive restorative dentistry done in their lifetimes. Approximately 38% of patients between the ages of 55 and 64 years have root caries, and 47% of those between 65 and 74 years have experienced root caries.¹²⁷ The incidence of root caries in old-older adults (over 75 years) is even higher.¹²⁸

One of the primary etiologic factors for these patients is their use of prescription drugs for a wide variety of systemic medical problems. It has been estimated that 63% of the 200 most commonly prescribed medications have dry mouth as an adverse effect. It is the subsequent reduction in salivary flow rates and concomitant diminished buffering capacity resulting from use of these medications that is primarily responsible for the increase in root caries in older patients.

The critical pH of dentin (pH at which dentin begins to demineralize) is between 6.2 and 6.7, whereas that of enamel is about 5.5.¹²⁹ As a result, root dentin will demineralize in very weak acids, and root caries progresses at about twice the rate of coronal caries. Thus, it is critical that all older patients receive thorough clinical and radiographic examinations on a regular basis.

As described previously in this chapter, a caries risk assessment should be carried out for all older patients. Risk factors for root caries include the following:

1. Gingival recession
2. Poor oral hygiene
3. Cariogenic diet
4. Presence of multiple restorations or multiple missing teeth
5. Existing caries

6. Xerogenic medications
7. Compromised salivary flow rates

Once it has been determined that a patient is at high risk for root caries, an aggressive preventive protocol as described previously should be considered. This protocol is based upon four primary strategies for the prevention of root caries. The *first* strategy is to try to improve salivary flow rates and increase the buffering capacity. The *second* strategy is to try to reduce the numbers of cariogenic bacteria (*S. mutans*) in the oral cavity. The *third* strategy is to reduce the quantity and numbers of exposures of ingested refined carbohydrates, and the *fourth* is to attempt to remineralize noncavitated lesions and prevent new lesions from developing. In addition to following the aforementioned protocol, two additional considerations are important:

1. *Recommend the use of powered toothbrushes.* It is critical that patients susceptible to root caries practice meticulous oral hygiene. However, many of these patients have physical and visual deficiencies, and this makes it difficult for them to adequately cleanse the mouth. For these patients, a powered toothbrush may be advantageous. If the patient can use a water irrigation device (Waterpik, Water Pik Inc., Fort Collins, CO), daily use of the device will be beneficial. Although it will not remove plaque, studies have shown that daily use will change the composition of the plaque in a beneficial way.
2. *Restore all root caries lesions with a fluoride-releasing material.* All Fuji IX restorations should be removed, and all active caries removed. Resin-modified glass ionomer materials are preferred for definitive restorations primarily because they bond effectively to both enamel and dentin and they act as reservoirs for fluoride which can be re-released into the oral cavity.^{130,131} They are effective as anti-caries materials *only* if patients reload the material a minimum of three times a day by brushing with fluoride-containing toothpaste or by using other fluoride-containing products. Educating patients of the necessity for three exposures to fluoride per day and for reloading the fluoride-releasing materials can assist in motivating them to improved levels of compliance.

In summary, many older patients are experiencing an epidemic of root caries, primarily as a result of the xerogenic effects of medications prescribed for systemic illnesses. Many root caries lesions occur in locations that make them difficult, if not impossible, to restore. The dental profession has a strong track record of prevention, and it is clear that with root caries, prevention is much better than restoration.

Summary

Much of the remainder of this textbook presents information on when and how to restore tooth defects. Many tooth defects are the result of caries activity. As stated previously, the restoration of a caries lesion does not cure the carious process. Only implementation of appropriate caries-preventive measures reduces the probability that caries lesions will recur. Tooth restorations are preventive in the sense that they remove numerous cariogenic organisms in the affected site and

eliminate a protected habitat for other cariogenic bacteria; however, they primarily repair the tooth damage caused by caries and have only a limited impact on the patient's overall caries risk.

In managing caries, the objective is to focus on the diagnosis (identifying individuals at high risk for caries via caries risk assessment protocols), preventive or therapeutic measures, and treatment modalities. Caries management efforts must be directed not at the tooth level (traditional or surgical treatment) but at the total-patient level (medical model of treatment). Restorative treatment does not cure the caries process. Instead, identifying and eliminating the causative factors for caries must be the primary focus, in addition to the restorative repair of damage caused by caries.

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Patient Assessment, Examination and Diagnosis, and Treatment Planning

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This chapter provides an overview of the process through which a clinician completes patient assessment, clinical examination, diagnosis, and treatment plan for operative dentistry procedures. The chapter assumes that the reader has a background in oral medicine and an understanding of how to perform complete extraoral hard and soft tissue examinations along with intraoral cancer screening, as well as an understanding of the etiology, characteristics, risk assessment, and nonoperative management of dental caries as presented in Chapter 2. It is not in the scope of this chapter to incorporate the details of other aspects of a complete dental examination, including periodontal examination, occlusal examination, and esthetic evaluation.

Any discussion of diagnosis and treatment must begin with an appreciation of the role of the dentist in helping patients maintain their oral health. This role is summarized by the Latin phrase “primum non nocere,” which means “do no harm.” This phrase represents a fundamental principle of the healing arts over many centuries.

The implication of this concept for operative dentistry is that before we recommend treatment, we must be reasonably confident that the patient will be better off as a result of our intervention. However, how can we be reasonably confident when we realize that few, if any, of the tests we perform or the assessments of risk that we make are completely accurate? To make matters even more challenging, none of the treatments we provide is without adverse outcomes and none will likely last for the life of the patient. The answer is that we must acknowledge that the information or evidence we have is not perfect and that we must be clear about the possible consequences of our decisions. If we are as informed and clear about the options and their consequences, then we reduce the chances of doing any harm.

The success of operative treatment depends heavily on an appropriate plan of care, which, in turn, is based on a comprehensive analysis of the patient's reasons for seeking care and on a systematic assessment of the patient's current conditions and risk for future problems. This information is then

combined with the best available evidence on the approaches to managing the patient's needs so that an appropriate plan of care can be offered to the patient.

The collection of this information and the determinations based on these findings should be comprehensive and occur in a stepwise manner. Simply put, skipping steps can lead to overlooking potentially important parts of the patient's individual needs. These steps include reasons for seeking care, medical and dental histories, clinical examination for the detection of abnormalities, establishing diagnoses, assessing risk, and determining prognosis. All of these steps must occur before a sound and appropriate plan of care can be recommended.

Growing attention to using only the most effective and appropriate treatment has spawned interest in numerous activities. Research that provides information on treatments that work best in certain situations is expanding the knowledge base of dentistry and has led to an interest in translating the results of that research into practice activities and enhanced care for patients. This movement has been termed *evidence-based dentistry* and is defined as the “conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients.”¹ Systematic reviews emerging from the focus on evidence-based dentistry will provide practitioners with a distillation of the available knowledge about various conditions and treatments. Currently, the American Dental Association (ADA) has developed a Web site (<http://ebd.ada.org/>) that can be used by dental professionals for evidence-based dentistry decision making. This Web site helps clinicians identify systematic reviews, describes the preferred method for assembling the best available scientific evidence, and provides an appraisal of the evidence through critical summaries. As evidence-based dentistry continues to expand, professional associations will become more active in the development of guidelines to assist dentists and their patients in making informed and appropriate decisions.

Patient Assessment

General Considerations

Clinical examination is the “hands-on” process of observing the patient’s oral structures and detecting signs and symptoms of abnormal conditions or disease. This information is used to formulate diagnoses, which are a determination or judgment of health versus disease and variations from normal. During the clinical examination, the dentist must be keenly sensitive to subtle signs, symptoms, and variations from normal to detect pathologic conditions and etiologic factors. Meticulous attention to detail generates a base of information for assessing the patient’s general physical health and diagnosing specific dental problems.

Chief Concern

Before initiating any treatment, the patient’s chief concerns, or the problems that initiated the patient’s visit, should be obtained. Concerns are recorded essentially verbatim in the dental record. The patient should be encouraged to discuss all aspects of the current problems, including onset, duration, symptoms, and related factors. This information is vital to establishing the need for specific diagnostic tests, determining the cause, selecting appropriate treatment options for the concerns, and building a sound relationship with the patient.

Medical History

The patient or legal guardian completes a standard, comprehensive medical history form. This form is an integral part of the pre-examination patient interview, which helps identify conditions that could alter, complicate, or contraindicate proposed dental procedures. The practitioner should identify (1) communicable diseases that require special precautions, procedures, or referral; (2) allergies or medications, which can contraindicate the use of certain drugs; (3) systemic diseases, cardiac abnormalities, or joint replacements, which require prophylactic antibiotic coverage or other treatment modifications; and (4) physiologic changes associated with aging, which may alter clinical presentation and influence treatment. The practitioner also might identify a need for medical consultation or referral before initiating dental care. All of this information is carefully detailed in the patient’s permanent record and is used, as needed, to shape subsequent treatment.

Dental History

The dental history is a review of previous dental experiences and current dental problems. Review of the dental history often reveals information about past dental problems, previous dental treatment, and the patient’s responses to treatments. Frequency of dental care and perceptions of previous care may be indications of the patient’s future behavior. If a patient has difficulty tolerating certain types of procedures or has encountered problems with previous dental care, an alteration of the treatment or environment might help avoid future complications. Also, this discussion might lead to identification of other problems such as areas of food impaction, inability to floss, areas of pain, and broken restorations or tooth structure. It is crucial to understand past experiences to

provide optimal care in the future. Finally, the date and type of available radiographs should be recorded to ascertain the need for additional radiographs and to minimize the patient’s exposure to unnecessary ionizing radiation.

Magnification in Operative Dentistry

Clinical dentistry often requires the viewing and evaluation of small details in teeth, intraoral and perioral tissues, restorations, and study casts. Unaided vision is often inadequate to view details needed to make treatment decisions. Magnification aids such as loupes provide a larger image size for improved visual acuity, while allowing proper upright posture to be maintained with less eye fatigue.

When choosing loupes, several parameters should be considered.^{2,3,4} Magnification (power) describes the increase in image size. Most dentists use magnifications of 2× to 4×. The lower power systems of 2× to 2.5× allow multiple quadrants to be viewed, whereas the higher power systems of 3× to 4× enable viewing of several teeth or a single tooth. In general, higher magnification systems are heavier, have a narrower field of view, are more expensive, and require more light than lower power systems. The use of small, lightweight LED (light-emitting diode) headlamps attached to the eyeglass frame or attached to a headband offer the considerable visual advantage of added illumination when used with loupes.

Working distance (focal length) is the distance from the eye to the object when the object is in focus. This parameter should be considered carefully before selecting loupes because the desired working distance depends on the dentist’s height, arm length, and seating preferences. Dentists of average height typically choose a working distance of 13 to 14 inches (33–35 cm), whereas tall dentists and those who prefer to work farther away from the patient use working distances of 14 to 16 inches (35–40 cm).

Depth of focus, or the difference between the far and near focus limits of the working distance, depends on the magnification. Typically, the lower the magnification, the greater is the depth of focus.

Many choices of magnification loupes are currently available for dentistry. The simplest magnifiers are the diopter single-lens loupes, which are single-piece plastic pairs of lenses that clip onto eyeglass frames. These loupes are inexpensive and lightweight and can provide magnification of up to 2.5×. However, images can be distorted, and working lengths can be less than ideal. The more commonly used dental loupe is the binocular loupe with lenses mounted on an eyeglass frame. Binocular loupes typically have Galilean and prismatic optics that provide 2× to 3.5× magnification or even 4× and greater magnification. Prescription lenses can be fitted in the eyeglass frames for all loupe types. Most models also have side shields or a wraparound design for universal precautions and ease of infection control. Two mounting systems are currently available for binocular loupes: (1) flip-up and (2) fixed or through-the-lens.

Previously limited primarily to endodontic practices, dental microscopes now are being used in some restorative dentistry practices. Compared with high-powered loupes, dental microscopes allow the clinician to view intraoral structures at a higher level of magnification while maintaining a broader field of view. Because very small areas can be seen, microscopes are used in detail-oriented procedures such as the

finishing of porcelain restoration margins, identifying minute decay, and minimizing the removal of sound tooth structure. Generally, microscopes include five or six magnification stops that typically range from 2.5× to 20×. The largest manufacturers of dental microscopes include Carl Zeiss, Inc. (Dublin, CA); Global Surgical Corporation (St. Louis, MO); and Seiler Precision Microscope Instrument Company (St. Louis, MO). Cost, size of the equipment, and perceived lack of value to the clinician have been factors in limiting the use of microscopes in operative dentistry practice.

Photography in Operative Dentistry

Photography in dentistry has many uses and with newer digital technologies, photography is becoming mainstream in dental practice. Just as radiographs provide a historical look at a patient's situation, photography is an excellent tool for documentation and evaluation. Intraoral cameras and SLR (single-lens reflex) digital cameras that are easy to use provide opportunities to document existing esthetic conditions such as color, shape, and position of teeth. Close-up images of existing pits and fissures can provide the opportunity to see changes that cannot be documented in any other way for re-evaluation in the future. Photographs of preparations of deep caries lesions provide documentation to aid in future diagnosis of tooth conditions. Without preparation photographic documentation, this information would no longer be available once the restoration has been placed. Digital documentation with photographs is easier and more cost effective with the current quality of digital photography and ability to process and store images in an electronic patient record.

Examination, Risk Profile, Diagnosis, and Prognosis

This section describes examination, diagnosis, risk assessment, and prognosis. It details the examination of teeth and restorations using visual examination, radiographic examination, and adjunctive aids to detect caries and assess the structural integrity of teeth. Also described is the examination of occlusion and esthetics as related to operative dentistry procedures.

Interpretation and Use of Diagnostic Findings

The diagnostic effort of health care professionals has been enhanced by the use of principles adopted from clinical epidemiology. This analytic approach relies on “2 × 2” contingency tables (Fig. 3-1) derived from clinical trials data. Such studies compare the results of a diagnostic test with the results obtained from a “gold standard” (knowledge of the actual condition) to determine how well a test identifies the “true,” or actual, condition. The results of the diagnostic test, positive or negative, are shown across the rows of the table, and the results of a “gold standard” or the “truth” are displayed in the columns. Cell A of the table contains the cases that the test identifies as being positive (or diseased) that actually are positive (i.e., confirmed by the “gold standard”). These cases are termed *true positives*. Cell B contains all cases for which a positive finding from the diagnostic test is present, but where

		Gold Standard	
		+	–
Diagnostic Test Results	+	A	B
	–	C	D

Cell A = true positives
 Cell B = false positives
 Cell C = false negatives
 Cell D = true negatives

Fig. 3-1 Contingency table for interpretation of diagnostic tests.

the actual condition is negative. Therefore, this cell denotes *false positives*. Cell C includes the cases identified by the diagnostic test as not being diseased, but actually are diseased, as determined by the “gold standard.” Findings in this cell are termed *false negatives*. The final cell, cell D, includes *true negatives*, where the diagnostic test accurately identifies nondiseased cases that are truly negative as confirmed by the “gold standard.” A perfect diagnostic test would result in all cases being assigned to cells A or D with no false positives (cell B) or false negatives (cell C).

When the basics of this table are understood, the information it yields can be put to good use by the diagnostician. The first concept is test *sensitivity*, which is calculated as the number of true positives (A) divided by the number of total positive cases (A + C). The term *sensitivity* indicates the proportion of individuals with disease in any group or population that is identified positively by the test. In contrast, *specificity* refers to the proportion of individuals without disease properly classified by the diagnostic test and is the ratio of true negatives (D) to all negatives (B + D). Sensitivity and specificity will not vary on the basis of the prevalence of disease, that is, the proportion of cases in a population. Rather, these statistics indicate what proportions of existing disease and absence of disease will be correctly identified in any group of individuals.

A test with low sensitivity indicates that a high probability exists that many of the individuals with negative results have the disease and go undiagnosed. Conversely, a test with high sensitivity means that most of those who actually have disease will be identified as such. Tests with high specificity suggest that patients without the disease are highly likely to test negative. Tests with low specificity will misclassify a sizable proportion as diseased when many are really free of disease.

Very few tests have *both* high sensitivity and high specificity, so trade-offs are inevitable. The clinician must weigh the seriousness of the disease that is left untreated (in cases of low sensitivity) against the invasiveness of the treatment (in cases of low specificity). In the former, low sensitivity may be acceptable for tests diagnosing slowly progressing, non-fatal conditions but unacceptable for conditions that progress rapidly or are life threatening. In the latter, low specificity may not be acceptable if the treatment is invasive and irreversible,

but more acceptable if the treatment is non-invasive and temporary. In the case of dental caries, all things being equal, this means that the clinician can accept a less sensitive test (i.e., miss some initial lesions [cell C]) because caries usually progresses slowly over years. But given that operative treatment is invasive and irreversible, a highly specific test (i.e., few false positives [cell B]) means that fewer healthy teeth will be treated.

These concepts are widely used in medical practice. Although many of the necessary studies have not been conducted to develop these probabilities for dental conditions, interest in the use of clinical epidemiology in the dental profession has been growing. In the future, more studies will be conducted to provide this information to clinicians, and one should be prepared to take advantage of their use.

Examination of Teeth and Restorations

Preparation for Clinical Examination

A trained assistant familiar with the terminology, notation system, and charting procedure can survey the patient's teeth and existing restorations and record the information to save chair time for the dentist. The dentist subsequently performs the examination, confirms the charting, makes a diagnosis, establishes a risk assessment profile for the patient, establishes a prognosis, and develops the treatment plan in conjunction with the patient's current needs and desires. The clinical examination is performed systematically in a clean, dry, well-illuminated mouth. Proper instruments, including a mirror, an explorer, and a periodontal probe, are required. A routine for charting should be established, such as starting in the upper right quadrant with the most posterior tooth and progressing around the maxillary and mandibular arches. An accurate examination is possible only when teeth are clean and dry. This may require initial scaling, flossing, and a tooth-brushing prophylaxis before final clinical examination of teeth. A cotton roll in the vestibular space and another under the tongue maintain dryness and improve vision (Fig. 3-2). Dental floss is useful in identifying overhanging restorations, improper proximal contours, and open contacts.



Fig. 3-2 An accurate clinical examination requires a clean, dry, well-illuminated mouth. Cotton rolls are placed in the vestibular space and under the tongue to maintain dryness and enhance visibility.

Clinical Examination for Caries

Contemporary caries management, which encompasses expanded non-operative approaches and conservative operative interventions, relies on enhanced risk assessment and improved lesion detection and classification. The objective of improved detection and classification systems is to accurately identify those early enamel lesions that are most likely to be reversed and remineralized. Therefore, appropriate non-operative care can be attempted, and lesions that require operative treatment can be identified as early as possible in the disease process. With this approach, the restoration will result in the removal of the minimum amount of tooth structure.

Caries lesions can be detected by visual changes in tooth surface texture or color or in tactile sensation when an explorer is used judiciously to detect surface roughness by gently stroking across the tooth surface. Current thinking finds that the use of an explorer in this manner might have some relevance for assessing caries activity. However, it cannot be over-emphasized that the **explorer must not be used to determine a “stick,”** or a resistance to withdrawal from a fissure or pit. This improper use of a sharp explorer has been shown to irreversibly damage the tooth by turning a sound, remineralizable sub-surface lesion into a possible cavitation that is prone to progression. Forcing an explorer into pits and fissures also theoretically risks cross-contamination from one probing site to another. In contrast, for assessment of root caries, an explorer is valuable to evaluate root surface softness. Additional methods used in caries detection are radiographs that show changes in tooth density from normal and adjunctive tests that use various technologies to aid in caries lesion detection and caries activity.

Caries lesions are most prevalent in the faulty pits and fissures of the occlusal surfaces where the developmental lobes of posterior teeth failed to coalesce, partially or completely (Fig. 3-3). It is important to remember the distinction between primary occlusal grooves and fossae and occlusal fissures and pits. Primary occlusal grooves and fossae are smooth “valley or saucer” landmarks indicating the region of complete coalescence of developmental lobes. Normally, such grooves and fossae are not susceptible to caries because they are not niches for biofilm and frequently are cleansed by the rubbing action of food during mastication. Conversely, occlusal fissures and pits are deep, tight crevices or holes in enamel, where the lobes failed to coalesce partially or completely. Fissures and pits are detected visually.

As noted earlier, sharp explorers were used to diagnose fissure caries. However, numerous studies have found that the use of a sharp explorer for this purpose did not increase diagnostic validity compared with visual inspection alone.⁵⁻⁸ The use of the dental explorer for this purpose was found to fracture enamel and serve as a source for transferring pathogenic bacteria among various teeth.^{9,10} Therefore, the use of a sharp explorer in diagnosing pit-and-fissure caries is contraindicated as part of the detection process.

An occlusal surface is examined visually and radiographically.^{11,12} The visual examination is conducted in a dry, well-illuminated field. Through direct vision and reflecting light through the occlusal surface of the tooth, the occlusal surface is diagnosed as diseased if chalkiness or apparent softening or cavitation of tooth structure, forming the fissure or pit, is seen or a brown-gray discoloration, radiating peripherally from



Fig. 3-3 Caries can be diagnosed clinically by careful inspection. **A**, Carious pit on cusp tip. **B**, Loss of translucency and change in color of occlusal enamel resulting from a carious fissure. **C**, White chalky appearance or shadow under marginal ridge. **D**, Incipient smooth-surface caries lesion, or a white spot, has intact surface. **E**, Smooth-surface caries can appear white or dark, depending on the degree of extrinsic staining. **F**, Root-surface caries.

the fissure or pit, is present. In contrast, a nondiseased occlusal surface has either grooves or fossae that have shallow tight fissures, which exhibit superficial staining with no radiographic evidence of caries. The superficial staining is extrinsic and occurs over several years of oral exposure in a person with low caries risk. Pre-carious or carious pits are occasionally

present on cusp tips (see Fig. 3-3, A). Typically, these are the result of developmental enamel defects or following loss of enamel from tooth due to erosion or abrasion. Carious pits and fissures also occur on the occlusal two thirds of the facial or lingual surface of posterior teeth and on the lingual surface of maxillary incisors. Occlusal enamel can be evaluated for

loss of translucency and changes in color, which may be characteristic of a caries lesion (see Fig. 3-3, B). The color change can be dark gray and should not be confused with the noncari-ous fissures and pits that often become merely stained over time. These visual techniques of examining teeth are then translated into the codes used in the International Caries Detection and Assessment System (ICDAS).

Clinical caries lesion detection has been found lacking and improvement is needed.¹³ One means of addressing these concerns has been the development of a visual system for caries lesion detection and classification. The ICDAS was developed to serve as a guide for standardized visual caries assessment that could be used for clinical practice, clinical research, education, and epidemiology (Fig. 3-4). In the United States, the Caries Management by Risk Assessment (CAMBRA) movement, as discussed in Chapter 2 on cariology, embraces the principles of the ICDAS for visual examination and assessment of caries lesions.

The clinical examination for detecting caries lesions is aided by an assessment of the patient’s overall caries risk, along with the patient’s patterns of susceptibility. The patient’s medical history, dental history, oral hygiene, diet, and age, among other caries risk factors and indicators, can suggest a prediction of current and future caries activity. For example, caries lesions also tend to occur bilaterally and on adjacent proximal surfaces (see Fig. 3-3). During the clinical examination, every accessible

surface of each tooth must be inspected for localized changes in color, texture, and translucency, as described in the ICDAS codes. This requires two minimum conditions for the examination to be properly conducted: (1) Teeth must be sufficiently air-dried so that the changes can be seen properly, and (2) biofilm or plaque must be thoroughly removed from teeth prior to the examination. The ICDAS uses a two-stage process to record the status of the caries lesion. The first is a code for the restorative status of the tooth, and the second is for the severity of the caries lesion. The status of the caries severity is determined visually on a scale of 0 to 6:

- 0 = sound tooth structure
- 1 = first visual change in enamel
- 2 = distinct visual change in enamel
- 3 = enamel breakdown, no dentin visible
- 4 = dentinal shadow (not cavitated into dentin)
- 5 = distinct cavity with visible dentin
- 6 = extensive distinct cavity with visible dentin

This severity code is paired with a restorative/sealant code 0 to 8:

- 0 = not sealed or restored
- 2 = sealant, partial
- 3 = sealant, full; tooth-colored restoration








Occlusal Protocol ***							
ICDAS code	0	1	2	3	4	5	6
							
Definitions	Sound tooth surface; no caries change after air drying (5 sec); or hypoplasia, wear, erosion, and other noncaries phenomena	First visual change in enamel; seen only after air drying or colored, change "thin" limited to the confines of the pit and fissure area	Distinct visual change in enamel; seen when wet, white or colored, "wider" than the fissure/fossa	Localized enamel breakdown with no visible dentin or underlying shadow; discontinuity of surface enamel, widening of fissure	Underlying dark shadow from dentin, with or without localized enamel breakdown	Distinct cavity with visible dentin; frank cavitation involving less than half of a tooth surface	Extensive distinct cavity with dentin; cavity is deep and wide involving more than half of the tooth
Histologic depth		Lesion depth in P/F was 90% in the outer enamel with only 10% into dentin	Lesion depth in P/F was 50% inner enamel and 50% into the outer 1/3 dentin	Lesion depth in P/F with 77% in dentin	Lesion depth in P/F with 88% into dentin	Lesion depth in P/F with 100% in dentin	Lesion depth in P/F 100% reaching inner 1/3 dentin
Sealant/restoration Recommendation for low risk	Sealant optional DIAGNOdent may be helpful	Sealant optional DIAGNOdent may be helpful	Sealant optional or caries biopsy if DIAGNOdent is 20-30	Sealant or minimally invasive restoration needed	Minimally invasive restoration	Minimally invasive restoration	Minimally invasive restoration
Sealant/restoration Recommendation for moderate risk	Sealant optional DIAGNOdent may be helpful	Sealant recommended DIAGNOdent may be helpful	Sealant optional or caries biopsy if DIAGNOdent is 20-30	Sealant or minimally invasive restoration needed	Minimally invasive restoration	Minimally invasive restoration	Minimally invasive restoration
Sealant/restoration Recommendation for high risk *	Sealant recommended DIAGNOdent may be helpful	Sealant recommended DIAGNOdent may be helpful	Sealant optional or caries biopsy if DIAGNOdent is 20-30	Sealant or minimally invasive restoration needed	Minimally invasive restoration	Minimally invasive restoration	Minimally invasive restoration
Sealant/restoration Recommendation for extreme risk **	Sealant recommended DIAGNOdent may be helpful	Sealant recommended DIAGNOdent may be helpful	Sealant optional or caries biopsy if DIAGNOdent is 20-30	Sealant or minimally invasive restoration needed	Minimally invasive restoration	Minimally invasive restoration	Minimally invasive restoration
* Patients with one (or more) cavitated lesion(s) are high-risk patients. ** Patients with one (or more) cavitated lesion(s) and xerostomia are extreme-risk patients.							
*** All sealants and restorations to be done with a minimally invasive philosophy in mind. Sealants are defined as confined to enamel. Restoration is defined as in dentin. A two-surface restoration is defined as a preparation that has one part of the preparation in dentin and the preparation extends to a second surface (note: the second surface does not have to be in dentin). A sealant can be either resin-based or glass ionomer. Resin-based sealants should have the most conservatively prepared fissures for proper bonding. Glass ionomer should be considered where the enamel is immature, or where fissure preparation is not desired, or where rubber dam isolation is not possible. Patients should be given a choice in material selection.							

Fig. 3-4 International Caries Detection and Assessment System (ICDAS) chart showing visual caries detection. (From Jensen L, Budenz AW, Featherstone JD, et al: Clinical protocols for caries management by risk assessment, J Calif Dent Assoc 35:714, 2007.)

- 4 = amalgam restoration
- 5 = stainless steel restoration
- 6 = ceramic, gold, PFM (porcelain-fused-to-metal) crown or veneer
- 7 = lost or broken restoration
- 8 = temporary restoration

See Fig. 3-4 for the ICDAS for examples of coding for restorative status and caries severity. The details of this system for detection and training to use the system with an online tutorial are available at www.icdas.org.

Proximal surface caries, one form of smooth-surface caries, is usually diagnosed radiographically (Fig. 3-5, A). It also can be detected by careful visual examination after tooth separation or through fiberoptic transillumination.¹⁴ When caries has invaded proximal surface enamel and has demineralized dentin, a white chalky appearance or a shadow under the marginal ridge may become evident (see Fig. 3-5, C). Careful probing with an explorer on the proximal surface may detect cavitation, which is defined as a break in the surface contour of enamel. The use of all examination methods is helpful in arriving at a final diagnosis.

Brown spots on intact, hard proximal surface enamel adjacent to and usually gingival to the contact area are often seen in older patients, in whom caries activity is low. These discolored areas are a result of extrinsic staining during earlier caries demineralizing episodes, each followed by a remineralization episode. These areas are no longer carious and are usually more resistant to caries as a result of fluorohydroxyapatite formation. Restorative treatment is not indicated. These inactive caries lesions sometimes challenge the diagnosis because of faint radiographic evidence of the remineralized lesion.

Proximal surface caries in anterior teeth can be identified by radiographic examination, visual inspection (with optional transillumination), or probing with an explorer. Transillumination is accomplished by placing the mirror or light source on the lingual aspect of teeth and directing the light through teeth. Proximal surface caries, if other than early enamel lesions, appears as a dark area along the marginal ridge when

the light is directed through the tooth. In addition to transillumination, tactile exploration of anterior teeth is appropriate to detect cavitation because the proximal surfaces generally are more visible and accessible than in the posterior regions. Small early enamel lesions may be detectable only on the radiograph.

Another form of smooth-surface caries can occur on the facial and lingual surfaces of the teeth of patients with high caries activity, particularly in the cervical areas that are less accessible for cleaning. The earliest clinical evidence of early enamel lesions on these surfaces is a white spot that is visually different from the adjacent translucent enamel and partially or totally disappears with wetting. Drying again causes it to reappear. This disappearing–reappearing phenomenon distinguishes the smooth-surface early enamel lesion from the white spot resulting from nonhereditary enamel hypocalcification (see section on clinical examination for additional defects). Both types of white spots are undetectable tactilely because the surface is intact, smooth, and hard. For white spot lesions, nonsurgical remineralization therapies (discussed in Chapter 2) should be instituted to promote remineralization.

The presence of several facial (or lingual) smooth-surface caries lesions within a patient's dentition suggests a high caries rate, which means that if the existing risk factors are not addressed, the patient is at high risk for developing more lesions in the future. In a caries-susceptible patient, the gingival third of the facial surfaces of maxillary posterior teeth and the gingival third of the facial and lingual surfaces of mandibular posterior teeth should be evaluated carefully because these surfaces are often at a greater risk for caries. Advanced smooth-surface caries exhibits discoloration and demineralization and feels soft to penetration by the explorer. The discoloration can range from white to dark brown, with rapidly progressing caries usually being light in color. With slowly progressing caries in a patient with low caries activity, darkening occurs over time because of extrinsic staining, and remineralization of the decalcified tooth structure occasionally may harden the lesion. Such an arrested lesion at times may be rough, although cleanable, and a restoration is not

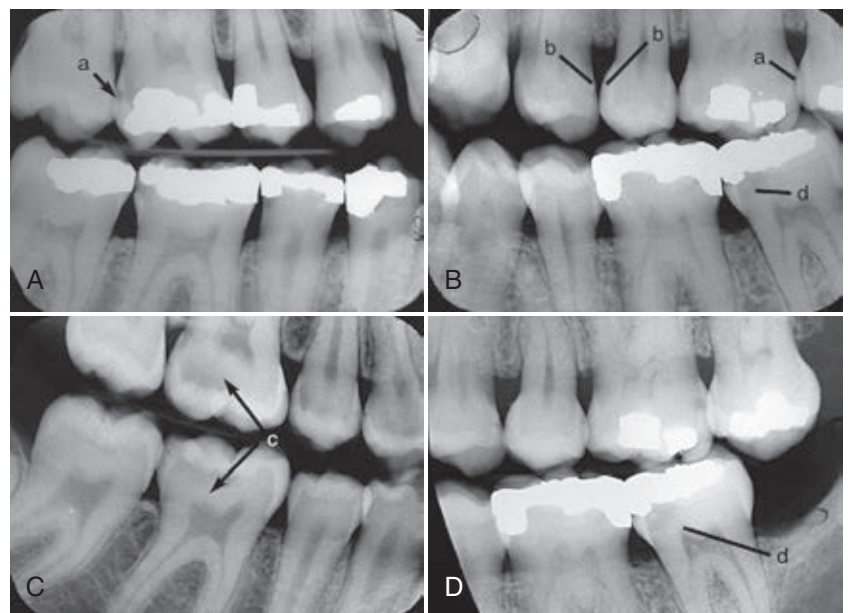


Fig. 3-5 Caries can be diagnosed radiographically as translucencies in the enamel or dentin. **A** and **B**, Proximal caries tends to occur bilaterally (*a*) and on adjacent surfaces (*b*). **C**, Occlusal caries (*c*). **D**, Recurrent caries gingival to an existing restoration (*d*). This same recurrent caries (*d*) also is shown in **B**.

indicated except to address the esthetic concerns of the patient. The dentin in an arrested remineralized lesion is sclerotic. These lesions are inactive lesions but remain susceptible to new caries activity in the future.

In patients with attachment loss, extra care must be taken to inspect for root-surface caries. A combination of root exposure, dietary changes, systemic diseases, and medications that affect the amount and character of saliva can predispose a patient, especially an older individual, to root-surface caries. Lesions are often found at the cementoenamel junction (CEJ) or more apically on cementum or exposed dentin in older patients or in patients who have undergone periodontal surgery (see Fig. 3-3, F). Early in its development, root caries appears as a well-defined, discolored area adjacent to the gingival margin, typically near the CEJ. Root caries is softer than the adjacent tissue, and typically lesions spread laterally around the CEJ. Although no clinical criteria are universally accepted for the diagnosis of root caries, it is generally agreed that softened cemental or dental tooth structure compared with the surrounding surface is characteristic.¹⁵ Active root caries is detected by the presence of softening and cavitation.^{16,17} Although root-surface caries may be detected on radiographic examination, a careful, thorough clinical examination is crucial. A difficult diagnostic challenge is a patient who has attachment loss with no gingival recession, limiting accessibility for clinical inspection. These rapidly progressing lesions are best diagnosed using vertical bitewing radiographs. Differentiation of a caries lesion from cervical burnout radiolucency is, however, essential.¹⁸

In addition to the traditional methods of caries detection, several new technologies have emerged and show promising results for the clinical detection and diagnosis of caries lesions. These devices may have the potential to replace the tactile portion of caries detection, where explorers are used to try to estimate the depth of the caries lesions into the pits and fissures. These devices have two limitations. The first is that they are only indicated for use on unrestored pits and fissures. The second is that their diagnostic accuracy has not been firmly established. The technologies currently approved by the U.S. Food and Drug Administration (FDA) include laser-induced fluorescence, light-induced fluorescence, and AC impedance spectroscopy.^{11,19}

The DIAGNOdent device (KaVo Dental Corporation, Charlotte, NC) uses laser fluorescence technology, with the intention of detecting and measuring bacterial products and changes in the tooth structure in a caries lesion. This compact and portable device, which requires a clean, dry occlusal surface, yields a numerical score from 0 to 99. The manufacturer has recommended threshold scores that represent the presence and extent of a lesion. A systematic review found that the “device is clearly more sensitive than traditional diagnostic methods, but the increased likelihood of false-positive diagnoses limits its usefulness as a principal diagnostic method.”²⁰

Another system currently available for caries lesion detection is the Spectra Camera (Air Techniques, Melville, NY). The Spectra system claims to detect caries lesions by measuring increased light-induced fluorescence. Special LEDs project high-energy violet or blue light onto the tooth surface. Light of this wavelength supposedly stimulates porphyrins—metabolites unique to cariogenic bacteria—to appear distinctly red, while healthy enamel fluoresces to appear green. Using this fluorescent technology, the data captured by the

Spectra system are analyzed by imaging software, which highlights the lesions in different color ranges and defines the potential caries activity on a scale of 0 to 5. Although this technology appears promising, as of the publication date of this textbook, no peer-reviewed randomized clinical trials have been reported.

The CarieScan PRO (CarieScan, LLC, Charlotte, NC) is a device for the detection and monitoring of caries by the application and analysis of AC (alternating current) impedance spectroscopy (ACIST). The CarieScan PRO claims to enable clinicians to evaluate demineralized tooth structure using ACIST by providing information about tissue being healthy, in the early stages of demineralization, or already significantly decayed. The device provides a color scale and a numerical scale to determine the severity of the caries lesion and is accompanied by management recommendations that range from therapeutic prevention to operative intervention appropriate for the extent of the demineralization.

As described earlier, an ideal diagnostic test accurately detects when a tooth surface is healthy (specificity); when a lesion or demineralization is present (sensitivity); and if demineralization is present, whether or not it is active and whether or not it has cavitated the surface. Except for the presence of frank cavitation and more advanced lesions, none of the available approaches to detecting caries or determining lesion activity is completely accurate. Thus, the clinician must take all of the available diagnostic information together—visual, tactile, radiographic, and so on—along with the respective reported levels of accuracy and combine that with an assessment of the patient’s overall caries status to make a final diagnosis to the presence and extent of a caries lesion.

After the clinical examination for detection of caries lesions is completed, the management and treatment of caries lesions discovered depends not only on a thorough assessment of the present activity of the lesions but also on an understanding of the future risk of the patient for increased activity of the lesions. Therefore, the next step is to determine the present activity of the lesions. Is the lesion progressing, or is the lesion arrested? If the lesion is determined to be progressing and the patient’s risk factors are not changed, some intervention, either surgical or nonsurgical, is indicated. If the lesion is determined to be arrested, or not progressing, and the risk factors have been controlled, no treatment is needed other than regular preventive dental care. Currently, a reliable and accurate gold standard test based on one examination at one point in time to accurately assess caries lesion activity is not available, so it is important for the clinician to use information from all the tests and risk assessment to judge which type of intervention is appropriate at the current time. The decision of surgical intervention or nonintervention carries some risk for the patient in either direction, but studies would conclude that all diagnostic doubts should benefit the tooth by choosing non-operative options over irreversible operative dentistry options.

Clinical Examination of Amalgam Restorations

Evaluation of existing restorations should be accomplished systematically in a clean, dry, well-lit field. Clinical evaluation of amalgam restorations requires visual observation, application of tactile sense with the explorer, use of dental floss, interpretation of radiographs, and knowledge of the

probabilities that a given condition is sound or at risk for further breakdown. At least 11 distinct conditions might be encountered when amalgam restorations are evaluated: (1) amalgam “blues,” (2) proximal overhangs, (3) marginal ditching, (4) voids, (5) fracture lines, (6) lines indicating the interface between abutted restorations, (7) improper anatomic contours, (8) marginal ridge incompatibility, (9) improper proximal contacts, (10) improper occlusal contacts, and (11) recurrent caries lesions.

Discolored areas or “amalgam blues” are often seen through the enamel in teeth that have amalgam restorations. This bluish hue results either from the leaching of amalgam corrosion products into the dentinal tubules or from the color of underlying amalgam seen through translucent enamel. The latter occurs when the enamel has little or no dentin support, such as in undermined cusps, marginal ridges, and regions adjacent to proximal margins. When other aspects of the restoration are sound, amalgam blues do not indicate caries, do not warrant classifying the restoration as defective, and require no further treatment. Replacement of the restoration may be considered, however, for elective improvement of esthetics or for areas under heavy functional stress that may require a cusp capping restoration to prevent possible tooth fracture.

Proximal overhangs are diagnosed visually, tactilely, and radiographically (Fig. 3-6). The amalgam–tooth junction is evaluated by moving the explorer back and forth across it. If the explorer stops at the junction and then moves outwardly onto the amalgam, an overhang is present. Overhangs also can be confirmed by the catching or tearing of dental floss. Such an overhang can provide an obstacle to good oral hygiene and result in inflammation of adjacent soft tissue. If it causes problems, an overhang should be corrected, and this often indicates the need for restoration replacement.

Marginal gap or ditching is the deterioration of the amalgam–tooth interface as a result of wear, fracture, or improper tooth preparation (Fig. 3-7, A). It can be diagnosed visually or by the explorer dropping into an opening as it crosses the margin. Shallow ditching less than 0.5 mm deep usually is not a reason for restoration replacement because such a restoration usually looks worse than it really is.²¹ The eventual self-sealing property of amalgam allows the restoration to continue serving adequately if it can be satisfactorily cleaned and maintained. If the ditch is too deep to be cleaned or jeopardizes the integrity of the remaining restoration or tooth structure, the restoration should be replaced.¹² In addition, secondary caries is frequently found around marginal gaps near the gingival wall and warrants replacement.²²

Voids that are usually localized and are caused by poor condensation of the amalgam can also occur at the margins



Fig. 3-6 Proximal overhang (a) can be diagnosed radiographically.

of amalgam restorations. If the void is at least 0.3 mm deep and is located in the gingival third of the tooth crown, the restoration is judged as defective and should be repaired or replaced. Accessible small voids in other marginal areas where the enamel is thicker may be corrected by recontouring or repairing with a small restoration.

A careful clinical examination detects any fracture line across the occlusal portion of an amalgam restoration. A line that occurs in the isthmus region generally indicates fractured amalgam, and the defective restoration that must be replaced (Fig. 3-8, A). Care must be taken to correctly evaluate any such line, however, especially if it is in the mid-occlusal area because this may be an interface line, a manifestation of two abutted restorations accomplished at separate appointments (see Fig. 3-8, B). If other aspects of the abutted restorations are satisfactory, replacement is unnecessary.

Amalgam restorations should duplicate the normal anatomic contours of teeth. Restorations that impinge on soft tissue, have inadequate embrasure form or proximal contact, or prevent the use of dental floss should be classified as defective, indicating recontouring or replacement (see Fig. 3-7, B).

The marginal ridge portion of the amalgam restoration should be compatible with the adjacent marginal ridge. Both ridges should be at approximately the same level and display correct occlusal embrasure form for passage of food to the facial and lingual surfaces and for proper proximal contact area. If the marginal ridges are incompatible and are associated with poor tissue health, food impaction, or the inability of the patient to floss, the restoration is defective and should be recontoured or replaced.

The proximal contact area of an amalgam restoration should touch the adjacent tooth (a “closed” contact) at the proper contact level and with correct embrasure form and possess the proper size. If the proximal contact of any restoration is suspected to be inadequate, it should be evaluated with dental floss or visually by trial angulations of a mouth mirror (held lingually when viewing from the facial aspect) to reflect light and see if a space at the contact (“open” contact) is present. For this viewing, the contact must be free of saliva. If the contact is open and is associated with poor interproximal tissue health, food impaction, or both, the restoration should be classified as defective and should be replaced or repaired. An open contact typically is annoying to the patients, so correcting the problem usually is an appreciated service.

Recurrent caries at the marginal area of the restoration is detected visually, tactilely, or radiographically and is an indication for repair or replacement (see Figs. 3-5, D, and 3-7, C). The same criteria for initial proximal and occlusal caries lesions apply for the diagnosis of and intervention for recurrent caries lesions around restorations.

Improper occlusal contacts on an amalgam restoration may cause deleterious occlusal loading, undesirable tooth movement, or both. Premature occlusal contacts can be seen as a “shiny” spot on the surface of the restoration or detected by occlusal marking paper. Such a condition warrants correction or replacement.

Clinical Examination of Indirect Restorations

Indirect restorations should be evaluated clinically in the same manner as amalgam restorations. If any aspect of the restoration is not satisfactory or is causing harm to tissue, it should



Fig. 3-7 Restorations can be diagnosed clinically as being defective by observing the following. **A**, Significant marginal ditching. **B**, Improper contour. **C**, Recurrent caries. **D**, Esthetically unappealing dark staining (*d*).

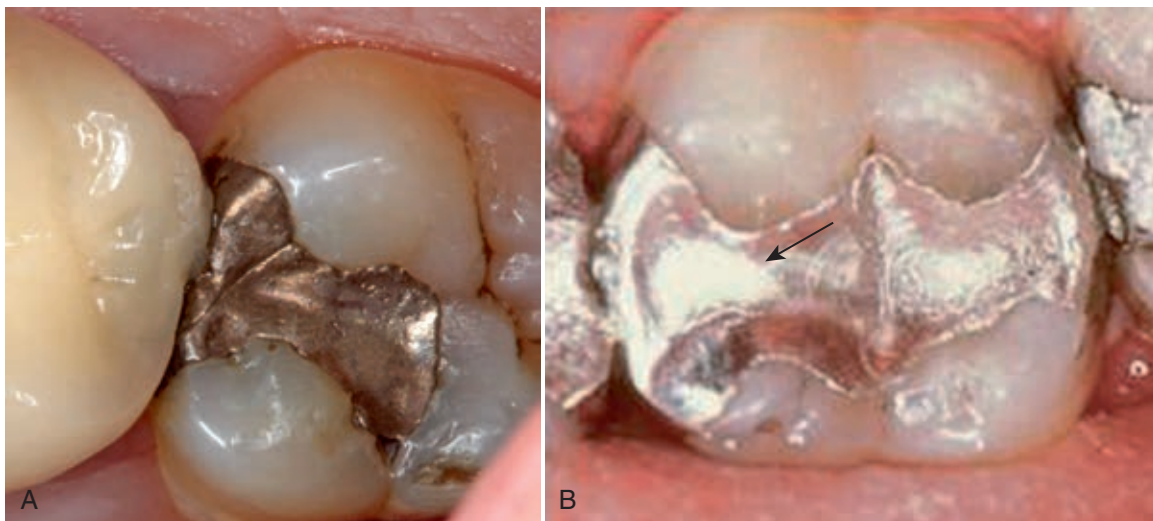


Fig. 3-8 Lines across the occlusal surface of an amalgam restoration. **A**, A fracture line indicates replacement. **B**, An interface line (arrow) indicates two restorations placed at separate appointments, which, by itself, is insufficient indication for replacement.

be classified as defective and considered for recontouring, repair, or replacement.

Clinical Examination of Composite and Other Tooth-Colored Restorations

Tooth-colored restorations should be evaluated clinically in the same manner as amalgam and cast-metal restorations. In the presence of an improper contour or proximal contact, an overhanging margin, recurrent caries, or other condition that impairs cleaning or harms the soft tissue, the restoration is considered defective. Corrective procedures include recontouring, polishing, repairing, or replacing.

One of the main concerns with anterior teeth is esthetics. If a tooth-colored restoration has dark marginal staining or is discolored to the extent that it is esthetically unappealing and the patient is unhappy with the appearance, the restoration should be judged defective (see Fig. 3-7, D). Marginal staining that is judged noncarious may be corrected by a small repair restoration along the margin. Occasionally, the staining is superficial and can be removed by resurfacing.

Clinical Examination of Dental Implants and Implant-Supported Restorations

Existing dental implants and implant restorations should be examined and evaluated on the basis of the same parameters for fit and seal as in the case of natural teeth. However, evaluation differences exist between implant restorations and restored natural teeth. Implant restorations in the molar area are generally one implant to replace a tooth with two or three large natural roots. This results in a large crown on a small root and may create issues for the restoration to re-establish a form with acceptable proximal contours. Often, pre-treatment vertical loss of bone support prior to implant placement makes it difficult to establish proper contours and vertical space and can create difficulties in managing the ratios for the vertical height of the crown to the length of the implant. When this happens, it can result in the same problems of long-term stability that poor crown–root ratios in natural teeth present. Therefore, it is important to evaluate implant restorations not only for fit and seal but also for contours that allow food to pack or plaque to easily build up in inaccessible areas. All of this increases risk for problems with the implant, the implant restoration, and with adjacent teeth.

Peri-implantitis is a concern that can affect implant survival along with survival of the implant restoration. Peri-implantitis is a multifactorial problem, and when this occurs, successful treatment can result in a guarded prognosis for the survival of the dental implant. Occlusion for implant restorations must be managed very carefully because dental implants lack the cushioning effect of natural teeth with periodontal ligaments. Restorations must be examined for careful placement of contacts in a single central area and to limit any deflective loading contacts or occlusal interferences.

Clinical Examination for Additional Defects

A thorough clinical examination occasionally discloses localized intact, hard white areas on the facial (Fig. 3-9) or lingual surfaces or on the cusp tips of teeth. Generally, these are hypocalcified areas of enamel resulting from childhood fever,



Fig. 3-9 Non-hereditary hypocalcified areas on facial surfaces. These areas may result from numerous factors but do not warrant restorative intervention unless they are esthetically offensive or cavitation is present.

trauma, or fluorosis that occurred during the developmental stages of tooth formation. Another cause of hypocalcification is arrested and remineralized incipient caries, which leaves an opaque, discolored, and hard surface. When smooth and cleanable, such areas do not warrant restorative intervention unless they are esthetically offensive to the patient. These areas remain visible whether the tooth is wet or dry. The smooth-surface incipient caries lesion also is opaque white when dried. Care must be exercised in distinguishing early enamel lesion from non-hereditary developmental enamel hypocalcification.

Chemical erosion is the loss of surface tooth structure by chemical action in the continued presence of demineralizing agents with low pH (Fig. 3-10). The resulting defective surface is usually smooth. Although these agents are predominant causative factors, it is thought that toothbrushing may be a contributing factor. It is necessary to document the severity of the erosion and the areas of teeth that are affected by the erosion. The areas of teeth affected can be important in helping the clinician determine the possible source of the chemical actions contributing to the erosive process. If the defect is only on the lingual of upper teeth, the diagnosis would be different from finding erosion on the occlusal surfaces of lower molars. Exogenous acidic agents such as lemon juice (through sucking on lemons) may cause crescent-shaped or dished defects (rounded as opposed to angular) on the surfaces of exposed teeth (see Fig. 3-10, A), whereas endogenous acidic agents such as gastric fluids cause generalized erosion on the lingual, incisal, and occlusal surfaces (see Fig. 3-10, B). The latter defective surfaces are associated with the binge–purge syndrome in bulimia, or with gastroesophageal reflux disease (GERD). Many patients with GERD are often not aware of their gastric symptoms or do not associate them with the problems with their teeth. Consultation with a physician to obtain a proper diagnosis of GERD can assist in the diagnosis and management of erosion. The flow and buffering capacity of saliva are factors in chemical erosion when other factors are present. Other sources of erosion can be use of sports drinks, herbal teas, and vomiting associated with chemotherapy, and, in the case of alcoholism, the presence of stomach contents in the mouth during periods of excessive alcohol consumption. It is necessary to document the erosion process as it occurs over a progressive period. It is possible to use accurate study models and photography to document



Fig. 3-10 Erosion. **A**, Crescent-shaped defects on enamel facial surfaces caused by exogenous demineralizing agent (from sucking on lemons several years previous to the time of the photograph). **B**, Generalized erosion caused by endogenous fluids. **C**, Idiopathic erosion lesion at the dentinoenamel junction is hypothesized to be associated with abnormal occlusal force. **D**, Wedge-shaped lesions caused by abrasion from toothbrush. **E**, Generalized attrition caused by excessive functional or parafunctional mandibular movements.

increasing erosion. Risk assessments for erosion would be included in the assessment of the patient, as indicated.

In contrast to chemical erosion, abfraction lesions are cervical, wedge-shaped defects (angular as opposed to rounded) similar to the defects customarily associated with toothbrush abrasion (discussed next) but in which one of the possible causative factors is heavy force in eccentric occlusion, resulting in flexure of the tooth and frequently associated with a wear facet (see Fig. 3-10, C). It is hypothesized further that the flexural force produces tension stress in the affected wedge-shaped region on the tooth side away from the tooth-bending direction, resulting in loss of the surface tooth structure by microfractures, which is termed *abfraction*.²³ Proponents of this hypothesis add that the microfractures can foster loss of tooth structure from toothbrush abrasion and from acids in the diet, plaque, or both. The resulting defect has smooth surfaces.

Abrasion is abnormal tooth surface loss resulting from direct frictional forces between teeth and external objects or

from frictional forces between contacting teeth in the presence of an abrasive medium. Such wear is caused by improper brushing techniques or habits such as holding a pipe stem between teeth, tobacco chewing, and chewing on hard objects such as pens or pencils. Toothbrush abrasion is the most common example and is usually seen as a sharp wedge-shaped notch in the gingival portion of the facial aspects of teeth (see Fig. 3-10, D). The surface of the defect is smooth. The presence of such defects does not automatically warrant intervention. It is important to determine and eliminate the cause.

Attrition is mechanical wear of the incisal or occlusal tooth structure as a result of functional or parafunctional movements of the mandible. Although a certain degree of attrition is expected with age, it is important to note abnormally advanced attrition (see Fig. 3-10, E). If significant abnormal attrition is present, the patient's functional movements should be evaluated, and inquiry needs to be made about any habits creating this problem, such as tooth grinding, or *bruxism*, usually resulting from stress, airway issues, or sleep apnea. In

some older patients, the enamel of the cusp tips (or incisal edges) is worn off, resulting in cupped-out areas because the exposed, softer dentin wears faster than the surrounding enamel. Sometimes, these areas are an annoyance because of food retention or the presence of peripheral, ragged, sharp enamel edges. Slowing such wear by appropriate restorative treatment is indicated. The sharp edges can result in tongue or cheek biting; rounding these edges does not completely resolve the problem but does improve comfort.

Complete cusp fracture is a common occurrence in posterior teeth. In general, the most frequently fractured cusps are the nonholding cusps. Specifically, the most frequently fractured teeth are mandibular molars and second premolars, with the lingual cusps fracturing more often than the facial cusps. Maxillary premolars also frequently fractured, but in contrast to mandibular teeth, the facial cusps fracture more often than the lingual cusps. The mesiofacial and distolingual cusps are the most commonly fractured cusps in maxillary molars.

A study of fracture severity found that 95% of the fractures exposed dentin, 25% were below the CEJ, and 3% resulted in pulp exposure. The consequences of posterior tooth fracture were found to vary, with maxillary premolar and mandibular molar fractures being generally more severe. Most fractures were treated with direct or indirect restorations or recontouring and polishing; 3% were extracted, and 4% received endodontic treatment.²⁴ Risk factors for nontraumatic fracture of posterior teeth were found to be the presence of a fracture line in enamel and an increase in the proportion of the volume of the natural tooth crown occupied by a restoration.^{25,26}

Fracture or “craze lines” in a tooth are often visible, especially with advancing age, and should be considered potential cleavage planes for possible future fractures. Appropriate dye materials or transillumination aid in detecting fracture lines. Any tooth that has an extensive restoration and weakened cusps should be identified as being susceptible to future fracture (Fig. 3-11) and should be considered for a cusp-protecting restoration. Deep developmental fissures across marginal or cusp ridges are cleavage planes, especially in a tooth weakened by caries or previous restoration. The dental examination also may reveal dental anomalies that include variations in size, shape, structure, or number of teeth—such as dens in dente, macrodontia, microdontia, gemination, concrescence, dilaceration, amelogenesis imperfecta, and dentinogenesis imperfecta. An in-depth discussion of these anomalies is beyond the scope of this text. The reader should consult an oral pathology textbook for additional information.

Radiographic Examination of Teeth and Restorations

Radiographs are an indispensable part of the contemporary dentist’s diagnostic armamentarium. The use of diagnostic ionizing radiation is, however, not without risks. Cumulative exposure to ionizing radiation potentially can result in adverse effects. The diagnostic yield or potential benefit that could be gained from a radiograph must be weighed against the financial costs and the potential adverse effects of exposure to radiation. Several technologies, particularly digital radiography, are now available and are designed to enhance diagnostic yield and reduce radiation exposure.



Fig. 3-11 Extensively restored teeth with weakened and fractured cusps. Note the distal developmental fissure in the second molar, which further predisposes the distal cusps to fracture.

The American Dental Association (ADA), in collaboration with the FDA, developed guidelines for the prescription of dental radiographic examinations to serve as an adjunct to the dentist’s professional judgment with regard to the best use of diagnostic imaging. Radiographs help the dental practitioner evaluate and definitively diagnose many oral diseases and conditions. However, the dentist must weigh the benefits of taking dental radiographs against the risk of exposing a patient to radiographs, the effects of which accumulate from multiple sources over time. The dentist, being aware of the patient’s health history and vulnerability to oral disease, is in the best position to make this judgment. For this reason, the guidelines are intended to serve as a resource for the practitioner and are not intended to be standards of care nor requirements or regulations. The ADA/FDA guidelines help direct the type and frequency of radiographs needed according to patient condition and risk factors (Table 3-1).²⁷

Generally, patients at higher risk for caries or periodontal disease should receive more frequent and more extensive radiographic surveys. A systematic review of methods of diagnosing dental caries lesions found that although radiographs were useful in detecting lesions, they do have limitations.²⁸ For the examination of occlusal surfaces, radiographs had moderate sensitivity and good specificity for diagnosing dentinal lesions; however, for enamel lesions, the sensitivity was poor, and the specificity was reduced. Studies of the radiographic examination of proximal surfaces found that there was moderate sensitivity and good specificity for the detection of cavitated lesions and low to moderate sensitivity and moderate to high specificity for enamel or dentinal lesions. Before rendering a diagnosis and deciding on treatment, information obtained from radiographs should be confirmed or augmented with other examination findings. In addition, the consequences of false positives, which may prompt unneeded treatment, and false negatives, which may leave disease undetected, as well as an understanding of the typically slow

Table 3-1 Guidelines for Prescribing Dental Radiographs

The recommendations in this chart are subject to clinical judgment and may not apply to every patient. They are to be used by dentists only after reviewing the patient's health history and completing a clinical examination. Because every precaution should be taken to minimize radiation exposure, protective thyroid collars and aprons should be used, whenever possible. This practice is strongly recommended for children, women of childbearing age, and pregnant women.

Type of Encounter	Patient Age and Dental Developmental Stage			
	Child with Primary Dentition (Prior to Eruption of First Permanent Tooth)	Child with Transitional Dentition (After Eruption of First Permanent Tooth)	Adolescent with Permanent Dentition (Prior to Eruption of Third Molars)	Adult, Dentate or Partially Edentulous
New patient* being evaluated for dental diseases and dental development	Individualized radiographic exam consisting of selected periapical/occlusal views and/or posterior bitewings if proximal surfaces cannot be visualized or probed. Patients without evidence of disease and with open proximal contacts may not require a radiographic exam at this time.	Individualized radiographic exam consisting of posterior bitewings with panoramic exam or posterior bitewings and selected periapical images.	Individualized radiographic exam consisting of posterior bitewings with panoramic exam or posterior A full mouth intraoral radiographic exam is preferred when the patient has clinical evidence of generalized dental disease or a history of extensive dental treatment.	Individualized radiographic exam, based on clinical signs and symptoms.
Recall patient* with clinical caries or at increased risk for caries**	Posterior bitewing exam at 6–12 month intervals if proximal surfaces cannot be examined visually or with a probe.			Posterior bitewing exam at 6–18 month intervals
Recall patient* with no clinical caries and not at increased risk for caries**	Posterior bitewing exam at 12–24 month intervals if proximal surfaces cannot be examined visually or with a probe		Posterior bitewing exam at 18–36 month intervals	Posterior bitewing exam at 24–36 month intervals
Recall patient* with periodontal disease	Clinical judgment as to the need for and type of radiographic images may consist of, but is not limited to, selected bitewing and/or periapical images for the evaluation of periodontal disease. Imaging (other than nonspecific gingivitis) can be identified clinically.			Not applicable
Patient for monitoring of growth and development	Clinical judgment as to need for and type of radiographic images for evaluation and/or monitoring of dento-facial growth and development		Clinical judgment as to need for and type of radiographic images for evaluation and/or monitoring of dento-facial growth and development. Panoramic or periapical exam to assess developing third molars	Usually not indicated

Patient with other Clinical judgment as to need for and type of radiographic images for evaluation and/or monitoring in these circumstances.

circumstances including, but not limited to, proposed or existing implants, pathology, restorative/endodontic needs, treated periodontal disease and caries remineralization

(From American Dental Association, US Food and Drug Administration. The Selection of Patients for Dental Radiograph Examinations. Available on www.ada.org. Document created November 2004.)

*Clinical situations for which radiographs may be indicated include but are not limited to:

**Factors increasing risk for caries may include but are not limited to:

- A. Positive Historical Findings
 1. Previous periodontal or endodontic treatment
 2. History of pain or trauma
 3. Familial history of dental anomalies
 4. Postoperative evaluation of healing
 5. Remineralization monitoring
 6. Presence of implants or evaluation for implant placement
 - B. Positive Clinical Signs/Symptoms
 1. Clinical evidence of periodontal disease
 2. Large or deep restorations
 3. Deep carious lesions
 4. Malposed or clinically impacted teeth
 5. Swelling
 6. Evidence of dental/facial trauma
 7. Mobility of teeth
 8. Sinus tract ("fistula")
 9. Clinically suspected sinus pathology
 10. Growth abnormalities
 11. Oral involvement in known or suspected systemic disease
 12. Positive neurologic findings in the head and neck
 13. Evidence of foreign objects
 14. Pain and/or dysfunction of the temporomandibular joint
 15. Facial asymmetry
 16. Abutment teeth for fixed or removable partial prosthesis
 17. Unexplained bleeding
 18. Unexplained sensitivity of teeth
 19. Unusual eruption, spacing, or migration of teeth
 20. Unusual tooth morphology, calcification, or color
 21. Unexplained absence of teeth
 22. Clinical erosion
1. High level of caries experience or demineralization
 2. History of recurrent caries
 3. High titers of cariogenic bacteria
 4. Existing restoration(s) of poor quality
 5. Poor oral hygiene
 6. Inadequate fluoride exposure
 7. Prolonged nursing (bottle or breast)
 8. Frequent high sucrose content in diet
 9. Poor family dental health
 10. Developmental or acquired enamel defects
 11. Developmental or acquired disability
 12. Xerostomia
 13. Genetic abnormality of teeth
 14. Many multi-surface restorations
 15. Chemotherapy/radiation therapy
 16. Eating disorders
 17. Drug/alcohol abuse
 18. Irregular dental care

progressing nature of caries lesions should factor into the diagnosis and management strategy.

For diagnosis of proximal surface caries, restoration overhangs, or poorly contoured restorations, posterior bitewing and anterior periapical radiographs are most helpful. When interpreting the radiographic presentation of proximal tooth surfaces, it is necessary to know the normal anatomic picture presented in a radiograph before any abnormalities can be diagnosed. In a radiograph, a proximal caries lesion usually appears as a dark area or a radiolucency in the enamel at or apical to the contact (see Fig. 3-5, A). This radiolucency is typically triangular and has its apex toward the dentinoenamel junction (DEJ).

Moderate-to-deep occlusal caries lesions may be seen as a radiolucency extending into dentin (see Fig. 3-5, C). Because the specificity of radiographs for detecting dentinal lesions on occlusal surfaces is relatively good at 80% (very few false positives), when a radiolucency is apparent beneath the occlusal enamel surface emanating from the DEJ a diagnosis of caries is appropriate. However, because the sensitivity of radiographs for dentinal lesions on the occlusal surface is rather low (50%), the absence of a radiolucency does not mean that a lesion is not present. In these situations, the clinician should rely more on the results of the visual–tactile examination and the findings of any adjunctive tests (discussed later).

Some defective aspects of restorations, including improper contour, overhangs (see Fig. 3-6), and recurrent caries lesions gingival to restorations (see Fig. 3-5, D), may also be identified radiographically. Pulpal abnormalities such as pulp stones and internal resorption may be identified in anterior periapical radiographs. The height and integrity of the marginal periodontium may be evaluated from bitewing radiographs. Periapical radiographs are helpful in diagnosing changes in the periapical periodontium such as periapical abscesses, dental granulomas, or cysts. Impacted third molars, supernumerary teeth, and other congenital or acquired abnormalities also may be discovered on periapical radiographic examination. The sensitivity and specificity of dental radiographs vary, however, according to the diagnostic task (e.g., surface of the tooth being examined, proximal versus occlusal, and depth, enamel vs. dentin).

Dental radiographs should always be interpreted cautiously. One limitation imposed when interpreting a dental radiograph is that the image is a two-dimensional representation of a three-dimensional mass. In addition, the interpretation of dental radiographs can produce a certain number of false-positive and false-negative diagnoses. Misdiagnosis can occur when cervical burnout (the radiographic picture of the normal structure and contour of the cervical third of the crown) mimics a caries lesion. A Class V lesion or a radiolucent tooth-colored restoration may be radiographically superimposed on the proximal area, mimicking a proximal caries lesion. Finally, although a caries lesion may be more extensive clinically than it appears radiographically, it is estimated that over half of the teeth with what appear to be radiographic proximal caries lesions in the outer half of dentin are likely to be non-cavitated and treatable with remineralization measures.²⁹ Although radiographs are an excellent diagnostic tool, they do have certain limitations. To guard against these limitations, clinical and radiographic findings should be correlated continually and the implications of their limitations should be understood when formulating a diagnosis and deciding on treatment.

Adjunctive Aids for Examining Teeth and Restorations

Study casts are helpful in evaluating a patient's clinical status in many situations. Study casts can be useful, as they provide an understanding of occlusal relationships, help in developing the treatment plan, and serve as a tool for educating the patient. Accurately mounted study casts provide an opportunity for a thorough evaluation of the tooth interdigitation, the functional occlusion, and any occlusal abnormalities that may need treatment. Study casts allow further evaluation of the plane of occlusion; tilted, rotated, or extruded teeth; cross-bites; plunger cusps; wear facets and defective restorations; coronal contours; proximal contacts; and embrasure spaces between teeth. Combined with clinical and radiographic findings, study casts allow the practitioner to develop a treatment plan without the patient present, thus saving valuable chair time. When a proposed treatment plan is discussed with the patient, study casts can be a valuable educational medium in helping the patient understand and visualize existing conditions and the need for the proposed treatment.

Radiographs aid in determining the relationship between the margins of existing or proposed restorations and bone. A biologic width of at least 2 mm is required for the junctional epithelium and the connective tissue attachments located between the base of the sulcus and the alveolar bone crest (Fig. 3-12, A). In addition to this physiologic dimension, the restoration margin should be placed occlusally as far away as possible from the base of the sulcus to foster gingival health. Encroachment on this biologic width may cause an inflammatory response in gingival tissue, causing redness, swelling, and bleeding on probing or flossing in the area of the violation of biologic width. It is possible that breakdown and apical migration of the attachment apparatus can also occur. The attachment breakdown and apical migration are in response to the inflammatory process caused by bacterial plaque that accumulates at the inaccessible restoration margins. The final position of a proposed gingival margin, which is dictated by the existing restoration, caries, or retention features, must be estimated to determine if crown-lengthening procedures are indicated before restoration (see Fig. 3-12, B). Another possible correction for biologic width violations is to orthodontically extrude the tooth to make room for the distance between the restoration margin and bone. Surgical crown lengthening procedures involve the surgical removal of the gingiva, bone, or both to create a longer clinical crown and provide more tooth structure for placing the restoration margin and for increasing retention form. Because of the obvious importance of the periodontium, operative procedures must be performed continually with respect, understanding, and concern for the periodontium.

Examination of Occlusion

Several reasons exist for completing a thorough occlusal examination, such as developing an analysis and understanding of the patient's occlusion before initiating restorative care. First, the clinician can establish the patient's presenting condition before any alterations are attempted. This documentation includes the identification of signs of occlusal trauma such as enamel cracks or tooth mobility and notation of occlusal abnormalities that contribute to pathologic conditions such

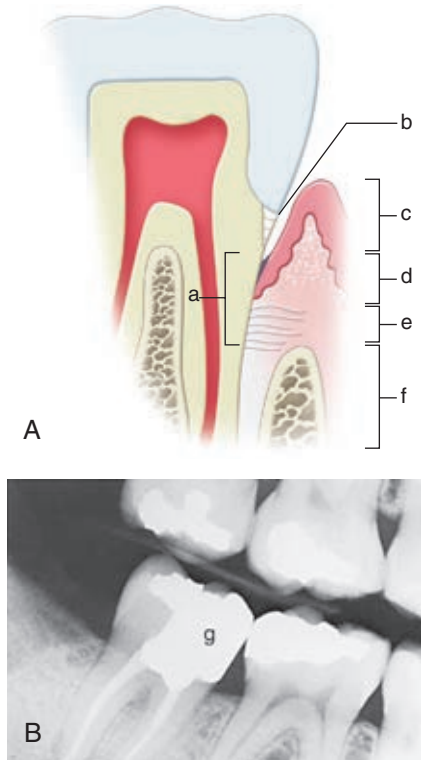


Fig. 3-12 **A**, Biologic width (a) is the physiologic dimension needed for the junctional epithelium (d) and the connective tissue attachment (e), which is measured from the base of the sulcus (c) to the level of the bone crest (f). The margin of the restoration (b) must not violate this dimension. **B**, Tooth with an existing restoration (g) that encroaches on the biologic width requires crown-lengthening procedures before placement of a new restoration.

as bone loss. Second, the potential effect of the proposed restorative treatment on the occlusion can be assessed. The potential of the proposed restoration to provide a beneficial and harmonious occlusion must be determined. Third, the effect of the current occlusal scheme on the proposed restorative treatment can be identified, and the existing occlusion can be altered, if needed, before placement of restorations.

The static and dynamic occlusion must be examined carefully (see Chapter 1). Not all occlusal variances from normal require treatment, mostly because the patient's ability to adapt to the abnormalities without pathologic symptoms. However, the clinician must be able to identify deviations from normal and be prepared to treat, refer, or make allowances for these problems in any planned therapy. A description of the patient's static anatomic occlusion in maximum intercuspation, including the relationship between molars and canines (Angle's Classes I, II, or III), and the amount of vertical overlap (overbite) and horizontal overlap (overjet) of anterior teeth should be recorded. The presence of missing teeth and the relationship of the maxillary and mandibular midlines should be determined. The appropriateness of the occlusal plane and the positions of malposed teeth should be identified. Supererupted teeth, spacing, fractured teeth, and marginal ridge discrepancies should be noted. The dynamic functional occlusion in all movements of the mandible (right, left, forward, and all excursions in between) should be evaluated. This evaluation also includes assessing the relationship of teeth in

centric relation, which is the orthopedic position of the joint where the condyle head is in its most anterior and superior position against the articular eminence within the glenoid fossa. Functional movements of the mandible are evaluated to determine if canine guidance or group function exists. The presence and amount of anterior guidance is evaluated to note the degree of potential posterior disclusion. Nonworking-side contacts are recorded so that any planned restorative care for the involved teeth would not perpetuate these contacts. Any mobility of teeth or fremitus during function is identified and classified as primary or secondary occlusal traumatism. Movement of the mandible from maximum intercuspation to maximum opening is observed; any clicking or popping of the joint during such movement could be a nonsymptomatic variation from normal or be an indication of a possible pathologic condition. A load test for the joint and palpation of the joint would be completed to further test for joint tenderness to determine joint pathology that is symptomatic.

Teeth are examined for abnormal wear patterns that are excessive and not age appropriate. If signs of abnormal or premature wear are present, the patient is queried as to the presence of any contributing habits such as nocturnal bruxism or parafunctional habits. The examination also should disclose possible unfavorable occlusal relationships such as a plunger cusp, which is a pointed cusp "plunging" deep into the occlusal plane of the opposing arch. A plunger cusp might contact the lower of two adjacent marginal ridges of different levels, contacting directly between two adjacent marginal ridges in maximum intercuspation, or positioned in a deep fossa. These may result in food impaction and tooth or restoration fracture.

The results of the occlusal analysis should be included in the dental record and considered in the restorative treatment plan. Acceptable aspects of the occlusion must be preserved and not altered during treatment. When possible, improvement of the occlusal relationship is desirable; abnormalities must not be perpetuated in the restorative treatment.

Examination for Esthetic Considerations

Examination of esthetic considerations can be described as the evaluation of tooth color, tooth display, and ideal tooth position in relation to the face. An important part of the evaluation is a discussion of what would be realistic esthetic expectations when discussing treatment options with the patient. Esthetic predisposing conditions for a patient are defined as the clinical conditions presented by the patient that might adversely affect the clinician's ability to meet the patient's esthetic expectations and vision. Attaining the desired esthetic outcomes may be complicated by maximum tooth display and excessive or uneven tissue display. Risk can be lowered primarily by establishing ideal intrafacial tooth position and secondarily, by establishing intra-arch tooth position. Tooth color evaluation becomes a factor as teeth are more visible when smiling or at the resting position of lips. Darker colored teeth, teeth with enamel intrinsic staining, and conditions such as tetracycline staining all increase the risk for not satisfying the esthetic expectations of patients with tooth color concerns. Gingival symmetry also becomes very important in maximum display situations, and lack of symmetry increases the risk of not meeting the patient's esthetic expectations. Presence of multiple risk factors would require more

aggressive treatment options to meet the patient's overall esthetic expectations. These treatment options may not be appropriate if they satisfy a patient's esthetic expectations but negatively affect the long-term health of teeth. In many of these situations, conservative direct or indirect enamel-supported restorations are more appropriate for long-term risk management than are more aggressive preparations that remove more tooth structure.

Risk Profiles

After the examination and data collection are completed, the next step is to assess the risk or likelihood of future problems, given the patient's current behaviors, clinical conditions, and so on. In relation to operative dentistry, risk assessments are made for caries and structural problems of teeth such as fractures and erosion. However, in addition to caries risk assessments, risk assessment profiles should be established in other areas of patient care, such as tooth structural concerns, periodontal disease, functional occlusal and temporomandibular joint (TMJ) issues, and for the "risk" involved in satisfying the patient's esthetic expectations. Taken together, these assessments provide a risk profile that helps guide the preventive and operative recommendations that are made to the patient with the goal of mitigating as many risk factors as possible.

The CAMBRA guidelines were developed over several years as an evidence-based approach to preventing, reversing, and, when necessary, repairing early damage to teeth caused by caries. Refer to [Chapter 2](#) for more information on how CAMBRA is used to determine caries risk and how this determination helps the clinician in the decision-making process for surgical or nonsurgical therapeutic interventions.

Risk assessments help organize the data on multiple causative factors. Few diseases or dental conditions are caused by a single factor. Rather, most diseases and dental conditions have been shown to be associated with numerous behavioral or sociodemographic, physical or environmental, microbiologic, or host factors. In addition, every patient has a different set of risk factors. This presents a challenge to determining the likelihood that a disease or condition would occur in the future or that some form of dental treatment or therapeutics would decrease the chances of disease occurrence. Many risk assessments use terms such as *low risk*, *medium risk*, and *high risk* to associate a level of risk to a category. This is sometimes expressed by using colors: red for high risk, yellow for medium risk, and green for low risk. This helps simplify the concept for the patient, as this is easily understood while discussing assessments and their implications for treatment recommendations. All treatment for patients should be designed to lower their risks for problems in each of these areas. The clinician must understand the concepts of risk management thoroughly. Dental treatment in any one of the above areas may improve risk status in that area but at a cost of increased risk in another area. For example, preparation of teeth for full-coverage crowns might reduce occlusal or esthetic risk but at a cost of increasing risk for future caries or tooth fracture.

Risk assessments are highly useful in managing patients who are candidates for operative dentistry. Patients who possess risk factors and risk indicators should be considered to be at risk for dental caries.^{6,30} The assessments are used to guide treatment. A patient at high risk for dental caries should receive aggressive intervention to remove or alter as many risk

factors as possible. Alternatively, regular monitoring and reassessment of the condition might be appropriate for a patient at low risk for dental caries. Risk assessment is a relatively young science in the dental profession, but as more research is completed, evidence is quickly validating this approach to patient care. Approaches to patient care using risk assessments and disease management such as CAMBRA are becoming the recognized standard of care.

Prognosis

Prognosis is the term used to describe the prediction of the probable course and outcome of a disease or condition as well as the outcome expected from an intervention, be it preventive or operative. Prognosis can also be used to estimate the likelihood of recovery from a disease or condition. In operative dentistry, prognosis can be used to describe the likelihood of success of a particular treatment procedure in terms of time of service, functional value to the patient, comfort for the patient, and esthetic value for the patient. A prognosis can be described as *excellent*, *good*, *fair*, *poor*, or even *hopeless*. Prognosis for a disease or condition is largely dependent on the risk factors and disease indicators that are present in the patient. However, other factors such as the skill of the dentist and the current status of the disease before beginning treatment also have an effect on the prognosis. For example, a patient with severe caries may be willing to eliminate all of the modifiable risk factors, but if the disease is too advanced, the long-term prognosis for the affected teeth may still be poor. Therefore, it is important for the clinician to take in account the entire risk profile of the patient in all areas of the person's medical and dental health when trying to establish a prognosis. It is also important to consider the skill level of the treating dentist and the current state of the disease or conditions before evaluating possible treatment options. Once the dentist and the patient have a good understanding of the patient's risk profile and the present disease state and conditions, they can work as a team to decide the best treatment options and alternatives to fit the patient's needs.

Treatment Planning

General Considerations

A treatment plan is a carefully sequenced series of services designed to eliminate or control etiologic factors, repair existing damage, and create a functional, maintainable environment. An appropriate treatment plan depends on thorough evaluation of the patient, the expertise of the dentist, and a prediction of the patient's response to treatment. An accurate prognosis for each tooth and for the patient's overall oral health is central to a successful treatment plan.

The development of a dental treatment plan for a patient often consists of four steps: (1) examination, problem identification, and risk assessment; (2) decision to recommend intervention; (3) identification of treatment alternatives; and (4) selection of treatment with the patient's involvement. Step one, examination, diagnosis, and risk assessment, which was discussed in detail in the first part of this chapter, results in the listing of the patient's dental problems. For step two, the decision to intervene surgically or non-surgically depends on the determination that a tooth is diseased, a restoration is

defective, or the tooth or restoration is at some increased risk of further deterioration if the intervention does not occur. If any of these conditions exists, intervention is recommended to the patient. Step three, identification of treatment alternatives, involves establishing a list of one or more reasonable interventions from the set of possible alternatives. Treatment alternatives for a specific condition may include, for example, periodic re-evaluation to monitor the condition, chemotherapeutics (e.g., applications of fluoride to promote remineralization or antimicrobials to reduce bacteria), recontouring defective restorations or irregular tooth surfaces, repair of an existing restoration, and restoration. This list of reasonable treatment alternatives is based on current evidence of the effectiveness of treatments, the prevailing standards of care, and clinical and nonclinical patient factors. Step four, selection of the treatment, is conducted in consultation with the patient. The patient is advised of the reasonable treatment alternatives and their related risks and benefits. After the patient is fully informed, the dentist and patient can select a course of action that is most appropriate.

Treatment plans are influenced by many factors, including patient preferences, motivation, systemic health, emotional status, and financial resources. The treatment plan is influenced by the dentist's knowledge, experience, and training; laboratory support; dentist–patient compatibility; availability of specialists; and the patient's functional, esthetic, and technical demands. Finally, a treatment plan is not a static list of services. Rather, it is often a multi-phase and dynamic series of activities. The success of the treatment plan is determined by its ability to meet the patient's initial and long-term needs. A treatment plan should allow for re-evaluation and be adaptable to meet the changing needs, preferences, and health conditions of the patient.

Treatment Plan Sequencing

Proper sequencing is a crucial component of a successful treatment plan. Certain treatments must follow others in a logical order, whereas other treatments can or must occur concurrently and require coordination. Complex treatment plans often are sequenced in phases, including an urgent phase, a control phase, a re-evaluation phase, a definitive phase, and a recare or re-assessment phase.³¹ For most patients, the first three phases are accomplished as a single phase. Generally, the principle of “greatest need” guides the order in which treatment is sequenced. This principle suggests that what the patient needs most is performed first—with pain, bleeding, and swelling at one end of the continuum to elective esthetic procedures on the other.

Urgent Phase

The urgent phase of care begins with a thorough review of the patient's medical condition and history. A patient presenting with swelling, pain, bleeding, or infection should have these problems managed as soon as possible, before initiation of subsequent phases.

Control Phase

Most patients will not need a formal control phase. A control phase is appropriate when the patient presents with multiple

pressing problems and extensive active disease or when the prognosis is unclear. The goals of this phase are to remove etiologic factors and stabilize the patient's dental health. These goals are accomplished by (1) eliminating active disease such as caries and inflammation, (2) removing conditions preventing maintenance, (3) eliminating potential causes of disease, and (4) beginning preventive activities. Examples of control phase treatment include extractions; endodontics; periodontal debridement and scaling; occlusal adjustment; caries removal; replacement or repair of defective restorations such as those with gingival overhangs; and use of caries control measures, as discussed in Chapter 2.

As part of the control phase, the dentist should develop a plan for the management and prevention of dental caries. After the patient's caries status and caries risk have been determined, chemical, surgical, behavioral, mechanical, and dietary techniques can be used to improve host resistance and alter the oral flora.^{30,32} Chapter 2 presents a detailed discussion of caries diagnosis, prevention, treatment, and control.

Re-evaluation Phase

This phase allows time between the control and definitive phases for resolution of inflammation and healing. Home care habits are reinforced, motivation for further treatment is assessed, and initial treatment and pulpal responses are re-evaluated before definitive care is begun.

Definitive Phase

After the dentist reassesses initial treatment and determines the need for further care, the patient enters the corrective or definitive phase of treatment. This phase may include endodontic, periodontal, orthodontic, and surgical procedures before fixed or removable prosthodontic treatment. This phase is discussed in detail in the section on interdisciplinary considerations in operative treatment planning.

Recare and Re-assessment Phase

The re-assessment phase includes regular re-evaluation examinations that (1) may reveal the need for adjustments to prevent future breakdown and (2) provide an opportunity to reinforce home care. The frequency of re-evaluation examinations during the maintenance phase depends, in large part, on the patient's risk for dental disease. A patient who has stable periodontal health, has a recent history of no caries lesions, and is at low risk, may have longer intervals (e.g., 9–12 months) between recall visits. In contrast, patients at high risk for dental caries or periodontal problems should be examined much more frequently (e.g., 3–4 months).

Interdisciplinary Considerations in Operative Treatment Planning

When an operative procedure is performed during the control or definitive phases, general guidelines help determine when the operative treatment should occur relative to other forms of care. Following is a discussion on sequencing operative care with endodontic, periodontal, orthodontic, surgical, and prosthodontic treatments.

Endodontics

All teeth to be restored with large restorations should have a pulpal or periapical evaluation. If indicated, teeth should have endodontic treatment before restoration is completed. Also, a tooth previously endodontically treated that shows no evidence of healing or has an inadequate filling or a filling exposed to oral fluids should be evaluated for re-treatment before restorative therapy is initiated.³³

Periodontics

Generally, periodontal treatment should precede operative care, especially when improved oral hygiene, initial scaling, and root planing procedures can create a more desirable environment for performing operative treatment. A tooth with a questionable periodontal prognosis should not receive an extensive restoration until periodontal treatment provides a more favorable prognosis. If a tooth has a good periodontal prognosis, however, operative treatment can occur before or after periodontal therapy, as long as the operative treatment is not compromised by the existing tissue condition. Treatment of deep carious lesions often requires caries control, foundations, or temporization or root canal therapy or both before periodontal therapy. The correction of gross restorative defects in restoration contours (e.g., open contacts, gingival overhangs, and poor embrasure form) is considered a part of initial periodontal therapy, and such corrections enhance a favorable tissue response. If periodontal surgical procedures are required, permanent restorations such as inlays or onlays, crowns, and prostheses should be delayed until the surgical phase is completed. Teeth planned for cast restorations can, however, be prepared and temporized before periodontal surgery. This approach permits confirmation of the restoration prognosis before surgery and allows improved access for the surgical procedure.

Patients with gingivitis and early periodontitis generally respond favorably to improved oral hygiene and scaling or root planing procedures. Patients with more advanced periodontitis might require surgical pocket elimination or reduction procedures or various regenerative procedures. If indicated, an increase in the zones of attached gingiva and the elimination of abnormal frenal tension should be achieved by corrective periodontal surgical procedures around teeth receiving restorations with subgingival margins. In addition, any teeth requiring restorations that may encroach on the biologic width of the periodontium should have appropriate crown-lengthening surgical procedures performed before the final restoration is placed. Usually, a minimum of 6 weeks is required after the surgery before final restorative procedures are undertaken.

Orthodontics

Orthodontic therapy may include extrusion or realignment of teeth to provide favorable interdental spacing, stress distribution, function, and esthetics. All teeth should be caries-free before orthodontic banding. Treatment of caries may include the placement of amalgam and composite restorations. Few indications exist for cast restorations before orthodontic treatment is completed. In addition, patients undergoing

orthodontic treatment should receive more intense caries prevention measures.

Oral Surgery

In most instances, impacted, unerupted, and hopelessly involved teeth should be removed before operative treatment. This recommendation especially applies when second molars that are to be restored might be damaged or dislodged during the removal of third molars. In addition, soft-tissue lesions, complicating exostoses, and improperly contoured ridge areas should be eliminated or corrected before final restorative care.

Occlusion

The occlusion should be evaluated, and several essential keys for acceptable functional occlusion should be present in the patient. Functional movements of the mandible and occlusion of teeth are necessary for chewing food and even talking. First, all movements and terminal closure of the mandible must be compatible for harmonious temporomandibular joint (TMJ) function. The envelope of function must create efficient use of opening and closing muscle movements. The envelope of function must not cause a premature loading of teeth which could result in excess tooth wear, mobility, or temporomandibular disorders. Maximum intercuspation should be as close as possible to providing equal bilateral simultaneous contacts of teeth on closure of the mandible. If these conditions are achieved, and the patient history and examination does not reveal any other significant risk factors or symptoms, the patient would be diagnosed as having acceptable functional occlusion at the current point in time.

Fixed, Removable, and Implant Prosthodontics

Preferably, operative direct restorations should be completed before placing indirect restorations. Occasionally, a large amalgam or composite restoration is placed as a foundation to provide improved retention for a full crown. For use as a foundation, retention features must be placed well inside the restoration so that the material remains after tooth preparation for a crown. In removable prosthodontics, tooth preparations and restorations should allow for the design of the removable partial denture. This includes allowance for rests, guide planes, and clasps. The design of the operative restoration and the selection of appropriate restorative materials must be compatible with the design of the contemplated removable prosthesis. In cases where dental implants have been or will be placed, operative dentistry restorations should be planned and executed to allow for all the necessary parameters for successful implant restorations, including adequate space mesiodistally and vertically. Also, implant restorations may sometimes have unusual proximal contours, and adjacent amalgam or composite restorations should be designed to create the best proximal contact relationships possible.

Decision Making for Caries Management and Operative Treatment

As discussed in [Chapter 2](#), dental caries is a multifactorial, transmissible, infectious oral disease caused primarily by the

complex interaction of cariogenic oral flora (biofilm) with fermentable dietary carbohydrates on the tooth surface over time. *Caries lesions are the result of the caries disease process, not the cause.*

As described earlier in this chapter, the *first* step in managing dental caries is a thorough examination of teeth. This is accomplished by using all available diagnostic information to identify the location, size, depth, and activity of a caries lesion. The *second* step is to inventory existing risk factors or indicators using a systematic process as described in Chapter 2. The *third* step is the development of a preventive management treatment plan designed to reduce the patient's risk for future caries. The *fourth* step is to decide how best to manage the lesions that were detected. In making these decisions, the dentist should be mindful of the fact that except in cases of relatively large caries lesions, *the accuracy of the methods used to detect lesions (visual inspection, radiographs, caries detection devices, etc.) are all prone to inaccuracies (Box 3-1).* These inaccuracies result in false-positive and false-negative findings. This situation raises the question, "What are the implications

Box 3-1 Assessing the Accuracy of a Diagnostic Test for Caries

Contingency Table for Diagnostic Test Evaluation

Histologic Gold Standard

Caries
No caries

Diagnostic Test

Caries
True positive (TP)
False positive (FP)
No caries
False negative (FN)
True negative (TN)

Desirable and Undesirable Outcomes Resulting from Diagnostic Tests with Low Sensitivity or Specificity

Example 1

Diagnosing 100 teeth (90 healthy and 10 carious) with a diagnostic test having a high sensitivity (0.80) and low specificity (0.50) would result in the following:

Desirable outcomes:

Correctly detect 8 of 10 carious teeth (TP)
Correctly diagnose 45 of 90 healthy teeth (TN)

Undesirable outcomes:

Fail to detect 2 of 10 carious teeth (FN)
Fail to diagnose 45 healthy teeth as carious (FP)

Example 2

Diagnosing 100 teeth (90 healthy and 10 carious) with a diagnostic test having low sensitivity (0.50) and high specificity (0.80) would result in the following:

Desirable outcomes:

Correctly detect 5 of 10 carious teeth (TP)
Correctly diagnose 72 of 90 healthy teeth (TN)

Undesirable outcomes:

Fail to detect 5 of 10 carious teeth (FN)
Fail to diagnose 18 healthy teeth as carious (FP)

of these inaccuracies for clinical decision making?" False-positives findings may result in the surgical treatment of a sound tooth, and false-negative findings will result in a diseased surface receiving remineralization treatment instead of operative treatment. The former situation is irreversible and should be avoided, whenever possible. In the latter situation, false negatives will be receiving remineralization therapy and regular monitoring so that they can be treated operatively at a later time, if needed. This approach is even sounder, considering that caries lesions generally do not progress rapidly.³⁴ Thus, the clinician should strive to reduce the number of false positives by making sure that strong diagnostic evidence supports the presence of cavitation or dentin penetration before recommending irreversible operative treatment.

As a general rule, remineralization therapies, as well as sealants in the case of pits and fissures, are the preferred methods of managing coronal lesions that are neither cavitated nor penetrated into the dentin. Remineralization is also recommended for root surface lesions, in which neither a break in the surface contour of the exposed root nor softening of the root surface occurs. However, it is very important to note that *remineralization requires a high level of patient compliance with the therapeutic regimen and frequent recall visits to assess the success of the treatment.* If lesion progression is detected at recall, then operative intervention is warranted.

However, there are exceptions to the general rule of managing noncavitated enamel lesions with remineralization. Because remineralization requires a shift in the delicate balance of the oral biofilm, it depends heavily on changes in patient behavior (improved home care, diet, etc.) and the timely application of antimicrobial agents, fluoride, and other remineralizing agents. Thus, when it is clear that the patient is unwilling or unable to follow the prescribed remineralization regimen of home care and professional care, it is often appropriate to treat these lesions with operative restorations.

If confirmed cavitation of the enamel or demineralization penetrating into the dentin on coronal surfaces is present or a break exists in the contour of exposed root and softening of the surface, then operative treatment is usually recommended. One exception to this general guideline is the lesion that is deemed arrested.

A paramount principle in dentistry, as was discussed earlier in this chapter, is to *do no harm*. Clinicians must have a sound knowledge of the current evidence on the risks and benefits of their treatment recommendations. In the context of planning dental treatment, the clinician should recommend invasive operative treatment only when the benefits outweigh the risks of adverse outcomes. As noted earlier, restorations which require permanent removal of tooth structure usually do not last forever. Studies have shown that the average lifespan of a restoration ranges from 5 to more than 15 years.³⁵ When a restoration is replaced, additional tooth structure usually is removed, regardless of how carefully the operator removes the existing restoration. This situation results in what has been termed *the cycle of re-restoration*, which leads to larger and more invasive restorations over the course of a patient's life.³⁶

Esthetic Treatment

Interest in improved esthetics is growing among many segments of the population. As a result, a range of treatments has

been developed to manage a wide array of esthetic concerns. Chapter 12 describes these conservative esthetic treatments, which include esthetic recontouring of anterior teeth, vital bleaching, and microabrasion. These conservative approaches have well-documented outcomes. In addition to these conservative techniques, advances in direct composite restorations have permitted the closure of diastemas, recontouring of teeth, and other tooth additions by means other than extensive full-coverage restorations.

Treatment of Abrasion, Erosion, Abfraction, and Attrition

Abraded or eroded areas should be considered for restoration only if one or more of the following is true: (1) the area is affected by caries, (2) the defect is sufficiently deep to compromise the structural integrity of the tooth, (3) intolerable sensitivity exists and is unresponsive to conservative desensitizing measures, (4) the defect contributes to a periodontal problem, (5) the area is to be involved in the design of a removable partial denture, (6) the depth of the defect is judged to be close to the pulp, (7) the defect is actively progressing, or (8) the patient desires esthetic improvements. Areas of significant attrition that are worn into dentin and are sensitive or annoying should be considered for restoration. Before indirect restorations are used, however, a complete occlusal analysis and an in-depth interview with the patient regarding the etiology should be conducted to reduce contributing factors. Also, occlusal guard therapy should be considered.

Treatment of Root-Surface Caries

Root caries is common in older adults and in patients following periodontal treatments. Increases in the number of older patients in the patient population and tooth retention have contributed to this growing problem. Areas with root-surface caries usually should be restored when clinical or radiographic evidence of cavitation exists. Care must be exercised, however, to distinguish the active root-surface caries lesion from the root-surface lesion that once was active but has become inactive or arrested. The latter lesion shows sclerotic dentin that has darkened from extrinsic staining, is firm to the touch of an explorer, may be rough but is cleanable, and is seen in patients whose oral hygiene or diet has improved. Generally, these lesions should not be restored except when the patient wants restoration, probably for esthetic reasons. If it is determined that the lesion needs restoration, it can be restored with tooth-colored materials or amalgam. Adhesive materials have enhanced the restorative treatment of root-surface caries.

Prevention is preferred over restoration. It is recommended that appropriate preventive steps such as improvements in diet and oral hygiene and fluoride treatment with or without cementoplasty, be taken in hopes of avoiding carious breakdown and the need for restoration.³⁷

Treatment of Root-Surface Sensitivity

It is not unusual for patients to complain of root-surface sensitivity, which is an annoying sharp pain usually associated with gingival recession and exposed root surfaces. The most widely accepted explanation of this phenomenon is *hydrodynamic theory*, which postulates that the pain results from

indirect innervation caused by dentinal fluid movement in the tubules that stimulates the mechanoreceptors near the pre-dentinal areas (see Chapter 1). Some causes of such fluid shifts are temperature change, air drying, and osmotic pressure. Any treatment that can reduce these fluid shifts by partially or totally occluding the tubules may help reduce the sensitivity.

Dentinal hypersensitivity is a particular problem for some patients that occurs immediately after periodontal surgery that results in the clinical exposure of root surfaces. Numerous forms of treatment have been used to provide relief, such as fluoride varnishes, oxalate solutions, resin-based adhesives, sealants, and desensitizing toothpastes that contain potassium nitrate. Although all of these methods have met with varying degrees of success, resin materials provide the best rate of success. When these conservative methods fail to provide relief, restorative treatment is indicated.

Repairing and Resurfacing Existing Restorations

Often amalgam, composite, or indirect restorations can be repaired or recontoured as opposed to complete removal and replacement. Growing evidence suggests that the removal and replacement result in the cycle of re-restoration, which leads to increasingly larger tooth preparations and the resultant trauma to the tooth and supporting structures.³⁶ In addition, resurfacing or repair of composites and repair of cast restorations have been shown to be effective.^{28,38} Also, amalgam restorations with localized defects can be repaired with amalgam or with sealant resins.^{22,38} If a restoration has an isolated defect, which, when explored operatively, can be confirmed, and if all carious tooth structure has been removed, it is acceptable and often preferable to repair or recontour. Reshaping of over-contoured restorations is an acceptable form of treatment.

Replacement of Existing Restorations

Generally, a restoration should not be replaced unless (1) it has significant marginal discrepancies, (2) the tooth is at risk for caries or fracture, or (3) the restoration is an etiologic factor to adjacent teeth or tissue.³⁹ In many instances, recontouring or resurfacing the existing restoration can delay replacement.

Indications for replacing restorations include the following: (1) marginal void, especially in the gingival one third, that cannot be repaired; (2) poor proximal contour or a gingival overhang that contributes to periodontal breakdown; (3) a marginal ridge discrepancy that contributes to food impaction; (4) over-contouring of a facial or lingual surface resulting in plaque gingival to the height of contour and resultant inflammation of gingiva overprotected from the cleansing action of food bolus or toothbrush; (5) poor proximal contact that is either open, resulting in interproximal food impaction and inflammation of impacted gingival papilla, or improper in location or size; (6) recurrent caries that cannot be treated adequately by a repair restoration; and (7) ditching deeper than 0.5 mm of the occlusal amalgam margin that is deemed carious or caries-prone. By itself, the presence of shallow ditching around an amalgam restoration is not an indication for replacement.

Indications for replacing tooth-colored restorations include (1) improper contours that cannot be repaired, (2) large voids, (3) deep marginal staining, (4) recurrent caries, and

(5) unacceptable esthetics. Restorations that have only light marginal staining and are deemed noncarious can be corrected by a shallow, narrow, marginal repair restoration.

Indication for Amalgam Restorations

Although its indications for use have decreased, dental amalgam still is recognized as a successful restorative material. The use of amalgam in dentistry has been the source of controversy. Although the use of amalgam is considered safe, as amalgam is removed from teeth, adverse environmental effects caused by mercury and amalgam waste do occur. Online [Chapter 18](#) presents a more complete discussion of the issue, and [Chapters 13 through 16](#) present the current indications for amalgam restorations.

Indications for Direct Composite and Other Tooth-Colored Restorations

Direct composite restorations are indicated for the treatment of many lesions in anterior and posterior teeth. Detailed indications for composite and other tooth-colored restorations are presented in [Chapters 8 through 12](#).

Indications for Indirect Tooth-Colored Restorations

Partial-coverage indirect tooth-colored restorations may be indicated for Classes I and II restorations because of esthetics, strength, and other bonding benefits. Because of the potential of bonded restorations to strengthen remaining tooth structure, indirect tooth-colored restorations also may be selected for the conservative restoration of weakened posterior teeth in esthetically critical areas. Indirect tooth-colored restorations are covered in detail in [Chapter 11](#).

Indications for Indirect Cast-Metal Restorations

Although indications for intracoronal cast restorations are few, a gold onlay that caps all of the cusps and includes some of the axial tooth line angles (see [Chapter 17](#)) is an excellent restoration. Cast metal restorations may be the treatment of choice for patients undergoing occlusal rehabilitation. Also, teeth with deep subgingival margins are appropriately treated with cast metal restorations because compared with direct restorations, they provide a better opportunity for control of proximal contours and for restoration of the difficult subgingival margin.

Treatment Considerations for Older Patients

In the past, older adults constituted a relatively minor proportion of the population. Older individuals used dental services infrequently because most were edentulous, had limited financial resources, and delayed unmet dental needs until they became symptomatic. Today, individuals 65 years and older represent a rapidly growing segment of the population. Older individuals today are better educated consumers, have greater financial resources, are more prevention minded, and have retained more teeth compared with their predecessors.²⁷ Older

individuals are living with increasingly more complex medical, mental, emotional, and social conditions that affect their ability to care for their dentition and periodontium. These conditions must be considered when planning dental treatments for them. A comprehensive review of geriatric dentistry is beyond the scope of this chapter; rather, issues that are important for treatment planning for older patients are highlighted here.

Clear and effective communication is crucial. Because many older adults have hearing loss, the dentist must speak more distinctly and at a higher volume. Patients with memory loss appreciate written summaries and instructions that assist them in remembering details of the visit and planned treatment when they leave the dental office. The use of large simple fonts in written communications is particularly helpful to patients with diminished visual acuity.

An accurate medical history, risk assessment, and integration of dental and medical care are particularly important considerations for older patients. Many chronic diseases of the cardiovascular, respiratory, endocrine, renal, gastrointestinal, musculoskeletal, immune, and neurologic systems are associated with aging, influence dental disease, and complicate dental treatment decision making. Cardiovascular disease, Alzheimer's disease, depression, osteoarthritis, rheumatoid arthritis, osteoporosis, cancer, and diabetes are a few of the diseases that commonly affect older adults, and their medical management increases in complexity with advancing years. It is estimated that older individuals living in community settings take an average of four medications each day; six of the top 10 drugs prescribed in 2001 were used to treat age-related chronic conditions.⁴⁰ Many of these medications have adverse drug reactions, drug interactions, and oral adverse effects that include dry mouth (xerostomia), increased bleeding of tissues, lichenoid reactions, tissue overgrowth, and hypersensitivity reactions. The dentist must be aware of the impact these medications may have on dental treatment planning and management. Consultation with the patient's physician is highly recommended to fully understand these medical, mental, and emotional conditions and their potential impact on dental treatment. The dentist should recognize the use of xerostomic medications and discuss with the physician the potential substitution of medications with fewer xerostomic effects.

Oral changes associated with undernourishment, immunosuppression, dehydration, smoking, alcohol use, disease, medications, and dental problems lead to a depressed sense of taste and smell in older patients.⁴¹ Perceptions of salty and bitter tastes and olfactory function decline with age, whereas perceptions of sweet and sour tastes do not. As a result, food can become tasteless and unappetizing, and more sugars, fats, and salts are added in an attempt to increase flavor. Undernourished individuals are encouraged to consume calorie-rich, complete-nutrition beverages, which also are rich in sugars. Smoking reduces the taste of foods by causing physical coating of the tongue and regression of the taste buds on the tongue and olfactory receptors in the roof of the nasal cavity over time. Inadequate fluid intake can lead to chronic dehydration and altered taste perception. These practices increase the risk of dental disease in this population. Dietary assessment and counseling are crucial in older patients to identify inadequate diets and suggest modifications that enhance taste and smell while lowering the risks of dental disease. Herb seasonings can enhance the flavor of foods in lieu of sugar

and salt. Salivary stimulants, citric-flavored candies containing xylitol or other sugar replacements, tongue brushing or scraping, and smoking cessation are some additional measures that can promote taste and olfactory perception in older adults.

Dental and periodontal diseases can progress more rapidly in older adults.⁴² Dental caries, particularly root caries, is the most significant reason for tooth loss in older adults. Ineffective plaque removal, xerostomia, soft sugar-rich diets, fixed and removable prostheses, abrasions at the CEJ, gingival recession, and bone loss from periodontal disease make root surfaces more prone to caries compared with other surfaces. Root-surface restorations are challenging to perform successfully and are at risk of recurrent decay in the future. Careful selection of restoration design, materials, and finishing can maximize the longevity and cleanability of restorations. Also, many dental practitioners prefer to intervene more aggressively with dental treatment rather than take a “watchful waiting” approach. As more teeth are being retained and have large restorations at risk of fracture or recurrent decay, attention must be placed on developing cost-effective and innovative means of restoring teeth, particularly for older individuals on a limited budget.

Prevention of dental disease increases in importance but becomes more challenging in older adults. Physical limitations such as arthritis, Parkinson’s disease, vision impairment, and other chronic illnesses reduce the patients’ ability to clean their teeth and periodontal tissues effectively. Powered rotation–oscillation toothbrushes and manual toothbrushes with larger handles for easier gripping are recommended to patients with decreased manual dexterity. Consistent use of fluoride-containing dentifrices and other remineralization products, antimicrobial mouth rinses, oral pH management, flossing, oral irrigation, and chewing of xylitol gum can reduce the risk of developing dental caries and periodontal infection.⁴¹ Written reminders can serve as a key aid for older patients who forget to brush their teeth because of memory loss associated with Alzheimer’s disease. Because many older individuals may have never been taught to clean their teeth effectively, the dentist must instruct them in proper oral hygiene procedures to be performed after each meal.

Financial and social barriers also prevent older individuals from seeking oral health care. Although as a group, older adults enjoy greater financial resources, many are on restricted budgets and are faced with tough decisions regarding the spending of limited resources. Transportation is another issue for older patients who no longer drive.

A unique aspect of aging is an increasing reliance on caregivers to assist with activities of daily living. As a result, the dentist must work with caregivers who provide dental care for patients in the home, assisted living facility, nursing home, and hospital settings. The dental professional may need to spend more time educating and training the caregiver, rather than the patient, in the importance of oral hygiene and effective plaque removal techniques.

Treatment Plan Approval

As mentioned earlier, informed consent has become an integral part of contemporary dental practice.⁴³ One aspect of informed consent is to provide patients with the necessary

information about the alternative therapies available to manage their oral conditions. For nearly all conditions, usually more than one treatment alternative is available. These alternatives, with their advantages and disadvantages, should be presented to the patient. In addition, the patient should be informed of the risks associated with each alternative therapy. Often, a reasonable alternative is *not* to intervene but, instead, to monitor the condition or, in the case of caries lesions, attempt remineralization. Finally, the cost of treatment alternatives should be discussed with the patient. Treatment can proceed when the dentist is sure that the patient has a full and complete understanding of the alternative treatments, their associated risks and benefits, and the results of possible non-treatment.^{44,45}

Summary

Proper diagnosis and treatment planning play a crucial role in the quality of dental care. Each patient must be evaluated individually in a thorough and systematic fashion. After the patient’s condition is understood and recorded, a treatment plan can be developed and rendered. A successful treatment plan carefully integrates and sequences all necessary procedures indicated for the patient. Few absolutes exist in treatment planning; the available information must be considered carefully and incorporated into a plan that fits the needs of the individual. Patients should have an active role in the process; they should be informed of the findings, advised of the risks and benefits of the proposed treatment, and given the opportunity to decide the course of treatment. Examination, diagnosis, and treatment planning can be challenging but are rewarding for both the patient and the dentist if done thoroughly and properly with the patient’s best interests in mind.

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Fundamental Concepts of Enamel and Dentin Adhesion

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Basic Concepts of Adhesion

The American Society for Testing and Materials (specification D 907) defines adhesion as “the state in which two surfaces are held together by interfacial forces which may consist of valence forces or interlocking forces or both.”¹ The word adhesion comes from the Latin *adhaerere* (“to stick to”). An adhesive is a material, frequently a viscous fluid, that joins two substrates together by solidifying and transferring a load from one surface to the other. Adhesion or adhesive strength is the measure of the load-bearing capacity of an adhesive joint.² Four different mechanisms of adhesion have been described, as follows:³

1. **Mechanical adhesion**—interlocking of the adhesive with irregularities in the surface of the substrate, or adherend
2. **Adsorption adhesion**—chemical bonding between the adhesive and the adherend; the forces involved may be primary (ionic and covalent) or secondary (hydrogen bonds, dipole interaction, or van der Waals) valence forces
3. **Diffusion adhesion**—interlocking between mobile molecules, such as the adhesion of two polymers through diffusion of polymer chain ends across an interface
4. **Electrostatic adhesion**—an electrical double layer at the interface of a metal with a polymer that is part of the total bonding mechanism

In dentistry, bonding of resin-based materials to tooth structure is a result of four possible mechanisms, as follows:⁴

1. **Mechanical**—penetration of resin and formation of resin tags within the tooth surface
2. **Adsorption**—chemical bonding to the inorganic component (hydroxyapatite) or organic components (mainly type I collagen) of tooth structure

3. **Diffusion**—precipitation of substances on the tooth surfaces to which resin monomers can bond mechanically or chemically
4. A **combination** of the previous three mechanisms

For good adhesion, close contact must exist between the adhesive and the substrate (enamel or dentin). The surface tension of the adhesive must be lower than the surface energy of the substrate. Failures of adhesive joints occur in three locations, which are generally combined when an actual failure occurs: (1) cohesive failure in the substrate; (2) cohesive failure within the adhesive; and (3) adhesive failure, or failure at the interface of substrate and adhesive.

A major problem in bonding resins to tooth structure is that all methacrylate-based dental resins shrink during free-radical addition polymerization.⁵ Dental adhesives must provide a strong initial bond to resist the stresses of resin shrinkage.

Trends in Restorative Dentistry

The introduction of enamel bonding, the increasing demand for restorative and nonrestorative esthetic treatments, and the ubiquity of fluoride have combined to transform the practice of operative dentistry.^{6,7} The classic concepts of tooth preparation were advocated in the early 1900s;⁸ but these have changed drastically. This transformation in philosophy has resulted in a more conservative approach to tooth preparation, with regard to not only the basic concepts of retention form but also the resistance form of the remaining tooth structure. Bonding techniques allow more conservative tooth preparations, less reliance on macromechanical retention, and less removal of unsupported enamel.

The availability of new scientific information on the etiology, diagnosis, and treatment of carious lesions and the introduction of reliable adhesive restorative materials have substantially reduced the need for extensive tooth preparations. With improvements in materials, indications for resin-based

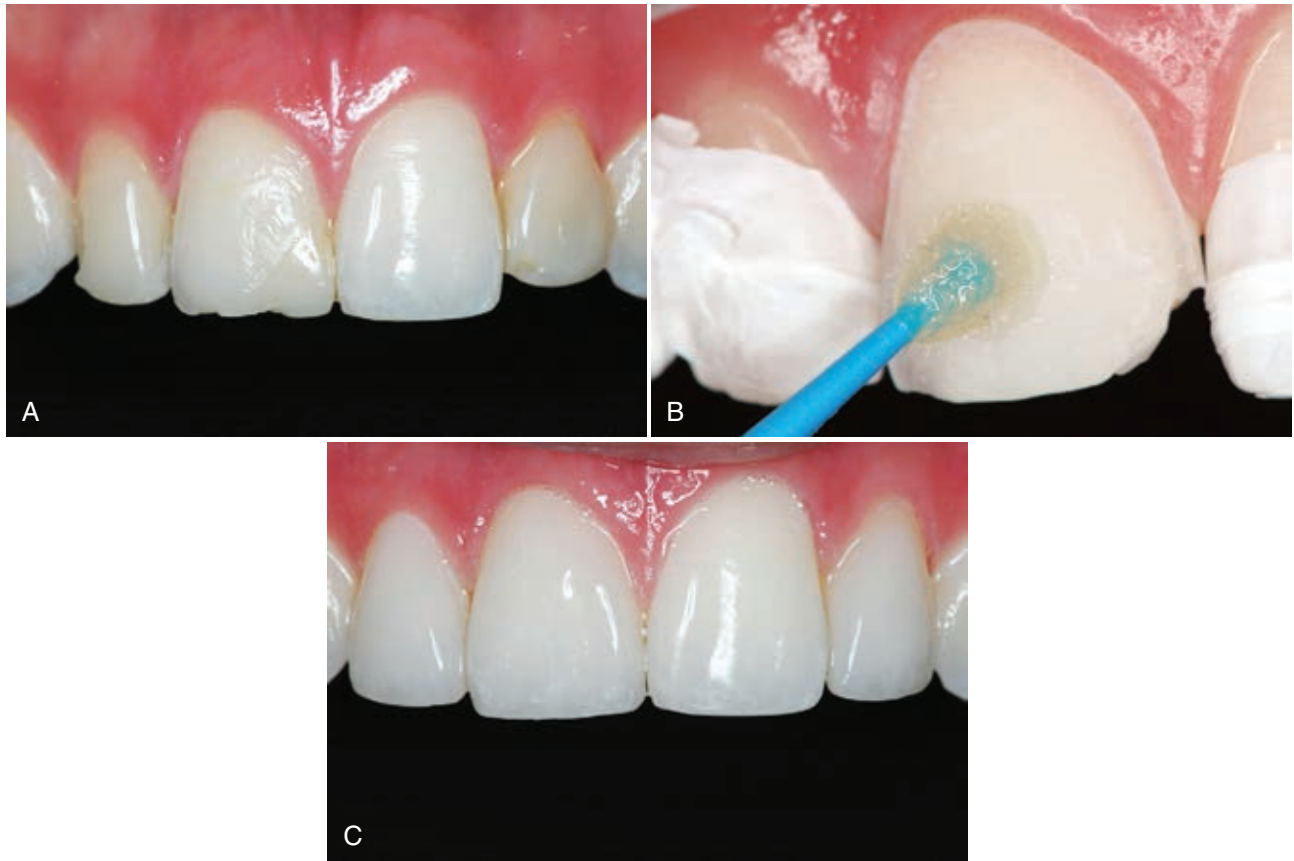


Fig. 4-1 **A**, Pre-operative view of anterior teeth in a 24-year-old patient with defective composite restorations. The treatment plan included bonded porcelain veneers on teeth #7, #8, and #10 to match the natural aspect of tooth #9. **B**, Porcelain veneers were bonded with a two-step etch-and-rinse adhesive and a light-activated resin cement. **C**, Final aspect 1 week after the bonding procedure.

materials have progressively shifted from the anterior segment only to posterior teeth as well. Adhesive restorative techniques currently are used to accomplish the following:

1. Restore Class I, II, III, IV, V, and VI carious or traumatic defects
2. Change the shape and the color of anterior teeth (e.g., with full or partial resin veneers)
3. Improve retention for porcelain-fused-to-metal (ceramometal) or metallic crowns
4. Bond all-ceramic restorations (Fig. 4-1)
5. Seal pits and fissures
6. Bond orthodontic brackets
7. Bond periodontal splints and conservative tooth-replacement prostheses
8. Repair existing restorations (composite, amalgam, ceramic, or ceramometal)
9. Provide foundations for crowns
10. Desensitize exposed root surfaces
11. Seal beneath or bond amalgam restorations to tooth structure
12. Impregnate dentin that has been exposed to the oral fluids, making it less susceptible to caries
13. Bond fractured fragments of anterior teeth (Fig. 4-2)
14. Bond prefabricated fiber or metal posts and cast posts
15. Reinforce fragile endodontically treated roots internally

16. Seal root canals during endodontic therapy
17. Seal apical restorations placed during endodontic surgery

Enamel Adhesion

Inspired by the industrial use of 85% phosphoric acid to facilitate adhesion of paints and resins to metallic surfaces, Buonocore envisioned the use of acids to etch enamel for sealing pits and fissures.⁶ Since Buonocore's introduction of the acid-etch technique, many dental researchers have attempted to achieve methods for reliable and durable adhesion between resins and tooth structure.

Acid-etching transforms the smooth enamel into an irregular surface (Fig. 4-3) and increases its surface free energy. When a fluid resin-based material is applied to the irregular etched surface, the resin penetrates into the surface, aided by capillary action. Monomers in the material polymerize, and the material becomes interlocked with the enamel surface (Fig. 4-4).^{9,10} The formation of resin microtags within the enamel surface is the fundamental mechanism of resin-enamel adhesion.¹⁰⁻¹² Figure 4-5 shows a replica of an etched enamel surface visualized through the extensions of resin that penetrated the irregular enamel surface. The acid-etch technique has revolutionized the practice of restorative dentistry.

Enamel etching results in three different micromorphologic patterns.^{13,14} The type I pattern involves the dissolution of

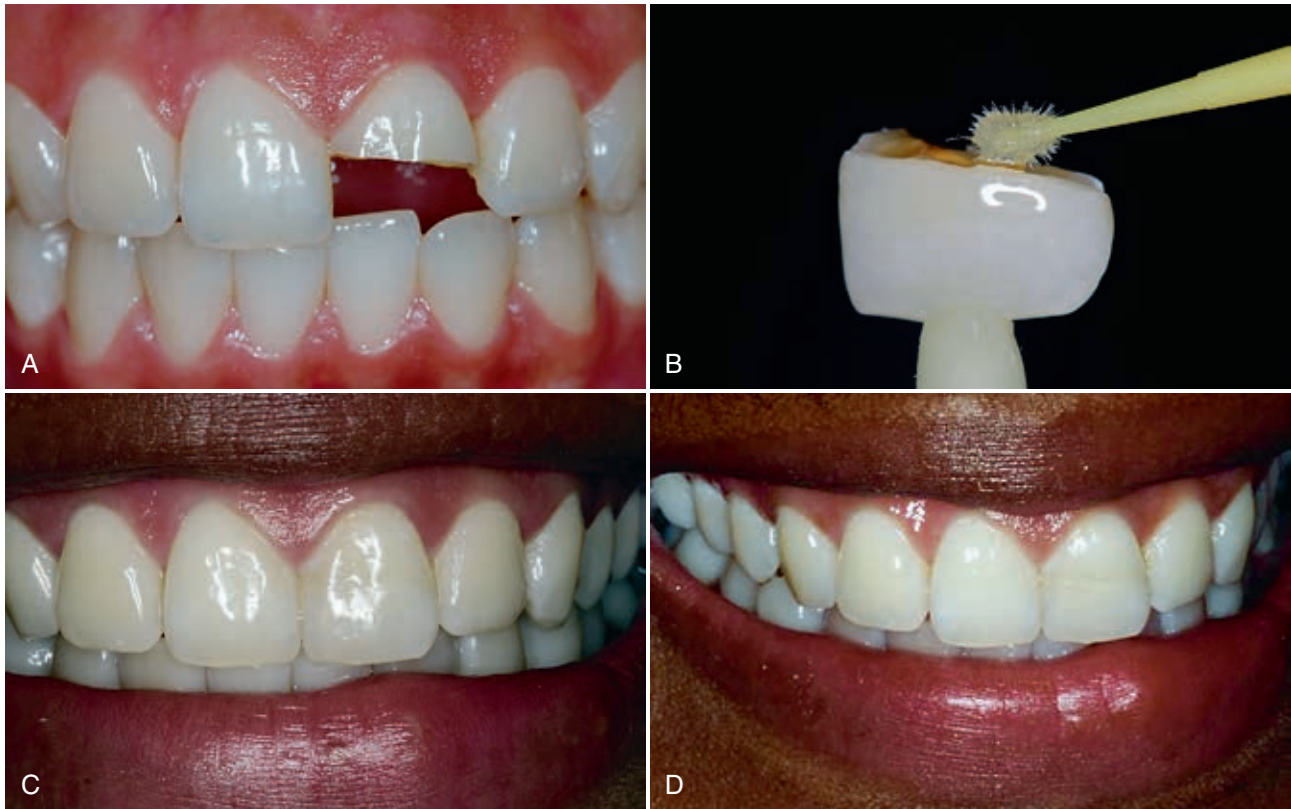


Fig. 4-2 **A**, Intraoral frontal view of a 20-year-old female presenting with complicated crown fracture on tooth #9 after endodontic treatment. The fracture extends subgingivally on the mesial aspect of the lingual surface. **B**, A total-etch, two-step, ethanol-based adhesive applied to the crown fragment and tooth. **C**, Extraoral view 6 months after rebonding. **D**, Extraoral view 3 years after rebonding. (From Macedo GV, Ritter AV: *Essentials of rebonding tooth fragments for the best functional and esthetic outcomes*, *Pediatr Dent* 31(2):110–116, 2009.)

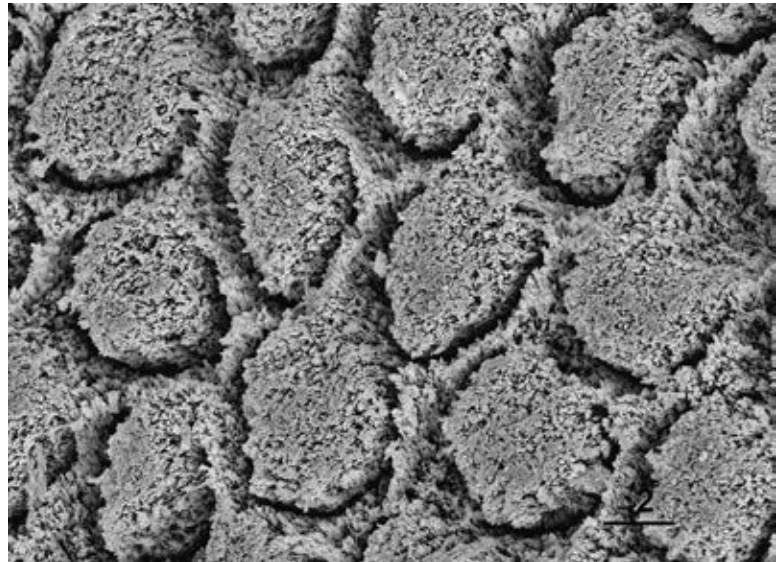


Fig. 4-3 Scanning electron micrograph (SEM) of enamel etched with 35% phosphoric acid for 15 seconds.

prism cores without dissolution of prism peripheries (Fig. 4-6, A). The type II etching pattern is the opposite of type I: the peripheral enamel is dissolved, but the cores are left intact (see Fig. 4-3). Type III etching is less distinct than the other two patterns. It includes areas that resemble the other patterns and

areas whose topography is not related to enamel prism morphology (see Fig. 4-6, B).

Beginning with Buonocore's use of 85% phosphoric acid, various concentrations of phosphoric acid have been used to etch enamel. Most current phosphoric acid gels have

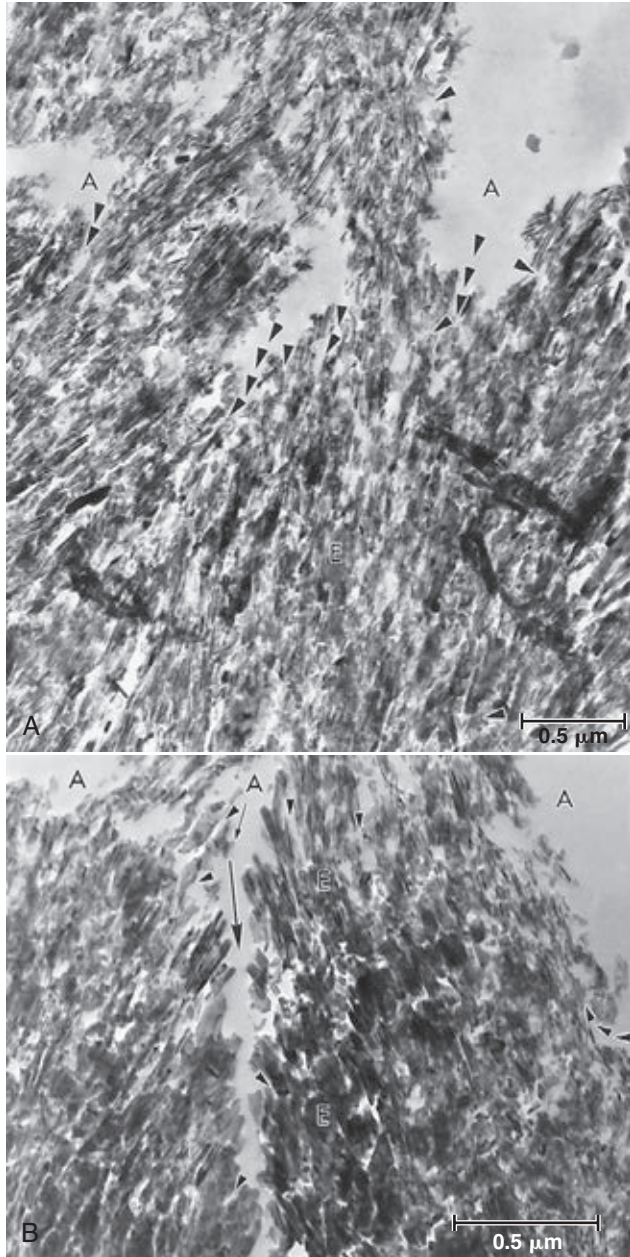


Fig. 4-4 **A** and **B**, Transmission electron micrographs (TEM) of the enamel-adhesive interface after application of Adper Single Bond (3M ESPE) as per manufacturer's instructions. Acid-etching with 35% phosphoric acid opened spaces between enamel prisms (*arrows*), allowing the permeation of resin monomers between the crystallites (*arrowheads*). *A*, adhesive; *E*, enamel.

concentrations of 30% to 40%, with 37% being the most common, although some studies using lower concentrations have reported similar adhesion values.¹⁵⁻¹⁷

An etching time of 60 seconds originally was recommended for permanent enamel using 30% to 40% phosphoric acid. Although one study concluded that shorter etch times resulted in lower bond strengths, other studies using scanning electron microscopy (SEM) showed that a 15-second etch resulted in a similar surface roughness as that provided by a 60-second etch.^{11,18-20} Other *in vitro* studies have shown similar bond

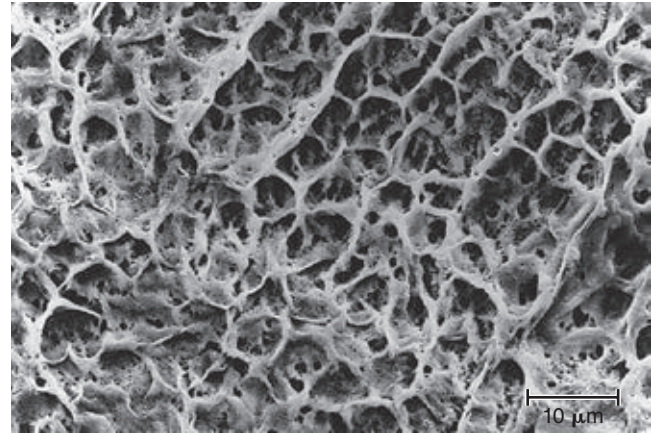


Fig. 4-5 Replica of enamel etched with 35% phosphoric acid. Enamel was dissolved completely in 6N hydrochloric acid for 24 hours. The resin extensions correspond to the interprismatic spaces (*asterisks*).

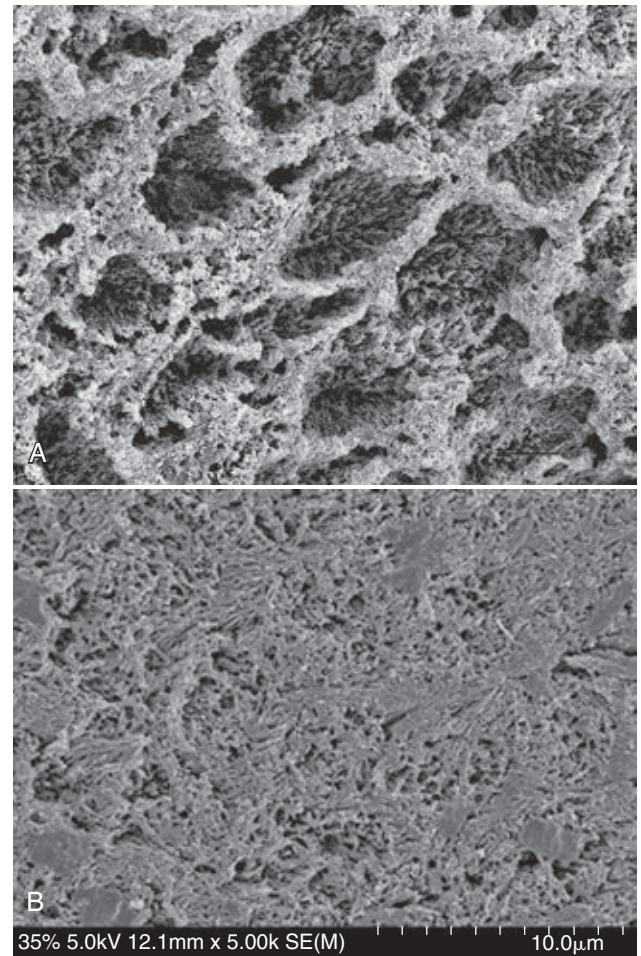


Fig. 4-6 **A**, Scanning electron micrograph of enamel etched with 35% phosphoric acid for 15 seconds, denoting a type I etching pattern. **B**, Scanning electron micrograph of enamel etched with 35% phosphoric acid for 15 seconds, denoting a type III etching pattern.

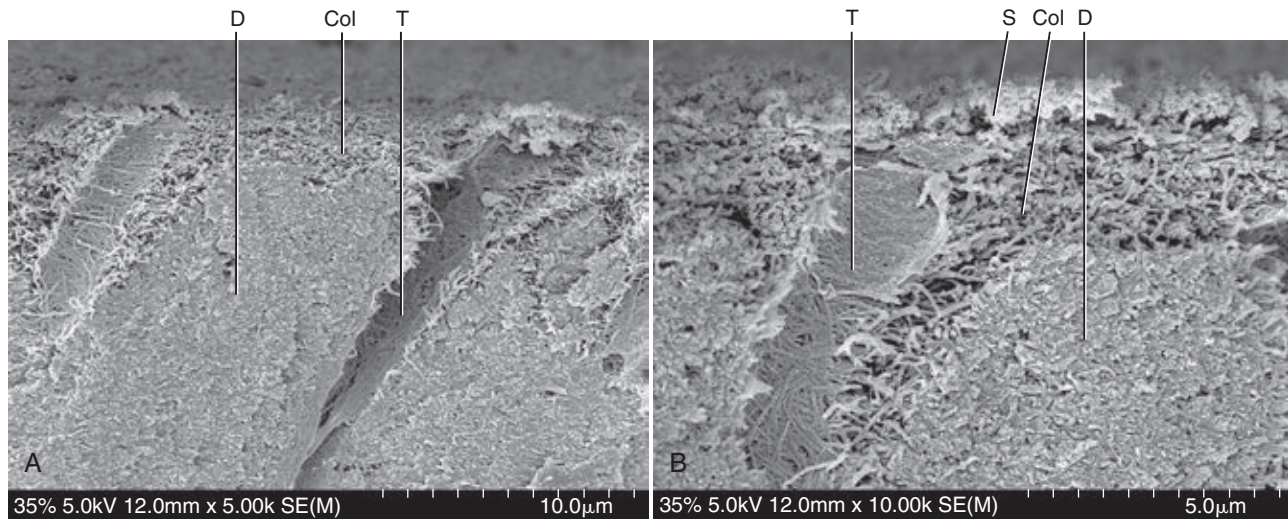


Fig. 4-7 **A**, Dentin etched with 35% phosphoric acid. **B**, Higher magnification view of etched dentin. *Col*, collagen exposed by the acid; *D*, normal dentin; *T*, dental tubule; *S*, residual silica particles used as acid gel thickener.

strengths and leakage for etching times of 15 and 60 seconds.²¹⁻²⁵

As measured in the laboratory, shear bond strengths of composite to phosphoric acid-etched enamel usually exceed 20 megapascals (MPa) and can range up to over 50 MPa, depending on the test method used.²⁶⁻²⁹ Such bond strengths provide adequate retention for a broad variety of procedures and prevent leakage around enamel margins of restorations.²⁴

Dentin Adhesion

The classic concepts of operative dentistry were challenged in the 1980s and 1990s by the introduction of new adhesive techniques, first for enamel and then for dentin. Nevertheless, adhesion to dentin remains difficult. Adhesive materials can interact with dentin in different ways—mechanically, chemically, or both.^{7,9,30-33} The importance of micromechanical bonding, similar to what occurs in enamel bonding, has become accepted.^{30,34,35} Dentin adhesion relies primarily on the penetration of adhesive monomers into the network of collagen fibers left exposed by acid etching (Fig. 4-7).^{35,36} However, for adhesive materials that do not require etching, such as glass ionomer cements and some phosphate-based self-etch adhesives, chemical bonding between polycarboxylic or phosphate monomers and hydroxyapatite has been shown to be an important part of the bonding mechanism.^{32,37,38} Contemporary strategies for bonding to dentin are summarized in Table 4-1.

Challenges in Dentin Bonding

Substrate

Bonding to enamel is a relatively simple process, without major technical requirements or difficulties. Bonding to dentin presents a much greater challenge. Several factors account for this difference between enamel and dentin bonding. Enamel is a highly mineralized tissue composed of more than 90% (by volume) hydroxyapatite, whereas dentin contains a substantial proportion of water and organic material, primarily type I collagen (Fig. 4-8). Dentin also contains a dense network of tubules that connect the pulp with the

dentinoenamel junction (DEJ) (Fig. 4-9). A cuff of hypermineralized dentin called *peritubular dentin* lines the tubules. The less mineralized intertubular dentin contains collagen fibrils with the characteristic collagen banding (Fig. 4-10). Intertubular dentin is penetrated by submicron channels, which allow the passage of tubular liquid and fibers between neighboring tubules, forming intertubular anastomoses.

Dentin is an intrinsically hydrated tissue, penetrated by a maze of fluid-filled tubules. Movement of fluid from the pulp to the DEJ is a result of a slight but constant pulpal pressure.³⁹ Pulpal pressure has a magnitude of 25-30 mm Hg or 34 to 40 cm H₂O.^{40,41}

Dental tubules enclose cellular extensions from the odontoblasts and are in direct communication with the pulp (Fig. 4-11). Inside the tubule lumen, other fibrous organic structures such as the lamina limitans are present, which substantially decreases the functional radius of the tubule. The relative area occupied by dentin tubules decreases with increasing distance from the pulp. The number of tubules decreases from about 45,000/mm² close to the pulp to about 20,000/mm² near the DEJ.⁴² The tubules occupy an area of only 1% of the total surface near the DEJ, whereas they occupy 22% of the surface close to the pulp.⁴³ The average tubule diameter ranges from 0.63 µm at the periphery to 2.37 µm near the pulp.⁴⁴

Adhesion can be affected by the remaining dentin thickness after tooth preparation. Bond strengths are generally less in deep dentin than in superficial dentin.⁴⁵⁻⁴⁷ Nevertheless, some dentin adhesives, including one-step self-etch adhesives, do not seem to be affected by dentin depth.⁴⁸

Whenever tooth structure is prepared with a bur or other instrument, residual organic and inorganic components form a “smear layer” of debris on the surface.^{49,50} The smear layer fills the orifices of dentin tubules, forming “smear plugs” (Fig. 4-12), and decreases dentin permeability by nearly 90%.⁵¹ The composition of the smear layer is basically hydroxyapatite and altered denatured collagen. This altered collagen can acquire a gelatinized consistency because of the friction and heat created by the preparation procedure.⁵² Submicron porosity of the smear layer still allows for diffusion of dentinal fluid.⁵³ Removal of the smear layer and smear plugs with acidic

Table 4-1 Current Strategies for Adhesion of Resins to Dentin

	Etchant (E)	Primer (P)	Bonding Agent (B)
Three-step etch-and-rinse* E + P + B	Removes the smear layer Exposes intertubular and peritubular collagen Opens the tubules in a funnel configuration Decreases surface free energy	Includes bifunctional molecules (simultaneously hydrophilic and hydrophobic) Envelops the external surface of collagen fibrils Re-establishes surface free energy to levels compatible with a more hydrophobic restorative material	Includes monomers that are mostly hydrophobic, such as Bis-GMA; however, can contain a small percentage of hydrophilic monomers, such as HEMA Co-polymerizes with the primer molecules Penetrates and polymerizes into the interfibrillar spaces to serve as a structural backbone to the hybrid layer
Two-step etch-and-rinse E + [PB]	Removes the smear layer Exposes intertubular and peritubular collagen Opens tubules in a funnel configuration Decreases surface free energy	Penetrates into the dentin tubules to form resin tags The first coat applied on etched dentin works as a primer—it increases the surface free energy of dentin The second coat (and third, fourth, and so on) acts as the bonding agent used in three-step systems—it fills the spaces between the dense network of collagen fibers	
Two-step self-etch [EP] + B	Enamel etch is typically shallow The self-etching primer (SEP) does not remove the smear layer, but fixes it and exposes about 0.5–1 μm of intertubular collagen because of its acidity (pH = 1.2–2.0) The smear plug is impregnated with acidic monomers, but it is not removed; some SEP monomers bond chemically to dentin When it impregnates the smear plug, the SEP prepares the pathway for the penetration of the subsequently placed fluid resin into the microchannels that permeate the smear plug	Uses the same type of bonding agent included in the three-step, etch-and-rinse systems The resin tags form on resin penetration into the microchannels of the primer-impregnated smear plug	
One-step self-etch [EPB]	Etches enamel, but etch pattern is typically shallow Incorporates the smear layer into interface Being an aqueous solution of a phosphonated monomer, it demineralizes and penetrates dentin simultaneously, leaving a precipitate on the hybrid layer Forms a thin layer of adhesive, leading to low bond strengths; a multi-coat approach is recommended; an extra layer of a hydrophobic bonding resin improves bond strengths and clinical performance Incompatible with self-cure composite resins unless coated with an hydrophobic bonding resin		

*Although the meaning of the two terms is the same, the term “etch-and-rinse” is preferred over “total-etch.”

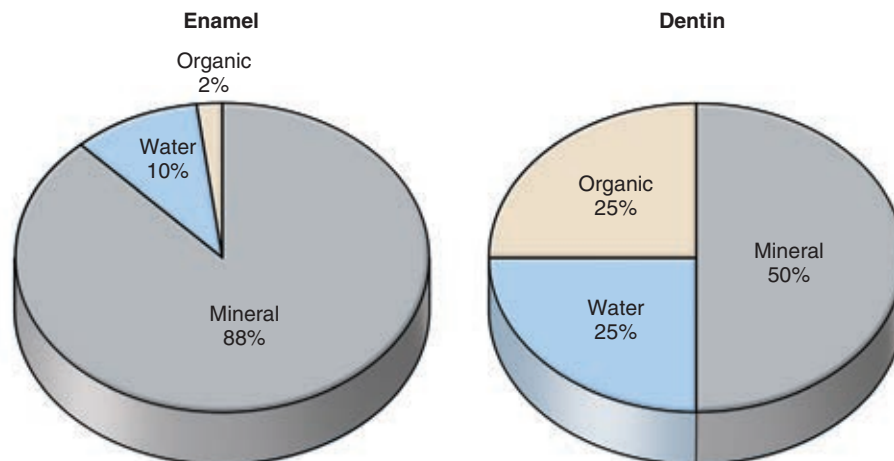


Fig. 4-8 Composition of enamel and dentin by volume percent.

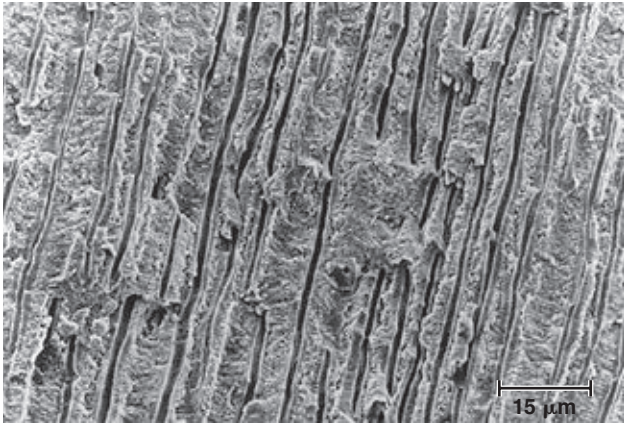


Fig. 4-9 Scanning electron micrograph of dentin that was fractured longitudinally to show dentinal tubules.

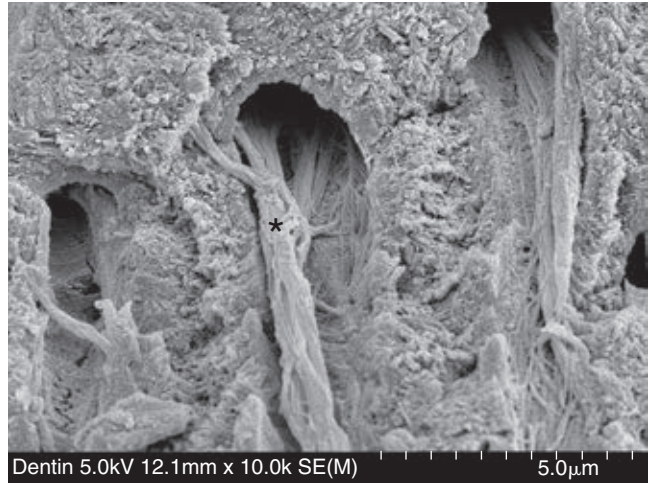


Fig. 4-11 Scanning electron micrograph of deep dentin displaying an odontoblastic process in a dentinal tubule (asterisk).

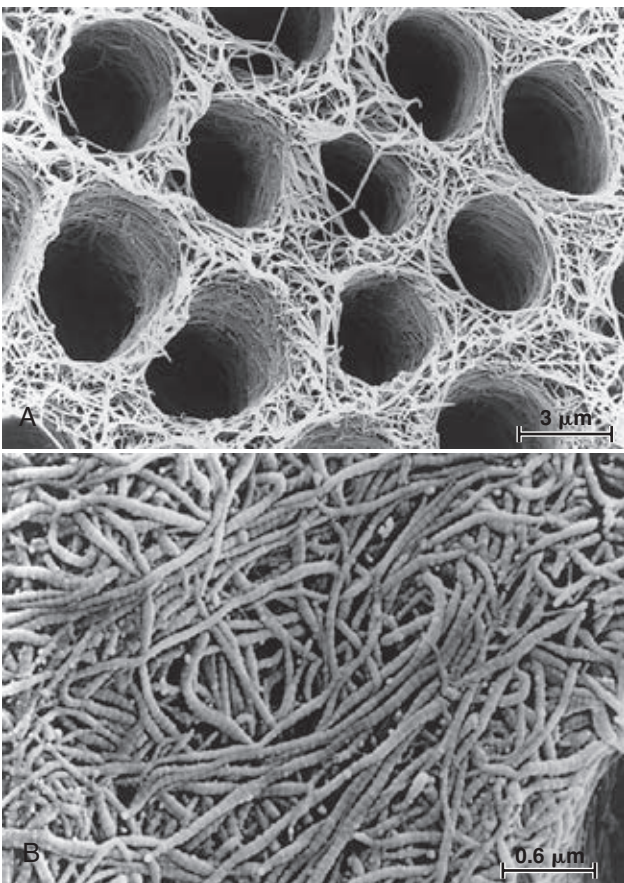


Fig. 4-10 **A**, Scanning electron micrograph of etched dentin showing exposed collagen fibers. **B**, Higher magnification shows the characteristic collagen banding in intertubular collagen. Superficial collagen was dissolved by collagenase to remove the most superficial collagen fibers that were damaged by tooth preparation.

solutions results in an increase of the fluid flow onto the exposed dentin surface. This fluid can interfere with adhesion because hydrophobic resins do not adhere to hydrophilic substrates, even if resin tags are formed in the dentin tubules.^{49,54}

Several additional factors affect dentin permeability. Besides the use of vasoconstrictors in local anesthetics, which decrease

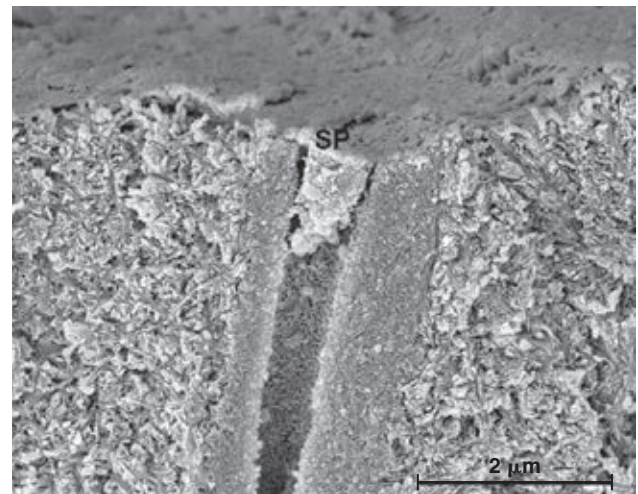


Fig. 4-12 Scanning electron micrograph of a smear plug blocking the entrance of a dentinal tubule. *SP*, smear plug.

pulpal pressure and fluid flow in the tubules, factors such as the radius and length of the tubules, the viscosity of dentin fluid, the pressure gradient, the molecular size of the substances dissolved in the tubular fluid, and the rate of removal of substances by the blood vessels in the pulp affect permeability. All of these variables make dentin a dynamic substrate and consequently a difficult substrate for bonding.^{43,55}

Stresses at the Resin–Dentin Interface

Composites shrink as they polymerize, creating considerable stresses within the composite mass, depending on the configuration of the preparation.⁵⁶⁻⁵⁹ When the composite is bonded to one surface only (e.g., for a direct facial veneer), stresses within the composite are relieved by flow from the unbonded surface. Stress relief within a three-dimensional bonded restoration is limited, however, by its configuration factor (C-factor).⁶⁰ In an occlusal preparation, composite is bonded to five tooth surfaces—mesial, distal, buccal, lingual, and pulpal. The occlusal surface of the composite is the only “free” or unrestrained surface. In such a situation, the ratio

between the number of bonded surfaces and the number of unbonded surfaces is 5:1, giving the restoration a configuration factor = 5. Stress relief is limited because flow can occur only from the single free surface.^{60,61}

Unrelieved stresses in the composite contribute to internal bond disruption and marginal gaps around restorations that increase microleakage and potential postoperative sensitivity.⁶² The C-factor might be partially responsible for the decrease in bond strengths observed when deep dentin is bonded as part of a three-dimensional preparation.⁶³

It has been reported that immediate bond strengths of approximately 17 MPa are necessary to resist the contraction stresses that develop in the composite during polymerization, to prevent marginal debonding.^{58,64} Water absorption by the resin might compensate for the effect of the polymerization shrinkage, as the resin might expand and seal off marginal gaps, but this occurs only over a relatively long time.⁶⁵ Water absorption is directly proportional to the resin content.⁶⁶

Enamel bond strengths usually are sufficient to prevent the formation of marginal gaps by polymerization contraction stresses. These stresses might, however, be powerful enough to cause enamel defects at the margins.⁶⁷ Extension of the enamel cavosurface bevel helps improve the enamel peripheral seal.^{56,68}

Each time a restoration is exposed to wide temperature variations in the oral environment (e.g., drinking coffee and eating ice cream), the restoration undergoes volumetric changes of different magnitude compared with those of the tooth structure. This occurs because the linear coefficient of thermal expansion of the composite is about four times greater than that of the tooth structure. Microleakage around dentin margins is potentiated by this discrepancy in linear coefficient of thermal expansion between the restoration and the substrate.⁶⁹

Loading and unloading of restored teeth can result in transitional or permanent interfacial gaps.⁷⁰ Additionally, the tooth substrate itself might be weakened by cyclic loading.⁷¹ A study found that 71% of Class V composite restorations in third molars with antagonists have significantly more leakage than restorations placed in teeth without opposing contact.⁷² Another study found that cyclic loading and preparation configuration significantly reduced the bond strengths of self-etch and etch-and-rinse adhesives.^{73,74}

Development Beginning

During the 1950s, it was reported that a resin containing glycerophosphoric acid dimethacrylate (GPDM) could bond to a hydrochloric acid-etched dentin surface.⁷⁵ (Note: A complete listing of the chemical names mentioned in this chapter is provided in Table 4-2.) The bond strengths of this primitive adhesion technique were severely reduced by immersion in water. A few years before that report, another researcher had used the same monomer chemically activated with sulfinic acid, and that combination would later be known commercially as Sevriton Cavity Seal (Amalgamated Dental Company, London, England).^{76,77}

First Generation

The development of the surface-active co-monomer NPG-GMA was the basis for Cervident (S.S. White Burs, Inc.,

Table 4-2 Abbreviations Commonly Used in Dentin/Enamel Adhesion Literature and in This Chapter

Abbreviation	Chemical Name
Bis-GMA	Bisphenol-glycidyl methacrylate
EDTA	Ethylenediamine tetra-acetic acid
GPDM	Glycerophosphoric acid dimethacrylate
HEMA	2-Hydroxyethyl methacrylate
10-MDP	10-Methacroyloxy decyl dihydrogen phosphate
4-META	4-Methacroyloxyethyl trimellitate anhydride
MMEP	Mono (2-methacroyloxy) ethyl phthalate
NPG-GMA	N-phenylglycine glycidyl methacrylate
PENTA	Dipentaerythritol penta-acrylate monophosphate
Phenyl-P	2-(Methacroyloxy) ethyl phenyl hydrogen phosphate

Lakewood, NJ), which is considered the first-generation dentin bonding system.^{31,78} Theoretically, this comonomer could chelate with calcium on the tooth surface to generate water-resistant chemical bonds of resin to dentinal calcium.^{79,80} The in vitro dentin bond strengths of this material were, however, in the range of only 2 to 3 MPa.⁸¹ Likewise, the in vivo results were discouraging; Cervident had poor clinical results when used to restore non-carious cervical lesions without mechanical retention.⁸²

Second Generation

In 1978, the Clearfil Bond System F^c was introduced in Japan (Kuraray Co., Ltd., Osaka, Japan). Generally recognized as the first product of the second-generation of dentin adhesives, it was a phosphate-ester material (phenyl-P and hydroxyethyl methacrylate [HEMA] in ethanol). Its mechanism of action was based on the polar interaction between negatively charged phosphate groups in the resin and positively charged calcium ions in the smear layer.⁸¹ The smear layer was the weakest link in the system because of its relatively loose attachment to the dentin surface. Examination of both sides of failed bonds revealed the presence of smear layer debris.⁸³

Several other phosphate-ester dentin bonding systems were introduced in the early 1980s, including Scotchbond (3M EPSE Dental Products, St. Paul, MN), Bondlite (Kerr Corporation, Orange, CA), and Prisma Universal Bond (DENTSPLY Caulk, Milford, DE). These second-generation dentin bonding systems typically had in vitro bond strengths of only 1 to 5 MPa, which was considerably below the 10 MPa value estimated as the threshold value for acceptable in vivo retention.^{9,52} In addition to the problems caused by the loosely attached smear layer, these resins were relatively devoid of hydrophilic groups and had large contact angles on intrinsically moist surfaces.⁸⁴ They did not wet dentin well, did not penetrate the entire depth of the smear layer, and, therefore, could not reach the superficial dentin to establish ionic bonding or resin extensions into the dentinal tubules.⁵²

Whatever bonding did occur was due to interaction with calcium ions in the smear layer.⁸⁵

The in vitro performance of second-generation adhesives after 6 months was unacceptable.⁸⁶ The bonding material tended to peel from the dentin surface after water storage, indicating that the interface between dentin and some types of chlorophosphate ester-based materials was unstable.^{86,87} The in vivo performance of these materials was found to be clinically unacceptable 2 years after placement in cervical tooth preparations without additional retention, such as beveling and acid-etching.^{88,89}

Third Generation

The concept of phosphoric acid-etching of dentin before application of a phosphate ester-type bonding agent was introduced by Fusayama et al in 1979.⁹⁰ Because of the hydrophobic nature of the bonding resin, however, acid-etching did not produce a significant improvement in dentin bond strengths, despite the flow of the resin into the open dentinal tubules.^{54,91} Pulpal inflammatory responses were thought to be triggered by the application of acid on dentin surfaces, providing another reason to avoid etching.^{92,93} Nevertheless, continuing the etched dentin philosophy, Kuraray introduced Clearfil New Bond in 1984. This phosphate-based material contained HEMA and a 10-carbon molecule known as 10-MDP, which includes long hydrophobic and short hydrophilic components.⁷⁹

Most other third-generation materials were designed not to remove the entire smear layer but, rather, to modify it and allow penetration of acidic monomers, such as phenyl-P or PENTA. Despite promising laboratory results, some of the bonding mechanisms never resulted in satisfactory clinical results.^{89,94}

Treatment of the smear layer with acidic primers was proposed using an aqueous solution of 2.5% maleic acid, 55% HEMA, and a trace of methacrylic acid (Scotchbond 2, 3M ESPE Dental Products).⁷⁹ Scotchbond 2 was the first dentin bonding system to receive “provisional” and “full acceptance” from the American Dental Association (ADA).⁹⁵ With this type of smear layer treatment, manufacturers effectively combined the dentin etching philosophy advocated in Japan with the more cautious approach advocated in Europe and the United States. The result was preservation of a modified smear layer with slight demineralization of the underlying intertubular dentin surface. Clinical results were mixed, with some reports of good performance and some reports of poor performance.^{88,89}

The removal of the smear layer using chelating agents such as EDTA was recommended in the original Gluma system (Bayer Dental, Leverkusen, Germany) before the application of a primer solution of 5% glutaraldehyde and 35% HEMA in water. The effectiveness of this system might have been impaired, however, by the manufacturer’s questionable recommendation of placing the composite over uncured unfilled resin.⁸⁹

Current Options for Resin–Dentin Bonding Three-Step Etch-and-Rinse Adhesives

Although the smear layer acts as a “diffusion barrier” that reduces the permeability of dentin, it also can be considered

an obstacle that must be removed to permit resin bonding to the underlying dentin substrate.⁵¹ Based on that consideration, a fourth generation of dentin adhesives was introduced for use on acid-etched dentin.⁹⁶ Removal of the smear layer via acid-etching led to significant improvements in the in vitro bond strengths of resins to dentin.⁹⁷⁻¹⁰⁰ Because the clinical technique involves simultaneous application of an acid to enamel and dentin, this method was originally known as the “total-etch” technique. Now more commonly called *etch-and-rinse technique*, it was the most popular strategy for dentin bonding during the 1990s and remains somewhat popular today (Fig. 4-13).

Application of acid to dentin results in partial or total removal of the smear layer and demineralization of the underlying dentin.⁹⁰ Acids demineralize intertubular and peritubular dentin, open the dentin tubules, and expose a dense filigree of collagen fibers (see Fig. 4-7), increasing the microporosity of the intertubular dentin (Fig. 4-14).^{35,101} Dentin is demineralized by up to approximately 7.5 μm , depending on the type of acid, application time, and concentration.^{35,101}

Despite the obvious penetration of early adhesives into the dentinal tubules, etching did not result in a significant improvement in bond strengths, possibly as a result of the hydrophobic nature of the phosphonated resin.⁹¹ On the basis of concerns about the potential for inflammatory pulpal responses, acids were believed to be contraindicated for direct application on dentin, and the total-etch technique was not readily accepted in Europe or the United States. Adhesive systems based on the total-etch philosophy have proved successful, however, in vitro and in vivo.^{89,102-104} Laboratory shear bond strengths usually vary from 17 to 30 MPa, which are similar to the values typically obtained on enamel.

Adhesive systems such as All-Bond 2 and All-Bond 3 (Bisco, Inc., Schaumburg, IL), OptiBond FL (Kerr Corporation), and Scotchbond Multi-Purpose (3M ESPE) are described by some authors as fourth-generation adhesives. However, because they include three essential components that are applied sequentially, they are more accurately described as three-step etch-and-rinse systems. The three essential components are (1) a phosphoric acid-etching gel that is rinsed off; (2) a primer containing reactive hydrophilic monomers in ethanol, acetone, or water; and (3) an unfilled or filled resin bonding agent. Some authors refer to this third step as *adhesive*. It contains hydrophobic monomers such as Bis-GMA, frequently combined with hydrophilic molecules such as HEMA.

The acid-etching step not only alters the mineral content of the dentin substrate but also changes its surface free energy.^{33,96} The latter is an undesirable effect because for good interfacial contact, any adhesive must have a low surface tension, and the substrate must have a high surface free energy.^{34,52,87} Substrates are characterized as having low or high surface energy. Among dental materials, hydroxyapatite and glass ionomer cement filler particles are high-energy substrates, whereas collagen and composite have low-energy surfaces.² Consequently, dentin consists of two distinct substrates, one of high surface energy (hydroxyapatite) and one of low surface energy (collagen). After etching, the dense web of exposed collagen is a low surface energy substrate.⁸⁶ A correlation exists between the ability of an adhesive to spread on the dentin surface and the concentration of calcium on that same surface.¹⁰⁵ The primer in a three-step system is designed to increase the critical surface tension of dentin, and a direct correlation between

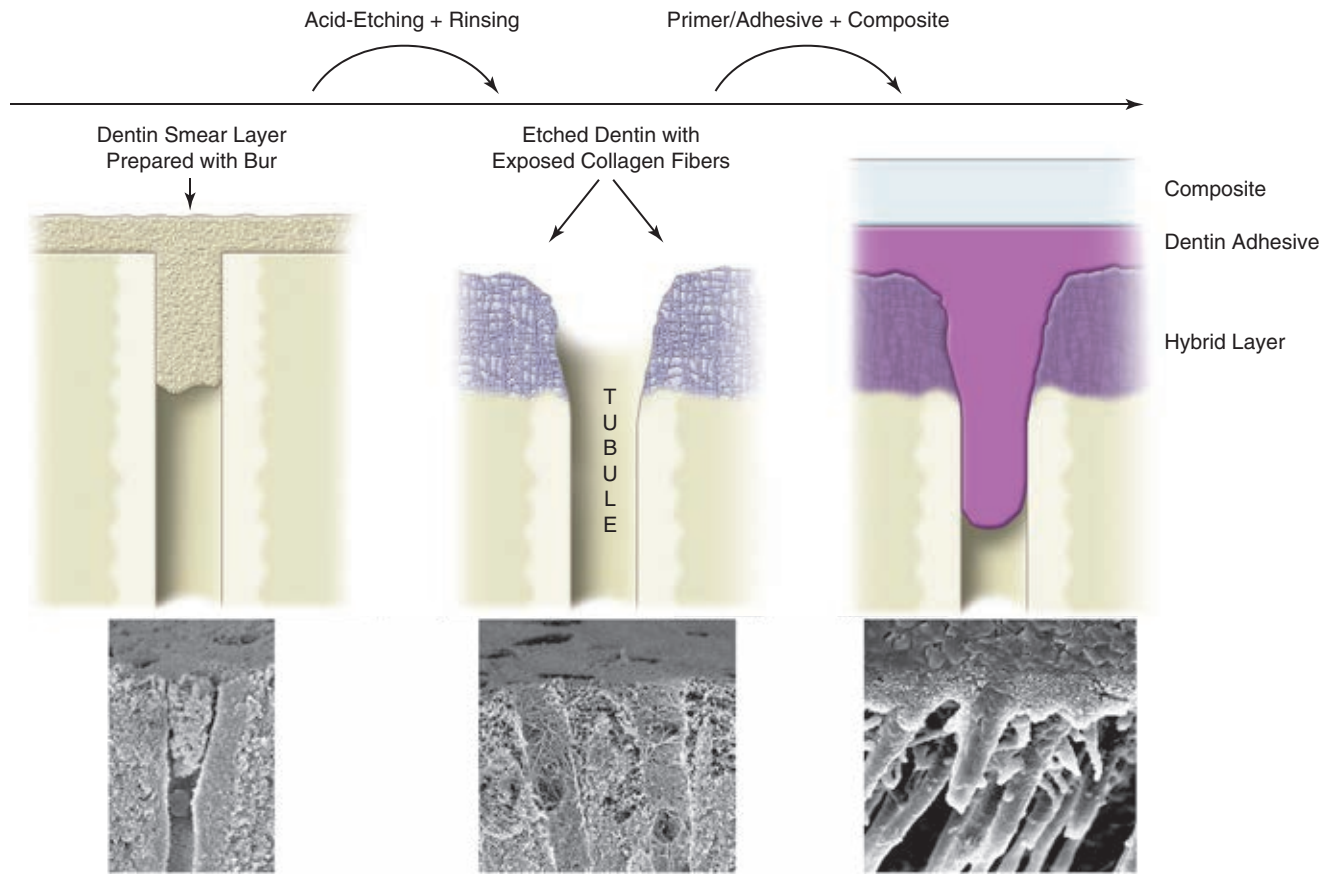


Fig. 4-13 Bonding of resin to dentin using an etch-and-rinse technique.

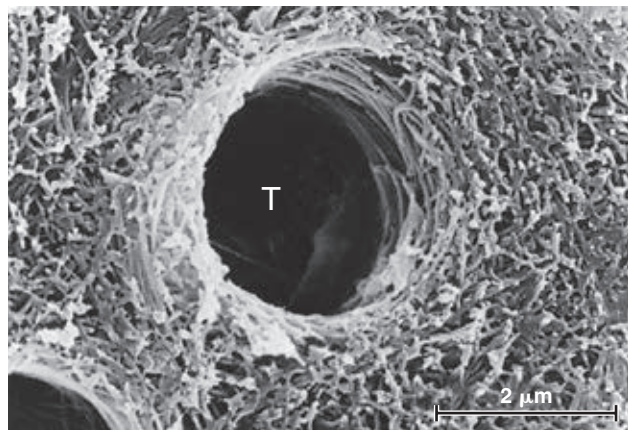


Fig. 4-14 Scanning electron micrograph of dentin that was kept moist after rinsing off the etchant. The abundant intertubular porosity serves as a pathway for the penetration of the dentin adhesive. *T*, dentinal tubule.

surface energy of dentin and shear bond strengths has been shown.⁴⁶

When primer and bonding resin are applied to etched dentin, they penetrate the intertubular dentin, forming a resin–dentin interdiffusion zone, or hybrid layer. They also penetrate and polymerize in the open dentinal tubules, forming resin tags. For most etch-and-rinse adhesives, the ultramorphologic characterization of the transition between

the hybrid layer and the unaffected dentin suggests that an abrupt shift from hybrid tissue to mineralized tissue occurs, without any empty space or pathway that could result in leakage (Figs. 4-15 and 4-16). The demarcation line seems to consist of hydroxyapatite crystals embedded in the resin from the hybrid layer (see Fig. 4-16, *B*). For self-etch systems, the transition is more gradual, with a superficial zone of resin-impregnated smear residues and a deeper zone, close to the unaffected dentin, rich in hydroxyapatite crystals (Fig. 4-17).

Two-Step Etch-and-Rinse Adhesives

In vitro dentin bond strengths have improved so much that they approach the level of enamel bonding.²⁷ Therefore, much of the research and development (R&D) has focused on the simplification of the bonding procedure. A number of dental materials manufacturers are marketing a simplified, two-step etch-and-rinse adhesive system. Some authors refer to these as fifth-generation adhesives, and they are sometimes called “one-bottle” systems because they combine the primer and bonding agent into a single solution. A separate etching step still is required.

Numerous simplified bonding systems are available, including One-Step Plus (Bisco, Inc.), Prime & Bond NT (DENT-SPLY Caulk), Adper Single Bond Plus (3M ESPE), OptiBond SOLO Plus (Kerr Corporation), PQ1 (Ultradent Products, South Jordan, UT), ExciTE (Ivoclar Vivadent, Schaan, Liechtenstein), Bond-1 (Pentron Clinical Technologies,

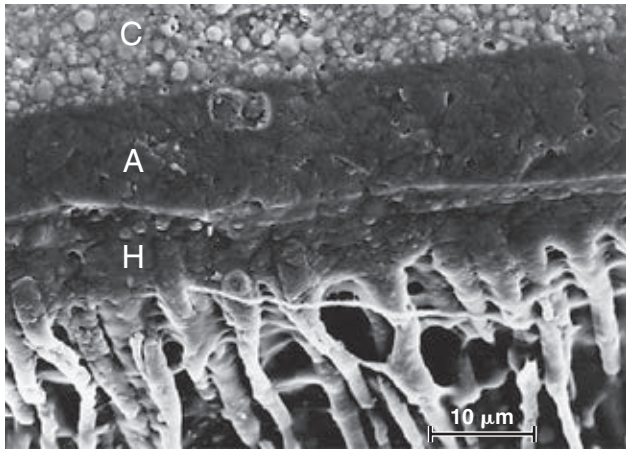


Fig. 4-15 Scanning electron micrograph of the transition between composite resin (C), adhesive (A), adhesive-hybrid layer (H), and hybrid layer-dentin.

Wallingford, CT), One Coat Bond (Coltène/Whaledent Inc., Mahwah, NJ), and XP Bond (DENTSPLY Caulk).

Two-Step Self-Etch Systems

An alternative bonding strategy is the self-etch approach (Figs. 4-17 and 4-18). Some self-etch systems are most accurately described as nonrinsing conditioners or self-priming etchants. Examples include NRC Non-Rinse Conditioner (DENTSPLY DeTrey, Konstanz, Germany) and Tyrian SPE (Bisco, Inc.). NRC and Tyrian SPE required the subsequent application of a separate adhesive, the same used with the etch-and-rinse technique (Prime & Bond NT [DENTSPLY Caulk] with NRC, and One-Step Plus [Bisco, Inc.] with Tyrian SPE). Nonrinsing conditioners did not etch enamel to the same depth as phosphoric acid, and did not provide higher bond strengths or better clinical performance than phosphoric acid etchants.^{106,107}

Another type of acidic conditioner was introduced in Japan—the self-etching primers (SEPs)—and has proved to be more successful. These acidic primers include a phosphonated resin molecule that performs two functions simultaneously—etching and priming of dentin and enamel. In contrast to conventional etchants, SEPs are not rinsed off. The bonding mechanism of SEPs is based on the simultaneous etching and priming of enamel and dentin, forming a continuum in the substrate and incorporating smear plugs into the resin tags (Fig. 4-19).^{108,109} In addition to simplifying the bonding technique, the elimination of rinsing and drying steps reduces the possibility of over-wetting or over-drying, either of which can affect adhesion adversely.^{98,99} Also, water is always a component of SEPs because it is needed for the acidic monomers to ionize and trigger demineralization of hard dental tissues; this makes SEPs less susceptible to variations in the degree of substrate moisture but more susceptible to chemical instability due to hydrolytic degradation.¹¹⁰⁻¹¹²

One disadvantage of SEPs that are currently available is that they do not etch enamel as well as phosphoric acid, particularly if the enamel has not been instrumented. The seal of enamel margins in vivo might be compromised.^{113,114} When enamel bonds are stressed in the laboratory by thermal cycling, SEPs are more likely than etch-and-rinse systems to undergo

deterioration.¹¹⁵ This decrease in bond strengths with thermal fatigue might be a sign that a potential exists for enamel microleakage when SEPs are employed to bond to enamel. In a 10-year recall of an older generation SEP, 39 of 44 restorations had marginal discoloration.¹¹⁶ The enamel bond strengths of some newer SEPs approach the enamel bond strengths of phosphoric acid-based adhesives, however, suggesting that SEPs are gradually being developed to replace etch-and-rinse adhesive systems.

Because they are user-friendly and do not require the etching and rinsing step, SEPs such as Clearfil SE Bond (Kuraray) have become very popular.¹¹⁷ Clearfil SE Bond contains an aqueous mixture of a phosphoric acid ester monomer (10-MDP), with a much higher pH than that of phosphoric acid etchants.¹¹⁸ Although the pH of a 34% to 37% phosphoric acid gel is much lower than 1.0, the pH of Clearfil SE Primer (Kuraray) is 1.9 to 2.0.^{101,106} SEPs have been classified in three categories: *mild*, *moderate*, and *aggressive*, with Clearfil SE Bond being a mild SEP.¹⁰⁶ Mild SEPs tend to provide excellent dentin bond strengths and poorer enamel bonds, whereas more aggressive self-etch systems provide the reverse. Clearfil SE Bond resulted in 98% retention rate in Class V composite restorations at 8 years with or without separate enamel etching of the margins, which did improve marginal adaptation.¹¹⁹ In posterior restorations, Clearfil SE Bond resulted in 100% retention rate at 2 years with a tendency for deterioration of the composite margins compared with the etch-and-rinse control Single Bond.¹⁰² The clinical success of Clearfil SE Bond might be a result of its chemical composition, specifically the monomer 10-MDP. This monomer bonds chemically to hydroxyapatite by forming stable calcium-phosphate salts without causing strong decalcification. The chemical bonding formed by 10-MDP is more stable in water than that of other monomers used in the composition of self-etch adhesives, such as 4-META and phenyl-P.¹²⁰

SEPs are less technique sensitive than are etch-and-rinse adhesives. Additionally, SEPs are less likely to result in a discrepancy between the depth of demineralization and the depth of resin infiltration because SEPs demineralize and infiltrate dentin simultaneously.¹¹⁸ SEPs do not remove the smear layer from dentin completely (see Figs. 4-17 and 4-18), which is the main reason that they might result in less postoperative sensitivity compared with etch-and-rinse adhesives.^{55,121}

Despite the prevailing opinion that SEPs cause less postoperative sensitivity compared with etch-and-rinse systems, the few clinical studies comparing these in posterior restorations have reported mixed results.^{55,121} Nevertheless, recent clinical studies have shown no relationship between the type of adhesive and the occurrence of postoperative sensitivity.¹²³⁻¹²⁹ One clinical study found no differences in postoperative sensitivity from 2 weeks to 6 months between an etch-and-rinse adhesive (Prime & Bond NT) and an SEP (Clearfil SE Bond) used in Class I and Class II composite restorations. These results suggest that the restorative technique is more important than the material itself.

One-Step Self-Etch Adhesives

Continuing the trend toward simplification, no-rinse, self-etching materials that incorporate the fundamental steps of etching, priming, and bonding into one solution have become increasingly popular. In contrast to conventional adhesive

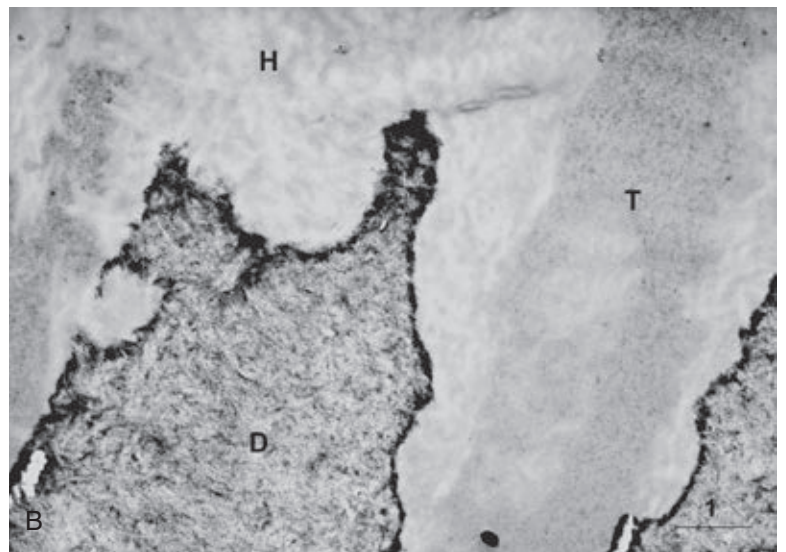
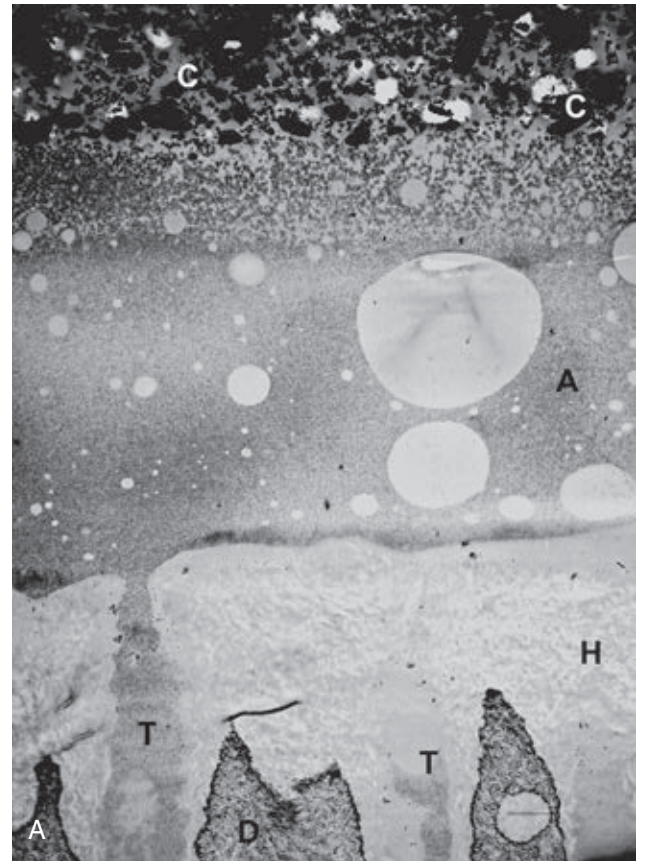


Fig. 4-16 Transmission electron micrograph of a resin–dentin interface formed by the etch-and-rinse adhesive Adper Single Bond Plus (3M ESPE). This specimen was not decalcified or stained; the unaltered dentin appears darker, and the hybrid layer appears lighter. **A**, General view showing the composite (C), the adhesive (A), the hybrid layer (H), a filled resin tag (T), and the unaffected dentin (D). **B**, Higher magnification of the transition between the hybrid layer and unaffected dentin. Note the filler in the resin tag as small dark dots (nanofiller).

systems that contain an intermediate light-cured, low-viscosity bonding resin to join the composite restorative material to the primed dentin–enamel substrate, these one-step self-etch or “all-in-one” adhesives contain uncured ionic monomers that contact the composite restorative material directly.^{128,129} Their acidic unreacted monomers are responsible, in part, for the incompatibility between these all-in-one adhesives and self-cured composites (discussed later).¹²⁹ Additionally, one-step adhesives tend to behave as semi-permeable membranes, resulting in a hydrolytic degradation of the resin–dentin interface.¹¹⁰ Because these adhesives must be acidic enough to be

able to demineralize enamel and penetrate dentin smear layers, the hydrophilicity of their resin monomers, usually organophosphates and carboxylates, also is high. Some of these resin monomers are too hydrophilic, which makes them liable to water degradation.^{111,130}

Many one-step self-etch adhesives with etching, priming, and bonding functions delivered in a single solution are now available, including AdheSE One F (Ivoclar Vivadent), Adper Easy Bond (3M ESPE), All-Bond SE (Bisco Inc.), Bond Force (Tokuyama Dental, Tokyo, Japan), Clearfil S³ Bond (Kuraray), iBOND Self-Etch (Heraeus Kulzer, South Bend, IN),

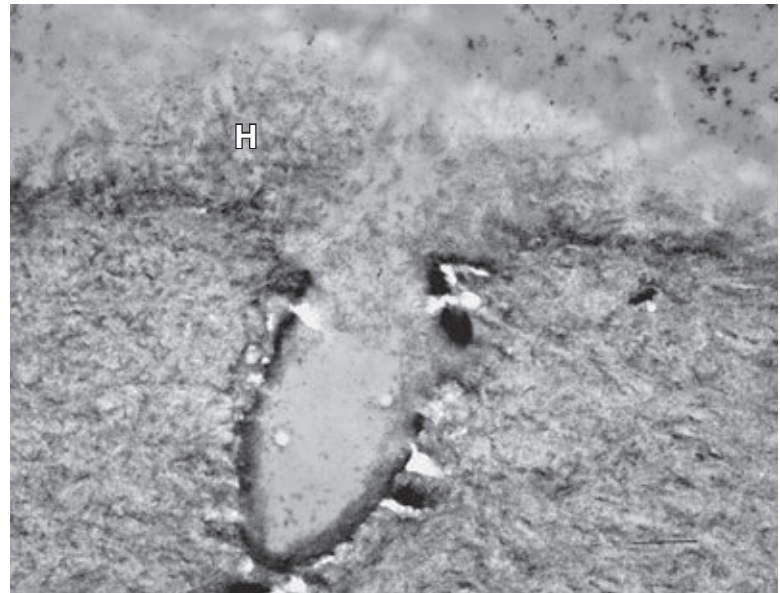


Fig. 4-17 Transmission electron micrograph of a resin–dentin interface formed with the two-step, self-etch adhesive Clearfil SE Bond (Kuraray). Residual hydroxyapatite crystals and residual components of the smear layer are embedded in the resin within the hybrid layer (*H*).

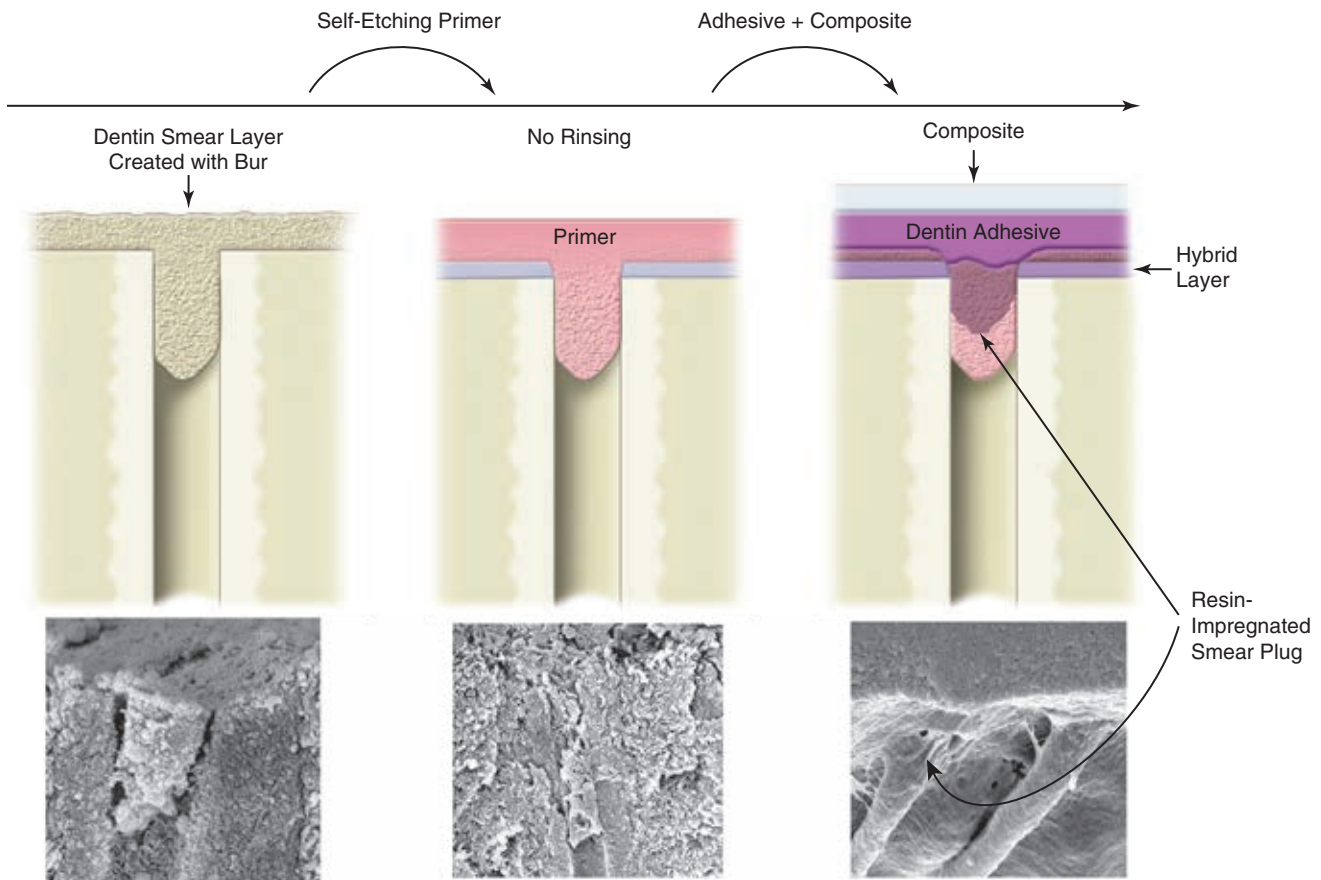


Fig. 4-18 Bonding to dentin using a self-etch primer.

OptiBond All-in-One (Kerr Corporation), and Xeno V+ (DENTSPLY DeTrey). As with the SEP systems, the pH of an all-in-one, self-etching adhesive affects its clinical properties. Also, application of multiple coats, such as four consecutive coats for Xeno III (DENTSPLY DeTrey) or five consecutive coats for iBond (Heraeus Kulzer), significantly increases

dentin bond strengths and decreases leakage, suggesting that some of the “all-in-one” adhesives might not coat the dentin surface uniformly.¹³¹

A clinical study of Adper Prompt L-Pop (3M EPSE) reported a 35% failure rate at 1 year in Class V restorations, although the material used in this study was an earlier version.¹³² A

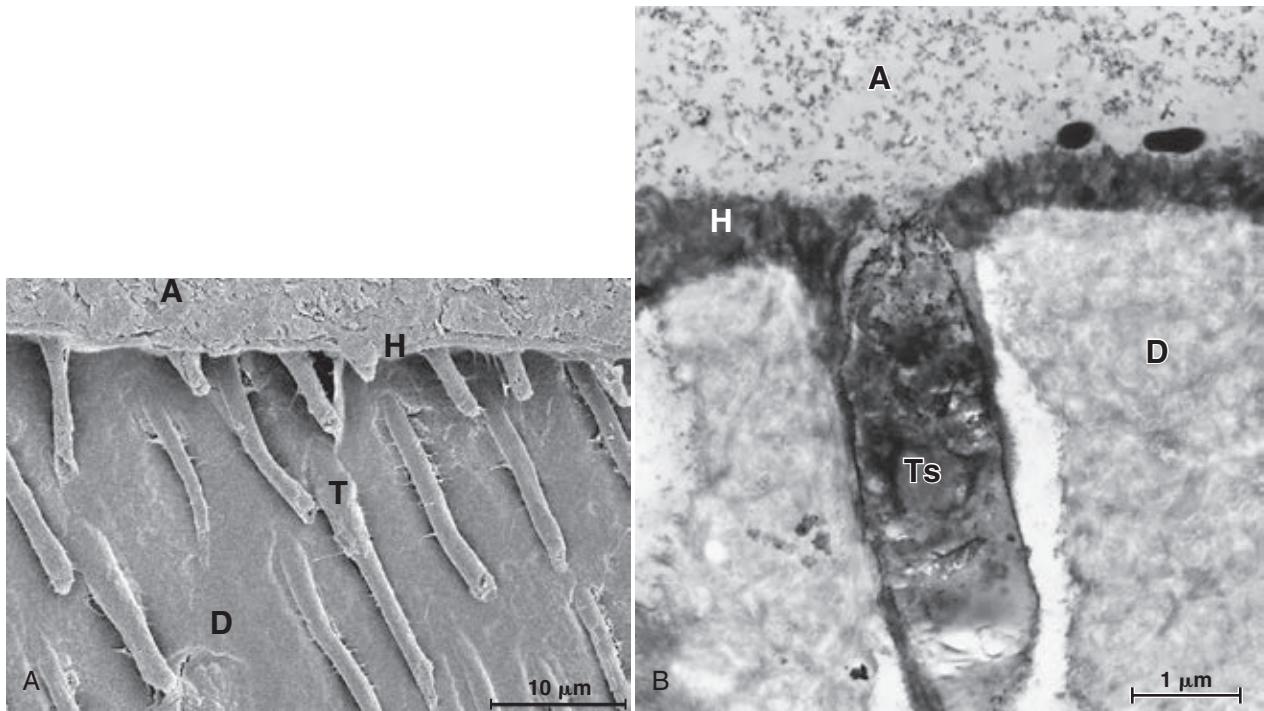


Fig. 4-19 **A**, Scanning electron micrograph of a resin–dentin interface formed with Clearfil SE Bond (Kuraray) on chemical dissolution of the superficial dentin. **B**, Transmission electron micrograph of a resin–dentin interface formed with Clearfil SE Bond on EDTA decalcification and staining with uranyl acetate and lead citrate. *A*, adhesive; *D*, residual dentin (appears gray in *B* because it was decalcified with EDTA); *H*, hybrid layer (appears dark in *B* because of decalcification followed by staining); *T*, resin tag; *Ts*, resin tag that incorporates the smear plug.

modified version of this material, Adper Prompt, had significantly worse marginal adaptation than Scotchbond Multi-Purpose in noncarious cervical lesions at 2 years.¹³³ Similar findings were reported for Adper Prompt L-Pop in another Class V clinical study. Although Adper Prompt L-Pop resulted in similar retention rates as Adper Single Bond at 3 years, the self-etch adhesive resulted in significantly higher incidence of marginal discoloration.¹³⁴

For iBond, marginal discoloration and marginal adaptation were much less than ideal at 3 years.¹³⁵ Another clinical trial in noncarious Class V lesions compared different generations of dentin adhesives—three-step etch-and-rinse, two-step etch-and-rinse, two-step self-etch, and one-step (or all-in-one) self-etch.¹³⁶ Out of four different adhesives from the same manufacturer, only the three-step etch-and-rinse adhesive resulted in retention rate greater than 90% at 18 months necessary to fulfill the ADA requirement for full acceptance.⁹⁶ In a clinical study with posterior composite restorations, iBond resulted in a significant decrease in the quality of color match, marginal staining, and marginal adaptation at 2 years.¹³⁷

The *in vitro* and clinical behavior of all-in-one (one-step) self-etch adhesives improves when the clinician adds an extra coat of a hydrophobic bonding layer.¹³⁸⁻¹⁴⁰ In a recent clinical study in Class V lesions, the one-step self-etch adhesive Clearfil S3 Bond resulted in 77.3% retention rate at 18 months.¹³⁹ For the group to which an extra layer of a thick bonding resin was added (Scotchbond Multi-Purpose Adhesive), the retention rate increased to 93.4% at 18 months. In the same study, iBond, also a one-step self-etch adhesive, resulted in a 60% retention rate at 18 months. However, the retention increased to 83% when a coat of the same hydrophobic resin was applied

over the cured iBond, transforming it in a two-step system. This behavior of one-bottle self-etch adhesives may be related to their behavior as semi-permeable membranes *in vitro* and *in vivo*.^{110,141} Simplified self-etch adhesives do not provide a hermetic seal for vital deep dentin as demonstrated by transudation of dentinal fluid across the polymerized adhesives to form fluid droplets on the surface of the adhesive.¹¹¹

Moist versus Dry Dentin Surfaces with Etch-and-Rinse Adhesives

Because vital dentin is inherently wet, complete drying of dentin is difficult to achieve clinically.^{99,142} Water has been considered an obstacle for attaining an effective adhesion of resins to dentin, so research has shifted toward the development of dentin adhesives that are compatible with humid environments. Many adhesives combine hydrophilic and hydrophobic monomers in the same bottle, dissolved in an organic solvent such as ethanol or acetone. The “moist bonding” technique used with etch-and-rinse adhesives prevents the spatial alterations (i.e., collagen collapse) that occur on drying demineralized dentin (Fig. 4-20; compare with Fig. 4-14).⁹⁹ Such alterations might prevent the monomers from penetrating the labyrinth of nanochannels formed by dissolution of hydroxyapatite crystals between collagen fibers.^{143,144}

The use of etch-and-rinse adhesive systems on moist dentin is made possible by incorporation of the organic solvents acetone or ethanol in the primers or adhesives. Because the solvent can displace water from the dentin surface and the moist collagen network, it promotes the infiltration of resin

monomers throughout the nanospaces of the dense collagen web. The moist bonding technique has been shown repeatedly to enhance bond strengths of etch-and-rinse adhesives because water preserves the porosity of collagen network available for monomer interdiffusion.^{99,142,145} If the dentin surface is dried with air, the collagen undergoes immediate collapse and prevents resin monomers from penetrating (Fig. 4-21).^{146,147}

Pooled moisture should not remain on the tooth because excess water can dilute the primer and render it less effective.^{148,149} A glistening hydrated surface is preferred (Fig. 4-22).¹⁵⁰ Many clinicians still dry the tooth preparation, however, after rinsing off the etching gel to check for the classic etched enamel appearance. Because it is very difficult to dry enamel without simultaneously drying dentin, the

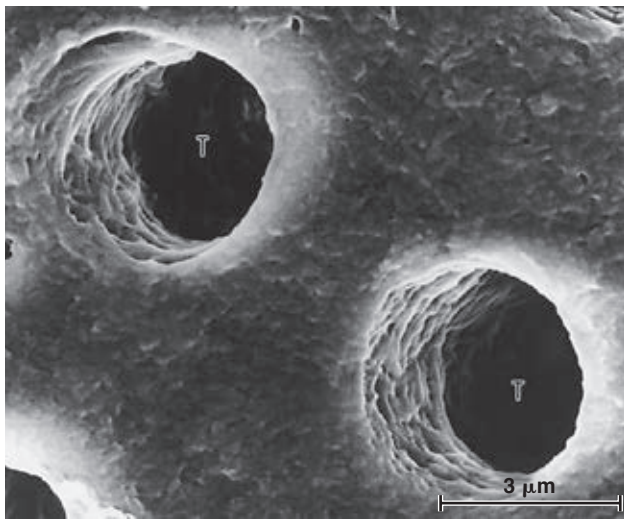


Fig. 4-20 Scanning electron micrograph of dentin collagen after acid etching with 35% phosphoric acid. Dentin was air-dried. The intertubular porosity disappeared as a consequence of the collapse of the collagen secondary to the evaporation of water that served as a backbone to keep collagen fibers raised.

dentin collagen collapses easily on air drying, resulting in the closing of the micropores in the exposed intertubular collagen.^{36,149} For acetone-based, water-free bonding systems, the etched dentin surface must be re-wetted before applying the adhesive. Re-wetting the dried etched dentin with aqueous re-wetting agents has been shown to restore bond strength values and to raise the collapsed collagen network to a level similar to that in a “moist bonding” technique.^{36,147,151} Some authors have suggested that the inclusion of water in the composition of some adhesives may result in re-wetting the collagen fibers in areas that are not left fully moist, opening the interfibrillar spaces to the infiltration of the priming resin.^{149,152}

When etched dentin is dried using an air syringe, bond strengths decrease substantially, especially for acetone-based and (to a lesser extent) ethanol-based dentin adhesive systems.^{98,147,149} When water is removed, the elastic characteristics of collagen may be lost. While in a wet state, wide gaps separate the collagen molecules from each other.¹⁵³ In a dry state, the molecules are arranged more compactly. This is because extrafibrillar spaces in hydrated type I collagen are filled with water, whereas dried collagen has fewer



Fig. 4-22 Clinical aspect of moist dentin—a glistening appearance without accumulation of water. (From Rubinstein S, Nidetz A: *The art and science of the direct posterior restoration: Recreating form, color, and translucency*, Alpha Omegan 100(1):30–35, 2007.)

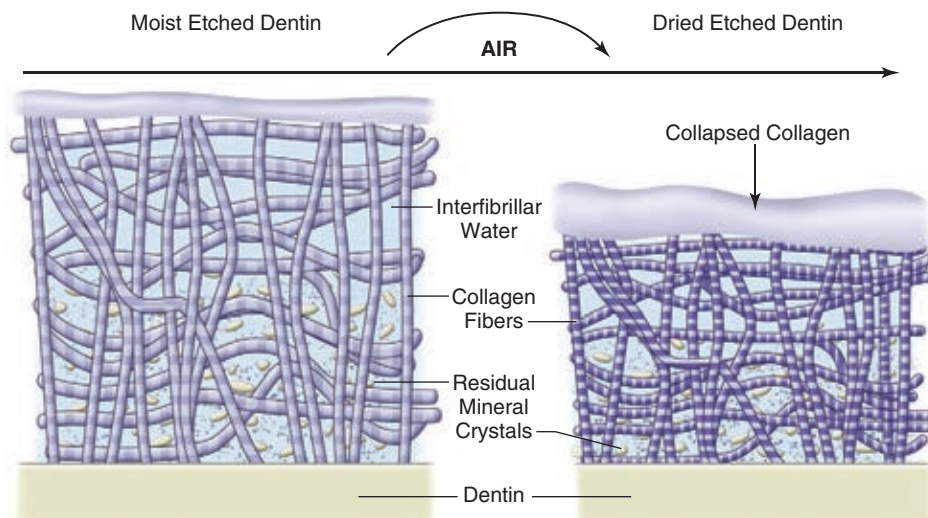


Fig. 4-21 Collapse of etched dentin by air-drying.

extrafibrillar spaces (see Fig. 4-1) open for the penetration of the monomers included in the adhesive systems.¹⁵⁴ During air drying, water that occupies the interfibrillar spaces previously filled with hydroxyapatite crystals is lost by evaporation, resulting in a decrease of the volume of the collagen network to about one third of its original volume.¹⁴⁶ Under the scanning electron microscope, the adhesive does not seem to penetrate etched intertubular dentin that has been dried.¹⁴⁷ Under the transmission electron microscope (TEM), collagen fibers coalesce into a structure without individualized interfibrillar spaces.¹⁴⁷ When air-dried demineralized dentin is re-wetted with water, the collagen matrix may re-expand and recover its primary dimensions to the levels of the original hydrated state.^{144,146,155} This spatial re-expansion is a result of the spaces between fibers being refilled with water, but also re-expansion occurs because type I collagen itself is capable of undergoing expansion on rehydration.¹⁵⁶ The stiffness of decalcified dentin increases when the tissue is dehydrated chemically in water-miscible solvents or physically in air.¹⁴⁴ The increase in stiffness is reversed when specimens are rehydrated in water. Re-wetting dentin after air drying to check for the enamel frosty aspect is an acceptable clinical procedure.^{36,157}

Recently, some *in vitro* research has evaluated the possibility of replacing water with ethanol in the etched dentin collagen network, a technique known as “ethanol wet-bonding.”^{158,159} When acid-etched dentin is saturated with 100% ethanol instead of water, the bond strengths of both hydrophilic and hydrophobic resins increase significantly.^{158,159} Although ethanol wet-bonding appears promising, it involves an extra step of replacing rinsing water with 100% ethanol, and no clinical studies are available. Additionally, the time needed to replace water with ethanol in the dentin collagen network would make the technique difficult to implement in a clinical setting.

Clinically, it is difficult to assess or to standardize the amount of moisture that should be left on the dentin surface before the application of the etch-and-rinse adhesive system. Ideally, water should form a uniform layer without pooling (over-wet) and without dry areas (over-dried). Unless it is done very carefully, air drying with an air-water syringe after rinsing off the etching gel is not recommended because it cannot produce a uniform layer of water on the surface and can cause over-drying of the collagen-rich surface. Laboratory studies have shown that re-wetting over-dried dentin using aqueous solutions of HEMA can increase the wettability of etched dentin and return bond strengths to normal levels, especially when used with adhesives without HEMA in their composition.^{147,160-162} A study showed that the excess water after rinsing the etching gel can be removed with a damp cotton pellet, high-volume suction, disposable brush, or laboratory tissue paper without adversely affecting bond strengths.^{163,164}

Role of Water in Self-Etch Adhesives

Water plays different roles in the bonding mechanisms of self-etch adhesives and etch-and-rinse adhesives. Unlike etch-and-rinse adhesives, self-etch systems do not include separate acid-etching and rinsing steps. The functions of etching and priming are simultaneously performed by the acidic monomers. Water (10–30 weight percent [wt%]) is added to the hydrophilic formulations to ionize the acidic methacrylate

monomers (usually phosphate or carboxylic) and to solubilize calcium and phosphate ions that form from the interaction of the monomers with dentin and enamel.^{165,166} When self-etching primers are formulated, a compromise must be made to provide sufficient water for adequate ionization of the acidic monomers without lowering the monomer concentration to levels that would jeopardize the bonding efficacy. Increasing the water concentration from 0 to 60 volume percent (vol%) resulted in improved acidic monomer ionization and increased depth of dentin demineralization created by the acidic monomers.¹⁶⁶ However, increasing the water concentration dilutes the concentration of the acidic monomer, thereby lowering the bonding efficacy of the respective adhesive system.

The mechanical properties of one-step self-etch adhesives might be significantly compromised in the presence of water, which is less likely to occur with two-step self-etch adhesives.¹⁶⁷ One-step self-etch adhesives have higher water absorption or solubility than two-step self-etch adhesives.¹⁶⁸

Role of Proteins in Dentin Bonding

The partial removal of phospho-proteins from root lesions may enhance the remineralization potential of those lesions.¹⁶⁹ This observation is important because acid-etching demineralizes dentin and may leave a layer of exposed collagen at the bottom of the hybrid layer.^{170,171} It has been reported that when demineralized dentin is restored with an adhesive system, the demineralized layer might undergo remineralization within 4 months.¹⁷²

Some evidence suggests that phosphoric acid causes denaturation of collagen fibers in dentin.⁵² Although evidence suggests that longer etching times might denature the collagen fiber, the normal 15-second etch does not change the spatial configuration of the collagen molecule. Etching for 15 seconds does not compromise the bonding substrate.¹⁷³

Matrix metalloproteinases (MMPs) are zinc- and calcium-dependent endopeptidases capable of degrading all extracellular matrix components.¹⁷⁴⁻¹⁷⁶ In 1999, one study suggested that the direct inhibition of the MMP activity by chlorhexidine might explain the beneficial effects of chlorhexidine in the treatment of periodontitis.¹⁷⁷ Chlorhexidine was first used in dentin bonding as a dentin disinfectant prior to the application of the dentin adhesive. SEM revealed that chlorhexidine debris remained on the dentin surface and within the tubules of etched dentin after rinsing, but chlorhexidine had no significant effect on the dentin shear bond strengths.¹⁷⁸

More recently, research has shifted toward the preservation of the hybrid layer through the inhibition of specific dentin proteases capable of degrading collagen, using chlorhexidine as a protease inhibitor.¹⁷⁹ Collagen fibrils that are not encapsulated by resin might be vulnerable to degradation by endogenous MMPs after acid-etching.¹⁷⁴ Collagenolytic and gelatinolytic activities found in partially demineralized dentin imply the existence of MMP in human dentin.¹⁷⁸ Dentin contains gelatinases (MMP-2 and MMP-9), collagenase (MMP-8), and enamelysin MMP-20.¹⁷⁴⁻¹⁷⁶ These enzymes are trapped within the mineralized dentin matrix during odontogenesis.^{174,176}

Dentin collagenolytic and gelatinolytic activities can be overcome by protease inhibitors, indicating that MMP inhibition might preserve the integrity of the hybrid layer and

reduce the rate of resin–dentin bond degradation within the first few months after restoration.^{179,180} When chlorhexidine is used, the integrity of the hybrid layer and the magnitude of bond strengths are preserved in aged resin–dentin interfaces.^{181,182} When phosphoric acid is applied without the subsequent application of chlorhexidine, it does not inhibit the collagenolytic activity of mineralized dentin. In contrast, the use of chlorhexidine after acid-etching—even in very low concentrations—strongly inhibits that activity.

However, the role of MMPs in dentin bonding is not completely clear for several reasons: (1) The immunoreactivity of MMP-2 is localized preferably in predentin and around the DEJ in teeth from subjects age 12 to 30 years; (2) MMP-2 and MMP-9 are both gelatinases and are unable to degrade the collagen fibrils directly, so the initial degradation step has to be performed by another mechanism; (3) MMPs do not inhibit the degradation of bonded interfaces created by self-etch adhesives; (4) preservation of the hybrid layer can occur even in the absence of MMP inhibitors.^{183–185}

Microleakage and Nanoleakage

“Microleakage” is defined as the passage of bacteria and their toxins between restoration margins and tooth preparation walls. Clinically, microleakage becomes important when one considers that pulpal irritation is more likely caused by bacteria than by chemical toxicity of restorative materials.^{186–188} An adhesive restoration might not bond sufficiently to etched dentin to prevent gap formation at margins.¹⁸⁹ The smear layer itself can serve as a pathway for leakage through the nano-channels within its core.¹⁹⁰

Several studies have shown that the pulpal response to restorative materials is related to the degree of marginal leakage.^{191–194} Bacteria are able to survive and proliferate within the fluid-filled marginal gaps under composite restorations. If the restoration is hermetically sealed, bacteria cannot survive.^{186,193}

In some cases, pulpal inflammation may occur in the absence of bacteria. Some bacterial byproducts such as endotoxins, material from cell walls, and some elements derived from bacterial lipopolysaccharides can cause damage to the pulpal tissue. This damage is initiated when leukocytes migrate into the pulp, sometimes 72 hours after the pulp has been challenged.^{191,195–198}

It is debatable whether the absence of marginal openings would result in a perfect seal between the resin and dentin.¹⁹⁹ Bonding the resin to a preparation with cavosurface margins in enamel is still the best way to prevent microleakage.¹⁵⁰

The occurrence of gaps at the resin–dentin interface may not cause immediate debonding of the restoration. Despite having shown excellent marginal seal in vitro, OptiBond (Kerr Corporation) does not completely seal the interface in vivo.⁶² Other reports showed excellent clinical retention of OptiBond and OptiBond FL in Class V lesions at 12 and 13 years, respectively.^{62,103,104} If a dentin adhesive system does not adhere intimately to the dentin substrate, an interfacial gap eventually develops, and bacteria are able to penetrate through this gap.²⁰⁰ Despite the probability of an incomplete dentin margin seal, Class V clinical studies using etch-and-rinse dentin adhesive systems reported no findings of pulpal inflammation or necrosis.^{45,89} A plausible explanation for this apparent paradox is that a gap forms between the hybrid layer and the

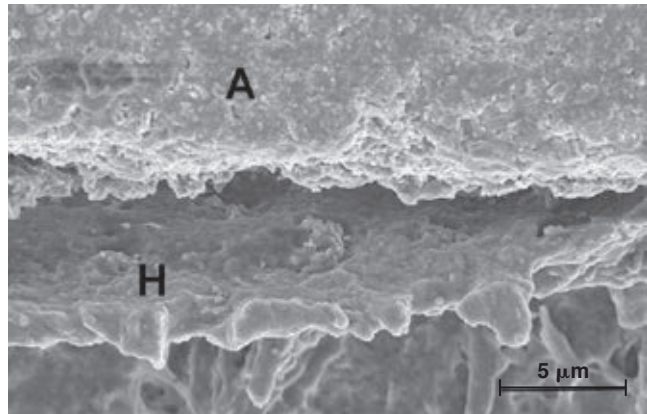


Fig. 4-23 Interfacial gap showing the top of the hybrid layer with tag filling the tubular space. **A**, adhesive; **H**, hybrid layer.

adhesive resin, leaving the tubules still plugged with resin tags (Fig. 4-23).⁶²

In vitro microleakage studies generally involve Class V restorations. Specimens are usually thermocycled and sometimes mechanically loaded to simulate oral conditions.²⁰¹ It has been estimated that 10,000 thermal cycles correspond approximately to 1 year of thermal fatigue in vivo.²⁰² Hot water may accelerate hydrolysis of nonprotected collagen fibers and remove poorly polymerized monomers.^{203,204} To quantify microleakage, specimens are immersed in a disclosing solution such as silver nitrate, basic fuchsin, or methylene blue. The dye penetrates the resin–dentin interface wherever gaps occurred. After the sectioning of teeth, the depth of dye penetration is usually measured and averaged for the sample size. The relationship between the laboratory testing and the oral cavity environment is, however, ambiguous at best. Silver nitrate penetration may be a particularly demanding test of marginal seal because silver ions are smaller than the bacteria that usually live in the oral cavity.²⁰⁵ Some authors have speculated that in vivo leakage is less than the corresponding dye penetration in vitro.

Bond strengths decrease with time, and the resin–dentin interface undergoes ultrastructural changes that jeopardize adhesion.^{203,206,207} When all margins of the restoration are in enamel, the quality and integrity of the bonds remain unchanged with time, at least in vitro.²⁰⁸ Degradation of the bonds might result from hydrolysis, which occurs either in the adhesive resin or in the collagen fibers that are not fully enveloped by the adhesive in the hybrid layer, especially when margins are in dentin.^{203,206,208} A nearly 50% reduction in bond strengths of the 24-hour control has been reported at 1 year with a one-step self-etching adhesive.²⁰⁶ The water absorption (and resulting degradation) of two-step etch-and-rinse adhesives is more pronounced than that of three-step etch-and-rinse adhesives.²⁰⁹

The term “nanoleakage” has been used to describe small porosities in the hybrid layer or at the transition between the hybrid layer and the mineralized dentin that allow the penetration of minuscule particles of a silver nitrate dye.²¹⁰ When ammoniacal silver nitrate is used, silver deposits penetrate the hybrid layer formed by either etch-and-rinse or self-etch adhesive materials.²¹¹ Penetration of ammoniacal silver nitrate results in two distinct patterns of nanoleakage: (1) a spotted

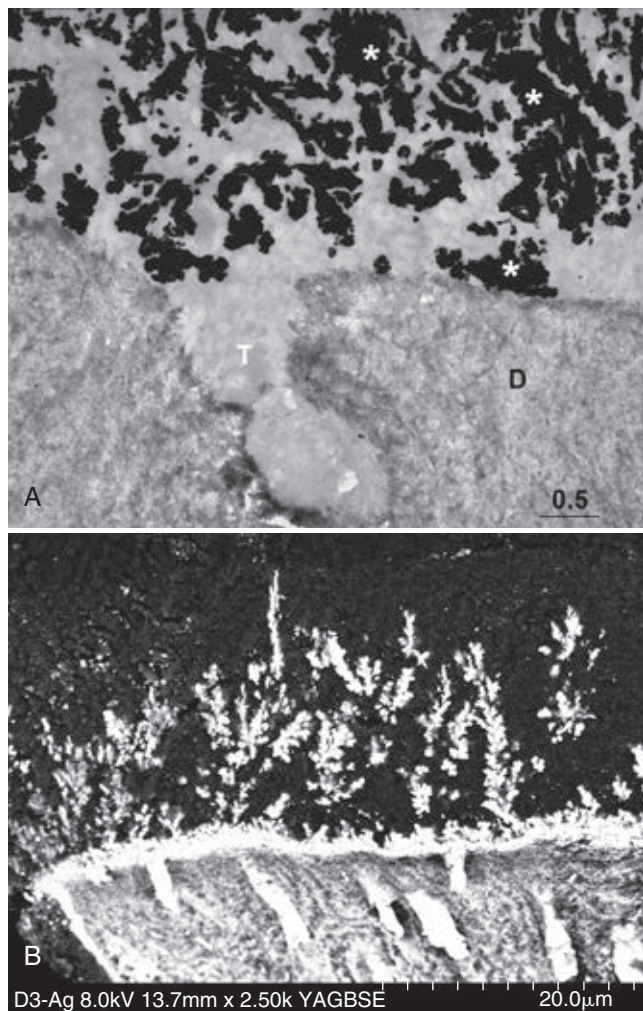


Fig. 4-24 Nanoleakage under the electron microscope. **A**, Spotted pattern in the hybrid layer formed by a one-step self-etch adhesive under the transmission electron microscope (TEM). **B**, Reticular pattern and “water trees” in the adhesive layer formed by a one-step self-etch adhesive under the scanning electron microscope (SEM) in backscattered mode.

pattern in the hybrid layer of self-etch adhesives, which might be caused by incomplete resin infiltration (Fig. 4-24, A), and (2) a reticular pattern that occurs in the adhesive layer, most likely caused by areas where water was not totally removed from the bonding area (see Fig. 4-24, B).²¹²

The term “water trees” is associated with porosities in the polymerized adhesive layer.²¹² Water trees might be one of the factors responsible for degradation of the bonding interface with time.²¹² Silver uptake in hybrid layers formed by one-step self-etch adhesives is associated with areas of increased permeability within the polymerized resin from which water was incompletely removed. The residual water prevents complete polymerization.²¹²

Biocompatibility

Besides demineralizing the dentin surface, phosphoric acid removes the smear layer and opens the orifices of the tubules (see Fig. 4-13).^{35,213} Despite past apprehension about potential acid penetration into the dentin tubules and pulp

space, the interaction of etchants with dentin is limited to the superficial 1 to 7 μm .^{35,101} It is unlikely that the acid is directly responsible for any injury to the pulp.^{214,215} Acid penetration occurs primarily along the tubules, with penetration of intertubular dentin occurring at a lower rate.^{215,216} The effects of etchants on dentin are limited by the buffering effect of hydroxyapatite and other dentin components, including collagen, which may act as a barrier that reduces the rate of demineralization.^{217,218} Marshall et al elucidated the importance of pH with regard to the effects of acids on dentin surfaces.²¹⁵ Etching rates increase dramatically with lower pH. Small differences in pH between acidic gels of similar phosphoric acid concentration may be responsible for distinct depths of dentin demineralization. Manufacturers add thickeners to facilitate handling and other modifiers (e.g., buffers, surfactants, and colorants) to their etching gels, and these may contribute to that phenomenon.

Several early studies suggested that acidic components included in restorative materials such as silicate cements would trigger adverse pulp reactions.^{92,219} For several decades, the development of adhesive systems was limited by the belief that acids applied to dentin during restorative procedures caused pulpal inflammation. The use of bases and liners was considered essential to protect the pulp from the toxicity of restorative materials. This concept has, however, changed over the years.^{185,186,220,221}

Dentin adhesive systems are well tolerated by the pulp–dentin complex in the absence of bacterial infection.²²¹ To prevent bacterial infection, restorations must be hermetically sealed. The pulp response to dentin adhesives, when teeth are restored in an ideal clinical environment, has been studied using histologic assessment of animal pulps or in human premolars extracted for orthodontic reasons and in third molars extracted for surgical reasons.^{188,220–227} Some clinical studies also have reported normal pulp responses after the application of adhesive on the dentin–pulp complex when the pulp is macroscopically exposed, although one report involved only one tooth.^{106,228} Another study showed that the newest dentin adhesive systems are not harmful when applied to exposed pulps.²²⁹ Several reports have shown, however, that etching the pulp and applying a dentin adhesive directly on the exposed pulp tissue results in severe inflammation and eventual formation of pulpal abscesses.^{230–233} The solution for this disparity would be long-term follow-up of patients in whom the pulp was treated with acid and adhesive. Ethical concerns do not allow the routine use of pulpal etching in patients. It is known, however, that the thicker the remaining dentin left between the pulpal aspect of the preparation and the pulp, the better the prognosis for that specific pulp.²³¹ The concept of pulp capping remains a controversial topic.

Adverse pulpal reactions after a restorative procedure are not caused by the material used in that procedure but by bacteria remaining in, or penetrating, the preparation. In some cases, adverse reactions are caused by a combination of factors, as follows:

1. Bacterial invasion of the pulp, either from the tooth preparation or from an existing carious lesion
2. Bacterial penetration into the pulp caused by a faulty restoration
3. Pressure gradient caused by excessive desiccation or by excessive pressure during cementation^{234,235}

4. Traumatic injuries
5. Iatrogenic tooth preparation—excessive pressure, heat, or friction²³⁴
6. Stress derived from polymerization contraction of composites and adhesives

With regard to the biocompatibility issue, tooth preparations with enamel peripheries are important. When all margins are in enamel, polymerization shrinkage stresses at the interface are counteracted by strong enamel adhesion. Marginal gaps are less likely to form, and the restoration is sealed against bacteria.

Relevance of In Vitro Studies

The laboratory parameter most often measured in dentin adhesion is shear bond strength. Flat dentin surfaces are prepared in extracted human or bovine teeth, the adhesive system is applied, and a composite is bonded to the adhesive using a matrix of some type. A shear force is applied at the resin–dentin interface, most often using a knife-edge rod. After testing, the specimens usually are evaluated to determine the nature of the fractures—adhesive, cohesive, or mixed.

The frequency of cohesive failures in the dentinal substrate increases with increasing bond strengths.²³⁶ However, some misinterpretation of cohesive failures in dentin may occur.²³⁷ A mean bond strength of 9.2 MPa has been reported to result in 82% of cohesive failures in dentin, whereas the intrinsic strength of dentin has been reported to be as high as 104 MPa.^{238,239} Cohesive failures of dentin obtained during bond strength testing may result from anomalous stress distribution.²⁴⁰

A major disadvantage of shear bond strength testing is that it does not consider the three-dimensional geometry of tooth preparations and consequent variations in polymerization shrinkage vectors.^{241,242} Additionally, it may not be a true representation of a shear force. In vitro shear bond strength studies are imprecise methods to evaluate the efficacy of dentin adhesive systems.^{243,244}

Although these studies are only rough categorizing tools for evaluating the relative efficacy of bonding materials, they are excellent tools for screening new materials and for comparing the same parameter among different adhesive systems.²⁴⁵ The results of in vitro bond strength tests have been validated with clinical results because improvements seen in the laboratory environment from the earlier generations to contemporary adhesive systems have been confirmed in clinical trials.⁸⁹ The combination of bond strength data with ultramorphologic analysis of adhesive interfaces supplies much useful information concerning the interaction of dentin bonding systems with dental substrates.¹⁶⁹

A systematic analysis of the correlation between in vitro marginal adaptation and the outcome of clinical trials of Class V restorations revealed that the correlation is weak and only present for studies that used the same composite for the in vitro and in vivo evaluation.²⁴⁶ Another systematic review found a correlation between bond strength data and clinical retention rates of Class V restorations, specifically when the bond strength specimens were aged prior to testing.²⁴⁵ The clinical parameter in Class V restorations that is more directly related to bond strength data is marginal adaptation.²⁴⁷

One of the major concerns with laboratory bond strength testing is the wide range of results obtained for the same material in different testing sites. It is not an uncommon occurrence for the same dentin adhesive system to have average shear bond strengths of 20 MPa in one laboratory and bond strengths less than 10 MPa in another.^{51,77} Also, some perplexity exists that no correlation can be established between bond strength and degree of resin penetration into the hybrid layer.^{248,249} To illustrate this discrepancy, some reports have suggested that dentin adhesives do not penetrate the whole depth of the demineralized dentin layer but still result in bond strengths greater than 20 MPa.^{250,251} In such cases, there would be good retention, despite a deficient seal over time, which could be a triggering factor for nanoleakage phenomena.¹⁷⁰ Intuitively, one would expect an inverse relationship between bond strength and microleakage, but that relationship has not been confirmed.²⁵²

Clinical studies with dentin adhesive systems are expensive for manufacturers and take at least 18 months to 3 years. Cost is a major concern, in part because of the constant developments in the area of adhesion, making new materials quickly obsolete. No financial incentive exists for the manufacturer to invest in a clinical study of a material that may not be on the market by the time the study is concluded. Consequently, in vitro studies are still used predominantly by manufacturers to anticipate the clinical behavior of their materials.

Several factors contribute to the questionable use of in vitro tests to predict clinical behavior. Among others, variables including age and storage conditions of the teeth used, dentin depth, degree of sclerosis, tooth surface to be bonded, dentin roughness, and type of test used frequently are not controllable.^{4,5,237,253} According to some authors, one of the major drawbacks of laboratory bond strength testing is the usual lack of simulated pulpal pressure to replicate the pulpal pressure that occurs in vivo. Other authors have reported, however, that the pulpal pressure does not interfere significantly with bond strength results.²⁵⁴

A newer bond strength testing methodology has become popular in recent years.²⁵⁵ This method, the microtensile test, allows for the assessment of bond strengths using bonded surfaces with a cross-sectional area in the range of 1 to 1.5 mm² or even less (Fig. 4-25). Microtensile testing has several advantages over conventional shear and tensile bond strength methods for the following reasons:

1. It permits the use of only one tooth to fabricate several bonded dentin–resin rods.
2. It allows for testing substrates of clinical significance, such as carious dentin, cervical sclerotic dentin, and enamel.²⁵⁶
3. It results in fewer defects occurring in the small-area specimens, as reflected in higher bond strengths.²⁵⁷



Fig. 4-25 Preparation of specimens for microtensile bond strength testing.

4. It allows for the testing of regional differences in bond strengths within the same tooth.²⁵⁸

Clinical Factors in Dentin Adhesion

Several clinical factors may influence the success of an adhesive restoration. The mineral content of dentin increases in different situations, including aged dentin; dentin beneath a carious lesion; and dentin exposed to the oral cavity in non-carious cervical lesions, in which the tubules become obliterated with tricalcium phosphate crystals.^{255,259,260} The dentin that undergoes these compositional changes is called sclerotic dentin and is much more resistant to acid-etching than “normal” dentin.^{97,261} Consequently, the penetration of a dentin adhesive is limited.^{238,261,262} Irrespective of the use of an etch-and-rinse or a self-etch technique, bonding to sclerotic dentin in noncarious cervical lesions has resulted in low bond strengths.^{260,263} Additionally, the clinical effectiveness of dentin adhesives is less in sclerotic cervical lesions than in normal dentin.^{264,265} Nevertheless, some specific dentin adhesives may perform better in sclerotic dentin than in normal dentin.²⁶⁶

Some evidence suggests that masticatory forces not only might cause noncarious cervical lesions but also might contribute to the failure of Class V restorations.^{263,267,268} Bruxism or any other eccentric movement may generate lateral forces that cause concentration of stresses around the cervical area of the teeth. Although this stress may be of very low magnitude, the fatigue caused by cyclic stresses may cause failure of bonds between resin and dentin.

The solvent used in the adhesive monomer solution has been shown to influence the clinical behavior of dentin adhesives. An acetone-based adhesive resulted in lower retention rate than an ethanol-based adhesive in a recent clinical study, which illustrates the technique sensitivity associated with acetone-based adhesives.²⁶⁹

The type of composite used might play an important role in clinical longevity of Class V restorations. Composites shrink as they polymerize, but the amount of shrinkage depends on the inorganic load of each specific composite. Microfilled composites have a low elastic (or Young’s) modulus, which means that they are better able to relieve stresses caused by polymerization or by tooth flexure.^{270,271} Materials that have a higher Young’s modulus do not relieve stresses by flow; they are unable to compensate for the stresses accumulated during polymerization. These stresses subsequently might be transferred to the adhesive interface and cause debonding. As adhesives have improved, however, restorative material stiffness might be less important. A 2-year clinical study of a three-step, etch-and-rinse adhesive showed no difference in retention rates of Class V composite restorations based on stiffness of the restorative material.²⁷² Another clinical study reported that composite stiffness did not affect the clinical longevity of cervical composite restorations.²⁷³

Nevertheless, polymerization shrinkage stresses of composite remain a concern, and stress relief in a restoration is important. Polymerization is initiated on the surface of the restoration, close to the light source, eliminating this surface as a potential stress relief pathway.²⁷⁴ Several methods have been advocated to improve the flow capacity of composites used in Class II tooth preparations. One of those methods is the use of a flowable composite between the composite and the tooth wall. Conceptually, this flowable low-modulus

composite would serve as a shock absorber and simultaneously protect the interface against fatigue stresses.^{241,275} Low-viscosity resins might decrease microleakage when used as part of dentin adhesive systems, but this has never been confirmed clinically.²⁷⁶ The use of flowable composites as an intermediate layer in noncarious cervical lesions or as the gingival increment of Class II preparations, however, has not been proved effective clinically.²⁷⁶⁻²⁸⁰

Incompatibility Issues with Self-Cure and Dual-Cure Composites

Chemically activated and dual-activated composites still have significant use in restorative dentistry, especially in areas of preparations with limited access to light. Examples include crown foundations; bonded posts; and ceramic and composite inlays, onlays, and crowns.

Several studies have reported incompatibility between specific light-cured adhesives and chemically activated composite resins.²⁸¹⁻²⁸³ In one study, Prime & Bond NT (DENTSPLY Caulk), which contains PENTA, a monomer with an acidic phosphate group, did not bond to a self-cured composite unless the adhesive was mixed with a sulfonic acid activator.²⁸³ In another study, the mean bond strength of adhesives decreased by 45% to 91% when self-cured composite was used instead of light-cured composite.²⁸³ The most drastic reduction was associated with Prime & Bond NT. The inhibition of polymerization of the self-cured composites by adhesives with specific compositions seems to be related directly to the pH of the adhesive.²⁸² One-Step, which caused the least reduction in bond strengths between self-cured and light-cured composite, was the adhesive with the highest pH. Prime & Bond NT had the lowest (more acidic) pH.

Similarly, an adverse chemical interaction occurred between catalytic components of chemically cured composite and acidic one-step self-etch adhesives.^{129,284} In contrast, despite the acidity of their primers, some two-step self-etch adhesives might be compatible with self-cure and dual-cure composites, owing to the presence of a thick resin layer that is less permeable and more hydrophobic than the layer formed with all-in-one systems.^{129,284}

Expanded Clinical Indications for Dentin Adhesives Desensitization

Dentin hypersensitivity is a common clinical condition that is difficult to treat because the treatment outcome is not consistently successful. Most authorities agree that the hydrodynamic theory best explains dentin hypersensitivity.²⁶¹ The equivalency of various hydrodynamic stimuli has been evaluated from measurements of the fluid movement induced in vitro and relating this to the hydraulic conductance of the same dentin specimen.²⁸⁵

Patients may complain of discomfort when teeth are subjected to temperature changes, osmotic gradients such as those caused by sweet or salty foods, or even tactile stimuli. Dentin hypersensitivity is a common problem and relatively high prevalence rates have been reported around the world. The cervical area of teeth is the most common site of

hypersensitivity. Cervical hypersensitivity may be caused not only by chemical erosion but also by mechanical abrasion or even occlusal stresses.^{286,287}

Theories about the transmission of pain stimuli in dentin sensitivity suggest that pain is amplified when the dentinal tubules are open to the oral cavity.^{288,289} Dentin hypersensitivity can be a major problem for periodontal patients, who frequently have gingival recession and exposed root surfaces. The relationship between dentin hypersensitivity and the patency of dentin tubules in vivo has been established, and occlusion of the tubules seems to decrease that sensitivity.²⁹⁰ It also has been suggested that the incorrect manipulation of some adhesive materials such as materials containing acetone might trigger postoperative sensitivity.^{148,149} Clinicians have used many materials and techniques to treat dentin hypersensitivity, including specific dentifrices, carbon dioxide (CO₂) laser irradiation, dentin adhesives, antibacterial agents, aldehydes, resin suspensions, fluoride rinses, fluoride varnishes, calcium phosphate, potassium nitrate, and oxalates, among others.^{281,291-299} More recently, dentin-desensitizing solutions also have been used under amalgam restorations and crowns to prevent postoperative sensitivity.³⁰⁰ The use of a dentin desensitizer before cementing full-coverage crowns is supported by studies that showed dentin-desensitizing solutions do not interfere with crown retention, regardless of the type of luting cement used.^{301,302}

The use of dentin adhesives to treat hypersensitive root surfaces has gained popularity.^{303,304} Reductions in sensitivity can result from formation of resin tags and a hybrid layer when a dentin adhesive is used.³⁰⁵ The precipitation of proteins from the dentinal fluid in the tubules also may account for the efficacy of desensitizing solutions.³⁰⁶ Other factors may be involved, however, in the action of dentin desensitizing solutions.³⁰⁷ The primers of the multi-bottle adhesive system All-Bond 2 have a desensitizing effect, even without consistent resin tag formation.³⁰⁸ In a clinical study using the primer of the original GLUMA adhesive system (an aqueous solution of 5% glutaraldehyde and 35% HEMA, currently marketed as GLUMA Desensitizer [Heraeus Kulzer]), the desensitizing solution was applied to crown preparations.³⁰⁹ The authors concluded that GLUMA primer reduced dentin sensitivity through a protein denaturation process with concomitant changes in dentin permeability. Glutaraldehyde has long been used as a fixative that cross-links proteins.³¹⁰ This theory has been supported by studies using confocal microscopy, which found the formation of transversal septa occluding the dentinal tubules after application of GLUMA Desensitizer.³¹¹ Another study evaluated dentin permeability in dogs up to 3 months. At the end of this period, GLUMA Desensitizer had the lowest permeability value, providing a longer lasting tubule-occluding effect.³¹² Another study used human molar dentin slices to compare in vitro the efficacy of five resin-based desensitizing agents, including GLUMA Desensitizer, and reported that all of the desensitizing agents greatly decreased dentin permeability.³¹³

The same glutaraldehyde-based desensitizing agent has been suggested as a re-wetting agent on etched dentin to help prevent postoperative sensitivity under posterior composite restorations.¹⁶¹ In spite of the favorable in vitro bond strengths, a clinical trial found that the operative technique might be more relevant to prevent postoperative sensitivity than the use of the glutaraldehyde-based desensitizer.^{161,314,315}

Indirect Adhesive Restorations

Some current dentin adhesive systems are considered to be universal adhesives because they bond to various substrates besides dentin.^{7,97,316-318} Developments in adhesion technology have led to new indications for bonding to tooth structure, such as indirect ceramic and resin-based restorations (crowns, inlays, onlays, and veneers). The use of a universal adhesive system in conjunction with a resin cement provides durable bonding of indirect restorations to tooth structure.³¹⁹

Ceramic restorations (with the exception of alumina-core porcelains, such as In-Ceram High Strength Ceramic [Vita Zahnfabrik/Vident, Bäd Säckingen, Germany] and zirconia-core porcelain such as Lava [3M ESPE]) must be etched internally with 6% to 10% hydrofluoric acid for 1 to 2 minutes to create retentive microporosities (Fig. 4-26) analogous to those created in enamel by phosphoric acid etching. Hydrofluoric acid must be rinsed off thoroughly with running water. Some clinicians use sandblasting with aluminum oxide particles in the internal surface of the restoration. Mean bond strengths decrease, however, when hydrofluoric acid etching is not used.³²⁰ After rinsing off the hydrofluoric acid and drying with an air syringe, a silane coupling agent is applied on the etched porcelain surface and air dried. The silane acts as a primer because it modifies the surface characteristics of etched

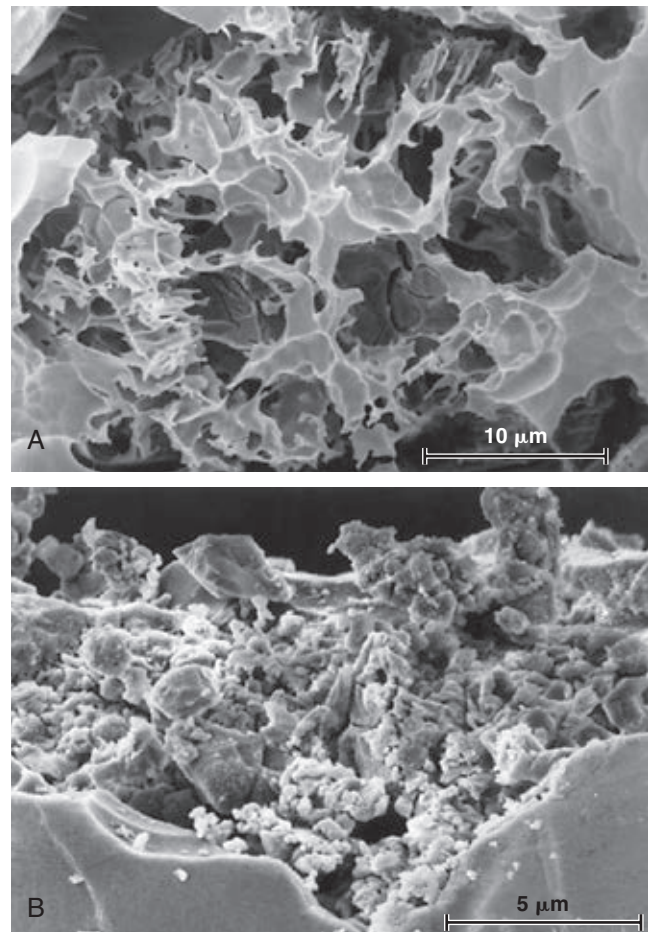


Fig. 4-26 Scanning electron micrograph of Vita (Vita/Vident) dental ceramic etched with 9.6% hydrofluoric acid for 2 minutes. **A**, Top view. **B**, Lateral view.

porcelain. Because etched porcelain is an inorganic substrate, silane makes this surface more receptive to organic materials, the adhesive system, and composite resin cement. Silane coupling agents were introduced in 1952 to bond organic with inorganic substances.³²¹ In 1962, this technology was transferred to dentistry to couple inorganic filler particles with Bis-GMA resin to form a composite.³²² The use of silanes might increase the bond between composite and porcelain in the range of 25%.³²³⁻³²⁵

The discovery of a transformation toughening phenomenon in zirconia (ZrO₂) has led to a new class of strong, tough, dense, relatively flaw-tolerant ceramics.³²⁶⁻³²⁸ The high strength of zirconia-based ceramics is derived from a stress-induced transformation from the metastable tetragonal form to the stable monoclinic form ($t \rightarrow m$).^{327,328} This $t \rightarrow m$ phase transformation can occur in the vicinity of a propagating crack, causing an increase in volume, thereby closing the crack tip and preventing further crack propagation.³²⁶⁻³²⁸ Etching with hydrofluoric acid does not create retentive microporosities in alumina- and zirconia-core porcelain. However, sandblasting with simultaneous “silicatization” of zirconia improves bond strengths.³²⁹ The use of primers containing a phosphonic acid monomer, a phosphate ester monomer, or a carboxylate monomer improves resin bonding to zirconia ceramic.^{330,331}

Many resin cements are dual-cured, that is, they polymerize both chemically and by light activation. Some materials marketed as “dual-cure” do not polymerize efficiently in the absence of a curing light, however.³³²⁻³³⁴ More recently, self-adhesive cements, a new category of resins, have become very popular to cement alumina- and zirconia-based ceramic restorations. Self-adhesive cements are dual-cured phosphate monomer-based resin cements (e.g., RelyX Unicem, 3M ESPE) that do not require any pretreatment of the tooth substrate. The acidic phosphate groups react with the filler and, simultaneously, etch enamel or dentin in the same manner as do self-etch adhesives. A chemical interaction between RelyX Unicem and hydroxyapatite has been reported.³³⁵ The pH of some self-adhesive cements increases from 1 to 5 or 6 during their acid-base setting reaction.³³⁶ The setting pH profiles of self-adhesive resin cements depend on the brand and mode of cure. In spite of their dual-curing ability, the physical properties improve significantly when light-activated.^{335,337}

Summary

Reliable bonding of resins to enamel and dentin has revolutionized the practice of operative dentistry. Improvements in dentin bonding materials and techniques are likely to continue. Even as the materials themselves become better and easier to use, however, proper attention to technique and a good understanding of the bonding process remain essential for clinical success.

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Fundamentals of Tooth Preparation and Pulp Protection

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This chapter emphasizes procedural organization for tooth preparation and associated nomenclature, including the historical classification of caries lesions. In the past, most restorative treatment was for caries, and the term *cavity* was used to describe a caries lesion that had progressed to the point that part of the tooth structure had been destroyed. The tooth was cavitated (a breach in the surface integrity of the tooth) and was referred to as a *cavity*. Likewise, when the affected tooth was treated, the cutting or preparation of the remaining tooth structure (to receive a restorative material) was referred to as *cavity preparation*. Currently, many indications for treatment are not related to carious destruction, and the preparation of the tooth no longer is referred to as *cavity preparation*, but as *tooth preparation*.

Definition of Tooth Preparation

Tooth preparation is the mechanical alteration of a defective, injured, or diseased tooth such that placement of restorative material re-establishes normal form and function, including esthetic corrections, where indicated. This textbook covers such preparations, with the exception of preparation for either a three quarter crown or full crown.

Much of the scientific foundation of tooth preparation techniques was presented by Black.¹ Modifications of Black's principles of tooth preparation have resulted from the influence of Bronner, Markley, J. Sturdevant, Sockwell, and C. Sturdevant; from improvements in restorative materials, instruments, and techniques; and from the increased knowledge and application of preventive measures for caries.²⁻⁶

In the past, most tooth preparations were precise procedures, usually resulting in uniform depths, particular wall forms, and specific marginal configurations. Such precise preparations are still required for amalgam, cast metal, and

ceramic restorations and may be considered *conventional preparations*. Conventional preparations require specific wall forms, depths, and marginal forms because of the properties of the restorative material. The use of adhesive restorations, primarily composites and glass ionomers, has allowed a reduced degree of precision of tooth preparations. Many composite restorations may require only the removal of the defect (caries, fracture, or defective restorative material) and friable tooth structure for tooth preparation, without specific uniform depths, wall designs, retentive features or marginal forms. This simplification of procedures results in a *modified preparation* and is possible because of the physical properties of the composite material and the strong bond obtained between the composite and the tooth structure (Table 5-1).

Much of this chapter presents information about the conventional tooth preparations because of the specificity required. The fundamental concepts relating to conventional and modified tooth preparation are the same: (1) all unsupported enamel tooth structure is normally removed; (2) the fault, defect, or caries is removed; (3) the remaining tooth structure is left as strong as possible; (4) the underlying pulpal tissue is protected; and (5) the restorative material is retained in a strong, esthetic (whenever possible), and functional manner. Conventional preparations achieve these concepts by specific, exact forms and shapes. Modified preparations are usually smaller and have more variable and less complex forms and shapes.

Need for Restorations

Teeth need restorative intervention for various reasons. Dental caries is an infectious disease, and prevention often requires prophylactic restorative procedures (see Chapter 2). Caries

Table 5-1 Tooth Preparation: Amalgam versus Composite

	Amalgam	Composite
Outline form	Include defect May extend to break proximal contact Include adjacent suspicious area	Same Same No Seal these areas
Pulpal depth	Uniform 1.5 mm	Remove defect; not usually uniform
Axial depth	Uniform 0.2-0.5 mm inside DEJ	Remove defect; not usually uniform
Cavosurface margin	Create 90-degree amalgam margin	≥90 degrees
Bevels	None (except gingival)	Large preparation, esthetics, and seal
Texture of prepared walls	Smoother	Rough
Cutting instrument	Burs	Burs or diamonds
Primary retention form	Convergence occlusally	None (roughness/bonding)
Secondary retention form	Grooves, slots, pins, (bonding)	Bonding; grooves for very large or root-surface preparation
Resistance form	Horizontal floors, rounded angles, box-shaped (floors perpendicular to occlusal forces)	Same for large preparations; no special form for small- to moderate-size preparations
Base indications	Provide 2 mm between pulp and amalgam	Not needed
Liner indications	Ca(OH) ₂ , for pulp exposures or near exposures RMGI in deep preparations	Same (also may use RMGI liner on root-surface extensions)
Desensitizer	Dentin desensitizer (5% glutaraldehyde + 35% HEMA) when not bonding	Sealed by bonding system used

Ca(OH)₂, calcium hydroxide; HEMA, 2-hydroxyethyl methacrylate; RMGI, resin-modified glass ionomer.

progression may cause destruction of tooth structure which requires repair. Another common need is the replacement or repair of restorations with serious defects such as improper proximal contact, gingival excess of restorative material, defective (open) margins, or poor esthetics. Restorations also are indicated to restore proper form and function to fractured teeth. Such teeth present with minor to major amounts of missing tooth structure or with an incomplete fracture (“greenstick fracture”), resulting in a tooth that has compromised function and often also associated pain or sensitivity. A tooth may require a restoration simply to restore form or function that is absent as a result of congenital malformation or improper position. Restorations also are required for teeth simply as part of fulfilling other restorative needs. When replacing a missing tooth with a fixed or removable partial denture, the teeth adjacent to the space may require some type of restorative procedure to allow for optimal placement and function of the prosthesis. Careful diagnosis and development of a comprehensive treatment plan must be accomplished before the restoration of individual teeth is pursued to ensure appropriate restorative intervention.

Objectives of Tooth Preparation

Generally, the objectives of tooth preparation are to (1) remove all defects and provide necessary protection to the pulp, (2) extend the restoration as conservatively as possible, (3) form the tooth preparation so that under the forces of mastication, the tooth or the restoration (or both) will not fracture and the restoration will not be displaced, and (4)

allow for the esthetic and functional placement of a restorative material.

Factors Affecting Tooth Preparation

General Factors

Diagnosis

A careful examination must be performed to determine an accurate diagnosis and to render subsequent appropriate treatment. An assessment of pulpal and periodontal status influences the potential treatment of the tooth.

Likewise, an assessment of the occlusal relationships must be made. Such knowledge often affects the design of tooth preparation and the choice of restorative material. For instance, a preparation may require further extension of the outline form to avoid heavy occlusal contact on a marginal interface between the tooth and the restoration.

The relationship of a specific restorative procedure to other treatment planned for the patient also must be considered. For example, if a tooth is planned to be an abutment for a fixed or removable partial denture, the design of the restoration may need to be altered to accommodate optimal success of the prosthesis.

Knowledge of Dental Anatomy

Proper tooth preparation is accomplished through systematic procedures based on specific physical and mechanical principles. A prerequisite for understanding tooth preparation is knowledge of the anatomy of each tooth and its

related parts. A mental image of the individual tooth being prepared must be visualized. The direction of the enamel rods, the thickness of enamel and dentin, the size and position of the pulp, the relationship of the tooth to its supporting tissues, and other factors all must be considered to facilitate appropriate tooth preparation.

Patient Factors

Patient factors play an important role in determining the appropriate restorative treatment rendered. The patient's esthetic concerns, economic status, medical condition, and age should be taken into consideration when selecting the various restorative materials to be used in a given procedure. Older adults who have physical or medical complications may require special positioning for restorative treatment and shorter, less stressful appointments. Because many older adults have new or replacement restorative needs that are completely or partially on the root surfaces, the treatment of many of these areas is more complex.

It is imperative that the level of caries risk be assessed for all patients prior to the initiation of restorative treatment. Patients at high risk for dental caries may require an initial treatment plan designed to limit disease progression (i.e., control caries) until caries risk factors are reduced or eliminated. This initial treatment plan, usually termed *caries control treatment plan*, may be followed by more definitive treatment once the patient's risk for caries has been reduced. In the design of the *definitive treatment plan*, the patient's ongoing risk of caries is taken into consideration. More conservative, less expensive definitive restorative procedures may be indicated until the patient develops oral conditions consistent with low caries risk.

Conservation of Tooth Structure

The primary objective of operative dentistry is to repair the damage from dental caries or trauma while preserving the vitality of the pulp. Pulp tolerance to insult is usually favorable; however, the pulp should not be subjected to unnecessary abuse from poor or careless operative procedures. When less tooth structure is removed, the potential for damage to the pulp is lower.

Every effort should be made to create restorations that are as conservative as possible. Small tooth preparations result in restorations that have less effect on intra-arch and inter-arch relationships and esthetics. Also, it follows that the smaller the tooth preparation is, the stronger will be the remaining unprepared tooth structure.

Restorative Material Factors

The choice of restorative material affects the tooth preparation and is made by considering many factors. The patient's input into the decision is important. Economic and esthetic considerations are primarily patient decisions. The ability to isolate the operating area and the extent of the lesion or defect are factors that the operator must consider in presenting material options to the patient. [Table 5-1](#) compares factors related to restorative choices when choosing between amalgam and composite materials.

An amalgam restoration requires a specific tooth preparation form that ensures (1) retention of the material within the tooth and (2) strength of the material in terms of bulk thickness and marginal edge strength. An indirect cast-metal restoration also requires a specific tooth preparation form that provides (1) draw to provide seating of the rigid restoration, (2) a beveled cavosurface configuration to provide optimal fit, and (3) retention of the casting by virtue of the degrees of parallelism of the prepared walls.

Adhesive composite restorations do not typically require preparations as precise as those for amalgam and cast-metal restorations. Unlike amalgam, adhesively bonded composite does not exhibit low edge strength and micromechanically "bonds" to the tooth structure. These features allow a reduction in the complexity of the tooth preparation. Other adhesive restorations may require more precise tooth preparations. Ceramic inlay or onlay restorations require specific preparation depths, wall designs, and cavosurface marginal configurations that allow for sufficient strength to resist fracture.

Nomenclature

Nomenclature refers to a set of terms used in communication among individuals in the same profession, which enables them to understand one another better. This section details terminology related to tooth defects and preparations.

Caries Terminology

Dental caries is an infectious microbiologic disease that results in localized dissolution and destruction of the calcified tissues of teeth. Caries is episodic, with alternating phases of demineralization and remineralization, and these processes may occur simultaneously in the same lesion.

Location of Caries

Caries can be described according to location, extent, and rate.⁷

PRIMARY CARIES

Primary caries is the original caries lesion of the tooth. The etiology, morphology, control, and prevention of caries are presented in [Chapter 2](#). Variations of this pathologic condition are associated with certain areas of teeth and fundamentally influence tooth preparation. Three morphologic types of primary caries are evident in clinical observation: (1) lesions originating in enamel pits and fissures, (2) lesions originating on enamel smooth surfaces, or (3) lesions originating on root surfaces. Also described in the following sections are backward caries, forward caries, and residual caries. Of these, the terms *backward caries* and *forward caries* are rarely used.

CARIES OF PIT-AND-FISSURE ORIGIN

Complete coalescence of the enamel developmental lobes results in enamel surface areas termed *grooves* and *fossae*. Usually, these areas are not susceptible to caries because they are cleansed by the rubbing of food during mastication. Caries

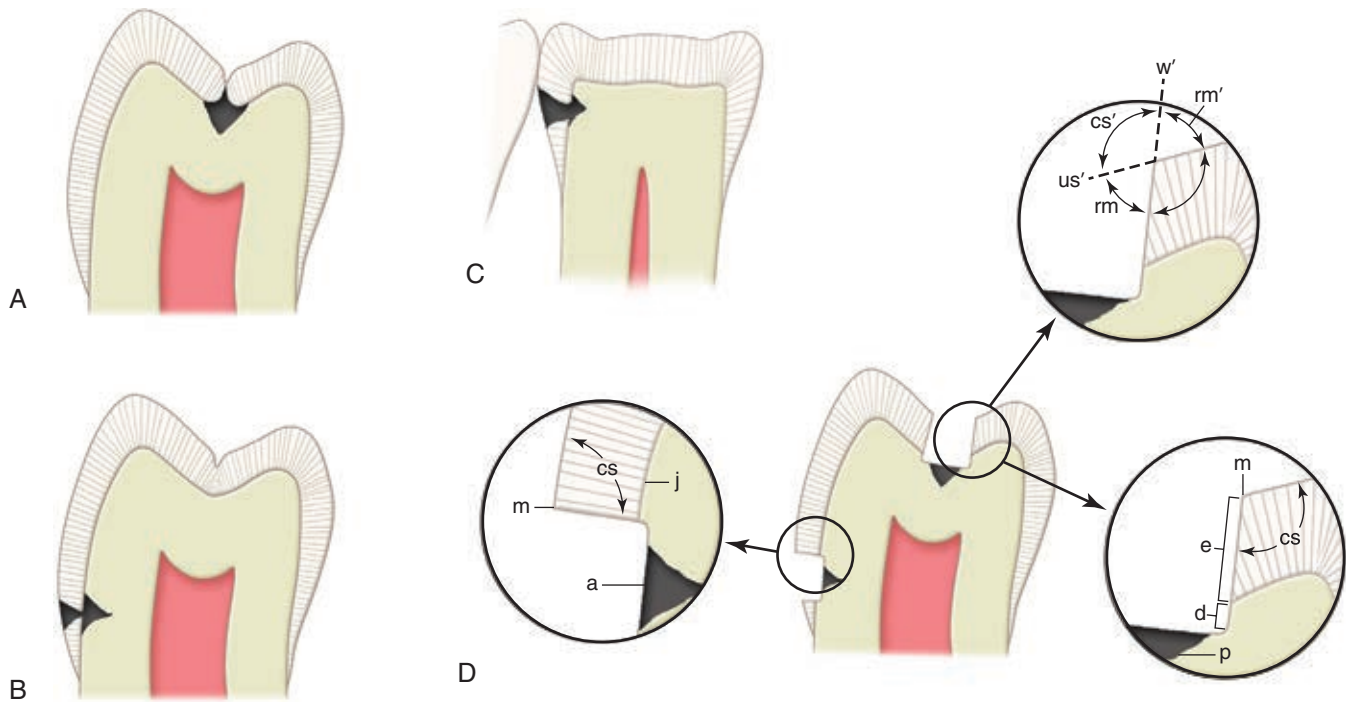


Fig. 5-1 Graphic example of cones of caries in pit and fissure of tooth (A) and on the facial (B) and proximal (C) surfaces when caries has penetrated approximately same depth into dentin. Note the differences in loss of enamel on the external surfaces. Sectional view (D) of initial stage of conventional (amalgam) tooth preparations for lesions in A and B shows cavosurface angle (cs), axial wall (a), pulpal wall (floor) (p), enamel wall (e), dentinal wall (d), margin (m), and DEJ (j). Note, in the upper exploded view, that the cavosurface angle (cs) can be visualized by imaginary projections of the preparation wall (w') and of the unprepared surface (us') contiguous with the margin, forming angle cs' . Angles cs and cs' are equal because opposite angles formed at the intersection of two straight lines are equal. Likewise, minimal restorative material angle rm is equal to angle rm' .

may develop in a groove or fossa, however, in areas of no masticatory action in neglected mouths. Imperfect coalescence of the developmental enamel lobes will result in enamel surface pits and fissures. When such areas are exposed to oral conditions conducive to demineralization, caries may develop (Fig. 5-1, A). The caries forms a small area of penetration in the enamel at the bottom of a pit or fissure and does not spread laterally to a great extent until the dentinoenamel junction (DEJ) is reached. Dentin caries initially spreads laterally along the DEJ and begins to penetrate the dentin toward the pulp via the dentinal tubules. This lateral and pulpal progression results in unsupported enamel. In diagrammatic terms, pit-and-fissure caries may be represented as two cones, base to base, with the apex of the enamel cone at the point of origin and the apex of the dentin cone directed toward the pulp. As caries progresses in these areas, sometimes little evidence is clinically noticeable until the forces of mastication fracture the increasing amount of unsupported enamel.

CARIES OF ENAMEL SMOOTH-SURFACE ORIGIN

Smooth-surface caries does not begin in an enamel defect but, rather, in a smooth area of the enamel surface that is habitually unclean and is continually, or usually, covered by plaque (see Figs. 5-1, B and C). It is emphasized in Chapter 2 that plaque is necessary for caries and that additional oral conditions also must be present for caries to ensue. The enamel disintegration in smooth-surface caries also may be pictured as a cone, but with its base on the enamel surface and the apex at, or directed

toward, the DEJ. The caries again spreads at this junction in the same manner as in pit-and-fissure caries. The apex of the cone of caries in the enamel contacts the base of the cone of caries in the dentin.

BACKWARD CARIES

When the spread of caries along the DEJ exceeds the caries in the contiguous enamel, caries extends into this enamel from the junction and is termed *backward caries* (Fig. 5-2).

FORWARD CARIES

Forward caries is said to be present wherever the caries cone in enamel is larger or at least the same size as that in dentin (see Fig. 5-1, A).⁸

RESIDUAL CARIES

Residual caries is caries that remains in a completed tooth preparation, whether by operator intention or by accident. Such caries is not acceptable if it is present at the DEJ or on the prepared enamel tooth wall (Fig. 5-3). It may be acceptable, however, when it exists as affected dentin, especially near the pulp (see the section *Affected and Infected Dentin*).

ROOT-SURFACE CARIES

Root-surface caries may occur on the tooth root that has been exposed to the oral environment and habitually covered with plaque (Fig. 5-4). Additional oral conditions (discussed in Chapter 2) conducive to caries development also must be

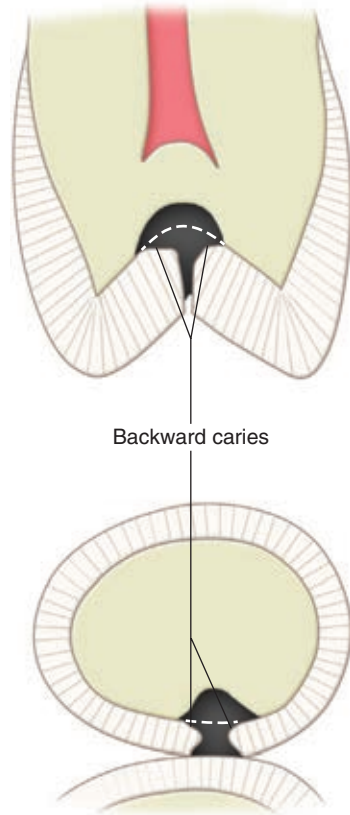


Fig. 5-2 Backward caries extends from the dentinoenamel junction (DEJ) into enamel.

present and often are prevalent in older patients. Root caries is usually more rapid than other forms of caries and should be detected and treated early. Root caries is becoming more prevalent because a greater number of older individuals are retaining more of their teeth and experiencing gingival recession, both of which increase the likelihood of root caries development.

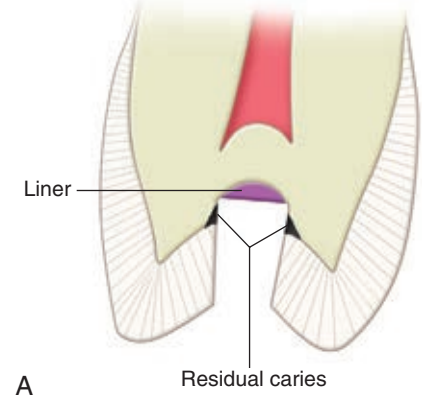
SECONDARY (RECURRENT) CARIES

Secondary caries occurs at the junction of a restoration and the tooth and may progress under the restoration. It is often termed *recurrent caries*. This condition usually indicates that microleakage is present, along with other conditions conducive to caries development (Fig. 5-5).

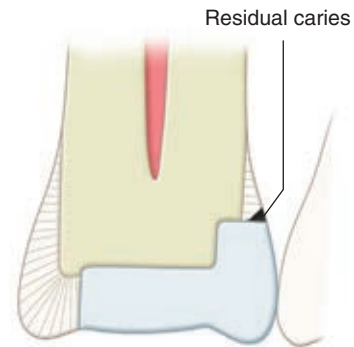
Extent of Caries

INCIPIENT CARIES (REVERSIBLE)

Incipient caries is the first evidence of caries activity in enamel. On smooth-surface enamel, the lesion appears opaque white when air-dried and seems to disappear when wet. This lesion of demineralized enamel has not extended to the DEJ, and the enamel surface is fairly hard, intact, and smooth to the touch. The lesion can be remineralized if immediate corrective measures alter the oral environment, including plaque removal and control. This lesion may be characterized as reversible. A remineralized lesion usually is either opaque white or a shade of brown-to-black from extrinsic coloration, has a hard surface, and appears the same whether wet or dry.



A



B

Fig. 5-3 Unacceptable types of residual caries remaining after tooth preparation at the dentinoenamel junction (DEJ) (A) and on enamel wall of tooth preparation (B). In post-operative radiograph, B appears similar to secondary (recurrent) caries.

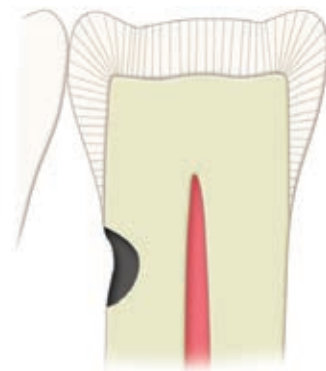


Fig. 5-4 Root-surface caries.

CAVITATED CARIES (IRREVERSIBLE)

In cavitated caries, the enamel surface is broken (not intact), and usually the lesion has advanced into dentin. Usually, remineralization is not possible, and treatment that includes tooth preparation and restoration is indicated.

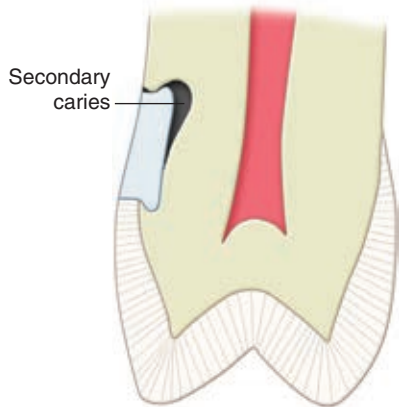


Fig. 5-5 Secondary (recurrent) caries.

Rate (Speed) of Caries

ACUTE (RAMPANT) CARIES

Acute caries, often termed *rampant caries*, refers to disease that rapidly damages the tooth. It is usually in the form of numerous soft, light-colored lesions in a mouth and is infectious. Less time for extrinsic pigmentation explains the lighter coloration.

CHRONIC (SLOW) OR ARRESTED CARIES

Chronic caries is slow, or it may be arrested after several active phases. The slow rate results from periods when demineralized tooth structure is almost remineralized (the disease is episodic over time because of changes in the oral environment). The condition may be found in only a few locations in a mouth, and the lesion is discolored and fairly hard. The slow rate of caries allows time for extrinsic pigmentation. An arrested enamel lesion is brown-to-black in color and hard and as a result of fluoride may be more caries resistant than contiguous, unaffected enamel. An arrested, dentinal lesion typically is “open” (allowing debridement from toothbrushing), dark, and hard, and this dentin is termed *sclerotic* or *eburnated dentin*.

Grooves and Fissures; Fossae and Pits

Chapter 1 presented information on the development of the enamel surface of the tooth. Anatomic depressions mark the location of the union of developmental enamel lobes. Where such union is complete, this “landmark” is only slightly involuted, smooth, hard, shallow, accessible to cleansing, and termed *groove*. Where such union is incomplete, the landmark is sharply involuted to form a narrow, inaccessible canal of varying depths in the enamel and is termed *fissure*. The distinction made between a groove and a fissure also applies to an enamel surface *fossa*, which is nondefective enamel lobe union, and a *pit*, which is defective. A fissure (or pit) may be a trap for plaque and other oral elements that together can produce caries, unless the surface enamel of the fissure or pit walls is fluoride rich.

Extension for Prevention

Black noted that in tooth preparations for smooth-surface caries, the restoration should be extended to areas that are

normally self-cleansing to prevent recurrence of caries.¹ This principle was known as *extension for prevention* and was broadened to include the extension necessary to remove remaining enamel defects such as pits and fissures. The practice of extension for the prevention on smooth surfaces virtually has been eliminated, however, because of the relative caries immunity provided by preventive measures such as fluoride application, improved oral hygiene, and a proper diet. This change has fostered a more conservative philosophy defining the factors that dictate extension on smooth surfaces to be (1) the extent of caries or injury and (2) the restorative material to be used. Likewise, extension for prevention to include the full length of enamel fissures has been reduced by treatments that conserve tooth structure. Tooth structure conservation ultimately leads to restored teeth that are stronger and more resistant to fracture. Such treatments are enameloplasty, application of pit-and-fissure sealant, and preventive resin or conservative composite restoration.⁹

Enameloplasty

Enameloplasty is the removal of a shallow developmental fissure or pit in enamel to create a smooth, saucer-shaped surface that is self-cleansing or easily cleaned. This prophylactic procedure can be applied not only to fissures and pits and deep supplemental grooves but also to some shallow, smooth-surface enamel defects (see *Initial Tooth Preparation Stage* later in the chapter).

Prophylactic Odontotomy

Prophylactic odontotomy is presented only as a historical concept.¹⁰ The procedure involves minimal preparation and amalgam filling of the developmental, structural imperfections of enamel, such as pits and fissures, to prevent caries originating in these sites. Prophylactic odontotomy is no longer advocated as a preventive measure.

Affected and Infected Dentin

Fusayama reported that carious dentin consists of two distinct layers—an outer layer and an inner layer.¹¹ This textbook refers to the outer layer as *infected dentin* and the inner layer as *affected dentin*. In tooth preparation, it is desirable that only infected dentin be removed, leaving affected dentin, which may be remineralized in a vital tooth after the completion of restorative treatment. This principle for the removal of dentinal caries is supported by the observation by Fusayama et al. that the softening front of the lesion always precedes the discoloration front, which always precedes the bacterial front.¹²

Infected dentin has bacteria present, and collagen is irreversibly denatured. It is not remineralizable and must be removed. Affected dentin has no bacteria, and the collagen matrix is intact, is remineralizable, and should be preserved. To clinically distinguish these two layers, the operator traditionally observes the degree of discoloration (extrinsic staining) and tests the area for hardness by the feel of an explorer tine or a slowly revolving bur. Some difficulties occur with this approach because (1) the discoloration may be slight and gradually changeable in acute (rapid) caries, and (2) the hardness (softness) felt by the hand through an instrument may

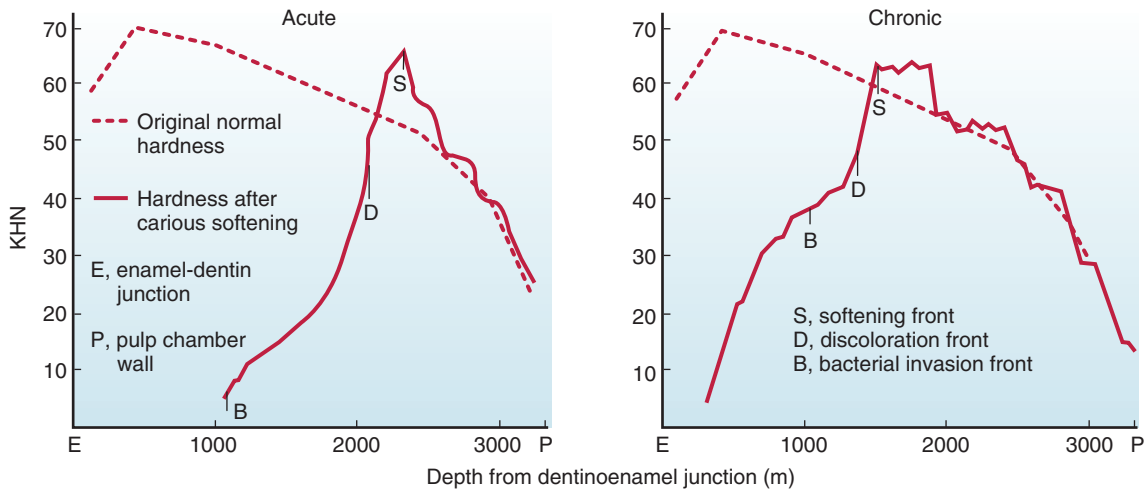


Fig. 5-6 Comparison of acute and chronic caries regarding closeness, hardness, and depth factors of the softening, discoloration, and bacterial invasion fronts.

be an inexact guide. To differentiate between remineralizable and non-remineralizable dentin, staining carious dentin was proposed by Fusayama.¹¹ Caries-detecting dyes are not specific for infected dentin and will stain the slightly demineralized protein matrix of affected dentin as well as normal DEJ.¹³ Caries-detecting dyes should be used with caution and only as an adjunct to clinical evaluation.

In chronic caries, infected dentin usually is discolored, and because the bacterial front is close to the discoloration front, it is advisable, in caries removal, to remove all discolored dentin unless judged to be within 0.5 mm of the pulp (Fig. 5-6). Because the discoloration is slight in acute caries, and the bacterial front is well behind the discoloration front, some discolored dentin may be left, although any “clinically remarkable” discoloration should be removed.¹²

Non-carious Tooth Defects Terminology

Abrasion

Abrasion is abnormal tooth surface loss resulting from direct forces of friction between teeth and external objects or from frictional forces between contacting teeth components in the presence of an abrasive medium.⁸ Abrasion may occur from (1) improper brushing techniques, (2) habits such as holding a pipe stem between teeth, (3) tobacco chewing, or (4) vigorous use of toothpicks between adjacent teeth. Toothbrush abrasion is the most common example and is usually seen as a sharp, V-shaped notch in the gingival portion of the facial aspect of a tooth.

Erosion

Erosion is the wear or loss of tooth surface by chemico-mechanical action. Regurgitation of stomach acid can cause this condition on the lingual surfaces of maxillary teeth (particularly anterior teeth). Other examples are the dissolution of the facial aspects of anterior teeth because of habitual sucking on lemons or the loss of tooth surface from ingestion of acidic beverages.

Attrition

Attrition is the mechanical wear of the incisal or occlusal surface as a result of functional or parafunctional movements of the mandible (tooth-to-tooth contacts). Attrition also includes proximal surface wear at the contact area because of physiologic tooth movement.

Abfraction

It has been proposed that the predominant causative factor of some cervical, wedge-shaped defects is a strong eccentric occlusal force (frequently manifested as an associated wear facet) resulting in microfractures or abfractions. Such microfractures occur as the cervical area of the tooth flexes under such loads. This defect is termed *idiopathic erosion* or *abfraction*.¹⁴

Fractures

Fractures are among the more difficult and challenging defects of teeth, in both diagnosis and treatment.

INCOMPLETE FRACTURE NOT DIRECTLY INVOLVING VITAL PULP

An incomplete fracture not directly involving vital pulp is often termed a “greenstick” fracture. This phenomenon is caused by excessive cyclic loading (or traumatic injury) from occlusal contact with resultant fracture development. The fracture begins in enamel, but becomes painful following propagation into dentin. This condition is very sensitive, and yet the patient may only be able to tell which side of the mouth is affected rather than the specific tooth. It is, therefore, sometimes challenging to diagnose and treat.

COMPLETE FRACTURE NOT INVOLVING VITAL PULP

This represents complete separation of a fragment of the tooth structure in such a way that the pulp is not involved. Usually, pain is not associated with this condition, unless the gingival

border of the fractured segment is still held by periodontal tissue. Restorative treatment (sometimes along with periodontal treatment) is indicated.

FRACTURE INVOLVING VITAL PULP

Fracture involving vital pulp always results in pulpal infection and severe pain. If the tooth is restorable, immediate root canal therapy is indicated; otherwise the tooth must be extracted.

Non-hereditary Enamel Hypoplasia

Non-hereditary enamel hypoplasia occurs when ameloblasts are injured during enamel formation, resulting in defective enamel (diminished form, calcification, or both). It usually is seen on anterior teeth and the first molars in the form of opaque white or light brown areas with smooth, intact, hard surface or as pitted or grooved enamel, which is usually hard and discolored and caused by fluorosis or high fever. The reader should consult a textbook on oral pathology for additional information.

Amelogenesis Imperfecta

In *amelogenesis imperfecta* the enamel is defective in form or calcification as a result of heredity and has an appearance ranging from essentially normal to extremely unsightly.¹⁵

Dentinogenesis Imperfecta

Dentinogenesis imperfecta is a hereditary condition in which only dentin is defective. Normal enamel is weakly attached and lost early. The reader should consult a textbook on oral pathology for additional information.

Tooth Preparation Terminology Simple, Compound, and Complex Tooth Preparations

A tooth preparation is termed *simple* if only one tooth surface is involved, *compound* if two surfaces are involved, and *complex* if a preparation involves three or more surfaces.

Abbreviated Descriptions of Tooth Preparations

For brevity in records and communication, the description of a tooth preparation is abbreviated by using the first letter, capitalized, of each tooth surface involved. Examples are as follows: (1) An occlusal tooth preparation is an “O”; (2) a preparation involving the mesial and occlusal surfaces is an “MO”; and (3) a preparation involving the mesial, occlusal, and distal surfaces is an “MOD”.

Tooth Preparation Walls (Fig. 5-7)

INTERNAL WALL

The *internal wall* is the prepared surface that does not extend to the external tooth surface.

AXIAL WALL

The *axial wall* is the internal wall parallel to the long axis of the tooth.

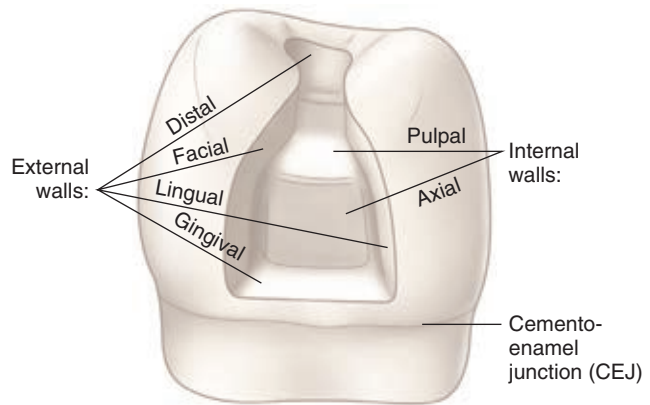


Fig. 5-7 The external and internal walls (floors) for an amalgam tooth preparation.

PULPAL WALL (FLOOR)

The *pulpal wall* is the internal wall that is perpendicular to the long axis of the tooth and occlusal of the pulp.

EXTERNAL WALL

The *external wall* is the prepared surface that extends to the external tooth surface. Such a wall takes the name of the tooth surface (or aspect) that the wall is adjacent to.

FLOOR (OR SEAT)

The *floor* (or seat) is the prepared wall that is reasonably horizontal and perpendicular to the occlusal forces that are directed occlusogingivally (generally parallel to the long axis of the tooth). Examples are pulpal and gingival floors. Such floors may be purposefully prepared to provide stabilizing seats for the restoration, distributing the stresses in the tooth structure rather than concentrating them. This preparation feature increases the resistance form of the restored tooth against post-restorative fracture.

ENAMEL WALL

The *enamel wall* is that portion of a prepared external wall consisting of enamel (see Fig. 5-1, D).

DENTINAL WALL

The *dentinal wall* is that portion of a prepared external wall consisting of dentin, in which mechanical retention features may be located (see Fig. 5-1, D).

Tooth Preparation Angles

Although the junction of two or more prepared surfaces is referred to as *angle*, the junction is almost always “softened” so as to present a slightly rounded configuration. Despite this rounding, these junctions are still referred to as *angles* for descriptive and communicative purposes.

LINE ANGLE

A *line angle* is the junction of two planar surfaces of different orientation along a line (Figs. 5-8 and 5-9). An *internal line angle* is the line angle whose apex points into the tooth. The

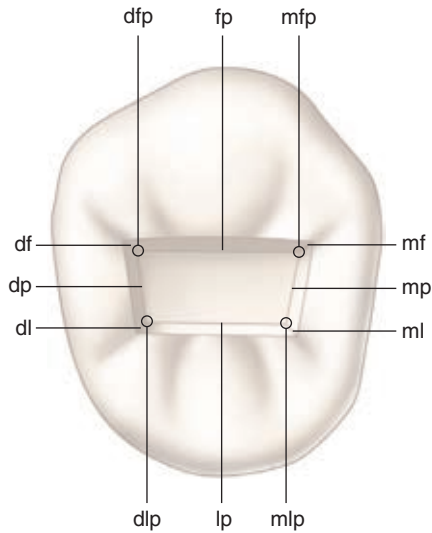


Fig. 5-8 Schematic representation (for descriptive purpose) illustrating tooth preparation line angles and point angles. Line angles are faciopulpal (*fp*), distofacial (*df*), distopulpal (*dp*), distolingual (*dl*), linguopulpal (*lp*), mesiolingual (*ml*), mesiopulpal (*mp*), and mesiofacial (*mf*). Point angles are distofaciopulpal (*dfp*), distolinguopulpal (*dlp*), mesiolinguopulpal (*mlp*), and mesiofaciopulpal (*mfp*).

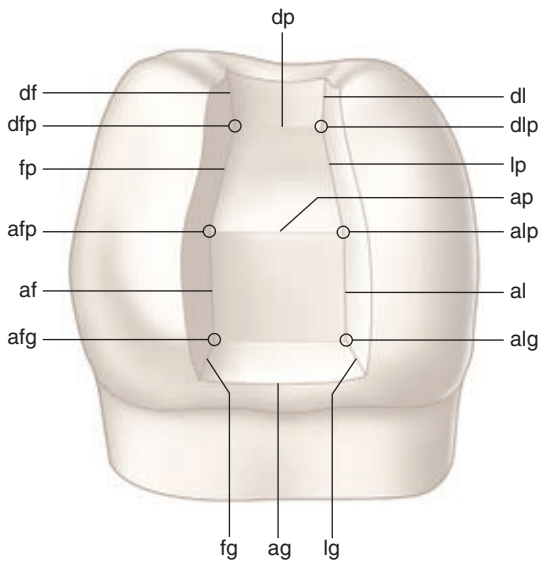


Fig. 5-9 Schematic representation (for descriptive purpose) illustrating tooth preparation line angles and point angles. Line angles are distofacial (*df*), faciopulpal (*fp*), axiofacial (*af*), faciogingival (*fg*), axiogingival (*ag*), linguogingival (*lg*), axiolingual (*al*), axiopulpal (*ap*), linguopulpal (*lp*), distolingual (*dl*), and distopulpal (*dp*). Point angles are distofaciopulpal (*dfp*), axiofaciopulpal (*afp*), axiofaciogingival (*afg*), axiolinguopulpal (*alp*), and distolinguopulpal (*dlp*).

external line angle is the line angle whose apex points away from the tooth.

POINT ANGLE

The *point angle* is the junction of three planal surfaces of different orientation (see Figs. 5-8 and 5-9).

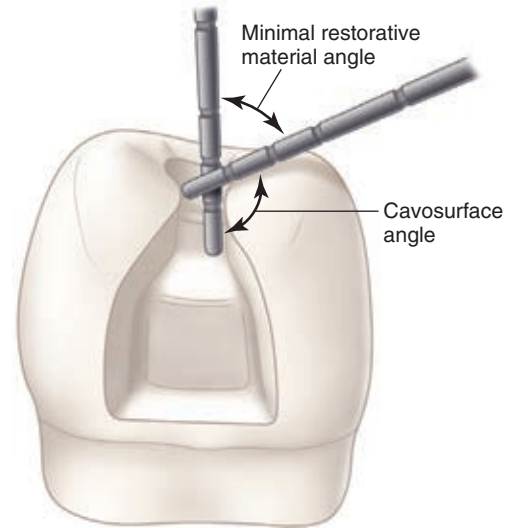


Fig. 5-10 Visualization of the cavosurface angle and the associated minimal restorative material angle for a typical amalgam tooth preparation.

CAVOSURFACE ANGLE AND CAVOSURFACE MARGIN

The *cavosurface angle* is the angle of tooth structure formed by the junction of a prepared wall and the external surface of the tooth. The actual junction is referred to as *cavosurface margin*. The cavosurface angle may differ with the location on the tooth, the direction of the enamel rods on the prepared wall, or the type of restorative material to be used. In Figure 5-1, D, the cavosurface angle (*cs*) is determined by projecting the prepared wall in an imaginary line (*w'*) and the unprepared enamel surface in an imaginary line (*us'*) and noting the angle (*cs'*) opposite to the cavosurface angle (*cs*). For better visualization, these imaginary projections can be formed by using two periodontal probes, one lying on the unprepared surface and the other on the prepared external tooth wall (Fig. 5-10).

Combination of Terms

When discussing or writing a term denoting a combination of two or more surfaces, the *-al* ending of the prefix word is changed to an *-o*. The angle formed by the lingual and incisal surfaces of an anterior tooth would be termed *linguoincisal line angle*. The tooth preparation involving the mesial and occlusal surfaces is termed *mesio-occlusal preparation*, or *MO preparation*. The preparation involving the mesial, occlusal, and distal surfaces is a *mesio-occluso-distal tooth preparation*, or *MOD preparation*.

Enamel Margin Strength

One of the important principles in tooth preparation is the concept of the *strongest enamel margin*. This margin has two significant features: (1) it is formed by full-length enamel rods whose inner ends are on sound dentin, and (2) these enamel rods are buttressed on the preparation side by progressively shorter rods whose outer ends have been cut off but whose

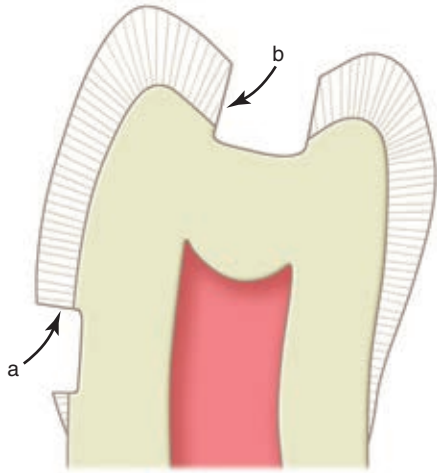


Fig. 5-11 All enamel walls must consist of either full-length enamel rods on sound dentin (a) or full-length enamel rods on sound dentin supported on preparation side by shortened rods also on sound dentin (b).

inner ends are on sound dentin (Fig. 5-11). Because enamel rods usually are perpendicular to the enamel surface, the strongest enamel margin results in a cavosurface angle greater than 90 degrees (see Fig. 5-1).

An enamel margin composed of full-length rods that are on sound dentin but are not buttressed tooth-side by shorter rods also on sound dentin is termed *strong*. Generally, this margin results in a 90-degree cavosurface angle. An enamel margin composed of rods that do not run uninterrupted from the surface to sound dentin is termed *unsupported*. Usually, this weak enamel margin either has a cavosurface angle less than 90 degrees or has no dentinal support.

Vertical (Longitudinal) and Horizontal (Transverse)

Tooth preparation features or sections that are parallel (or nearly so) to the long axis of the tooth crown are commonly described as *vertical*, such as vertical height of cusps, or vertical walls. Sometimes, the term *longitudinal* may be used in lieu of *vertical*. Tooth preparation features that are perpendicular (or nearly so) to the long axis of the tooth are termed *horizontal*, but sometimes referred to as *transverse*.

Intracoronary and Extracoronary Tooth Preparations

An intracoronary tooth preparation is usually “box-like,” having internal and external preparation walls (see Figs. 5-7 to 5-9). With a conservative tooth preparation for the treatment of a small lesion, much of the tooth crown and crown surface is not involved. Nevertheless, the remaining tooth usually is weakened, and the restoration may or may not restore the tooth strength.

Conversely, the extracoronary preparation is usually “stump-like,” having walls or surfaces that result from removal of most or all of the enamel. The extracoronary restoration, termed *crown*, envelops the remaining tooth crown and usually

restores some of its strength. This textbook does not include extracoronary tooth preparation for crown restorations.

Anatomic Tooth Crown and Clinical Tooth Crown

The anatomic tooth crown is the portion of the tooth covered by enamel. The clinical tooth crown is the portion of the tooth exposed to the oral cavity.

Classification of Tooth Preparations

Classification of tooth preparations according to the diseased anatomic areas involved and by the associated type of treatment was presented by Black.¹ These classifications were designated as Class I, Class II, Class III, Class IV, and Class V. Since Black’s original classification, an additional class has been added, Class VI. Class I refers to pit-and-fissure lesions; the remaining classes are smooth-surface lesions. Classification originally was based on the observed frequency of carious lesions on certain aspects of the tooth. Although the relative frequency of caries locations may have changed over the years, the original classification is still used, and the various classes also are used to identify preparations and restorations (i.e., a Class I amalgam preparation or a Class I amalgam restoration).

Class I Preparations

All pit-and-fissure preparations are termed *Class I*. These include preparations on (1) occlusal surfaces of premolars and molars, (2) occlusal two-thirds of the facial and lingual surfaces of molars, and (3) the lingual surfaces of maxillary incisors. Note that a preparation takes the name of the tooth surface (aspect) that will be restored.

Class II Preparations

Preparations involving the proximal surfaces of posterior teeth are termed *Class II*.

Class III Preparations

Preparations involving the proximal surfaces of anterior teeth that do not include the incisal angle are termed *Class III*.

Class IV Preparations

Preparations involving the proximal surfaces of anterior teeth that include the incisal edge are termed *Class IV*.

Class V Preparations

Preparations on the gingival third of the facial or lingual surfaces of all teeth are termed *Class V*.

Class VI Preparations

Preparations on the incisal edges of anterior teeth or the occlusal cusp tips of posterior teeth are termed *Class VI*.

Box 5-1 Steps of Tooth Preparation

Initial tooth preparation stage

- Step 1: Outline form and initial depth
- Step 2: Primary resistance form
- Step 3: Primary retention form
- Step 4: Convenience form

Final tooth preparation stage

- Step 5: Removal of any remaining infected dentin or old restorative material (or both), if indicated
- Step 6: Pulp protection, if indicated
- Step 7: Secondary resistance and retention forms
- Step 8: Procedures for finishing external walls
- Step 9: Final procedures—cleaning, inspecting, desensitizing

Initial and Final Stages of Tooth Preparation

The tooth preparation procedure is divided into two stages, each with several steps. Each stage should be thoroughly understood, and each step should be accomplished as perfectly as possible. The stages are presented in the sequence in which they should be followed if consistent, ideal results are to be obtained. The stages and steps in tooth preparation are listed in Box 5-1.

The sequence is changed under certain circumstances such as extensive caries that may involve the pulp. When this occurs, the sequence of these steps is altered to determine pulpal involvement and protect pulpal tissue as early in the procedure as possible. When necessary, it also is important to place the desired liner, base, or both in the preparation at this time, especially if a pulp capping procedure is necessary.

Before any restorative procedure can be undertaken, the environment in which the procedure will be done must be readied. Most restorative materials require a moisture-free environment; otherwise, the physical properties of the material are compromised. Chapter 7 presents methods of field isolation necessary to ensure the maximal effectiveness of the restorative material. In most cases, the use of the rubber dam best ensures correct isolation.

Treatment and management of the remainder of the oral environment also must be considered. Protecting the contiguous soft tissues in the operating site must be a primary objective. Oral mucosa, lips, cheek, and tongue should be protected against mechanical injury and the possible deleterious effects of substances placed in the mouth during the procedure and restoration.

The following sections present information regarding the initial and final stages of tooth preparation. The information presented is comprehensive and specific primarily for conventional (i.e., amalgam) tooth preparations. Major differences that exist for other types of tooth preparations (primarily for composite) are noted.

Initial Tooth Preparation Stage

Initial tooth preparation involves the extension of the external walls of the preparation at a specified, limited depth so as to

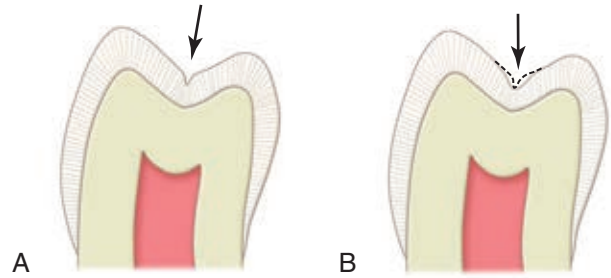


Fig. 5-12 A, Enameloplasty on area of imperfect coalescence of enamel. B, No more than one-third of the enamel thickness should be removed.

provide access to the caries or defect and to reach the peripheral sound tooth structure. The placement and orientation of the preparation walls are designed to resist fracture of the tooth or restorative material from masticatory forces principally directed with the long axis of the tooth and to retain the restorative material in the tooth (except for a Class V preparation). In some situations, non-carious fissures or pits at the periphery of the anticipated external walls are best treated through minor modification of the enamel contours as part of the initial preparation. This procedure is referred to as *enameloplasty* (Fig. 5-12).

Enameloplasty involves the removal of a shallow, enamel developmental fissure or pit to create a smooth, saucer-shaped surface that is self-cleansing or easily cleaned. This prophylactic procedure can be applied not only to fissures and pits and deep supplemental grooves but also to some shallow, smooth-surface enamel defects. Sometimes, a groove or fossa (fissured or not) does not penetrate to any great depth into enamel but still does not allow proper preparation of tooth margins except by undesirable extension. This observation is always true of the end of a fissure. If such a shallow feature is removed, and the convolution of enamel is rounded or “saucered,” the area becomes cleansable and finishable and allows conservative placement of preparation margins. Specific applications of this procedure are covered and illustrated in detail in other chapters pertaining to tooth preparations for gold and amalgam restorations. Enameloplasty does not extend the preparation outline form. The amalgam or gold restorative material is not placed into the recontoured area, and the only difference in the restoration is that the thickness of the restorative material at the enameloplastied margin (or pulpal depth of the external wall) is decreased. This approach differs from including adjacent faulty enamel areas in composite restorations because those areas are covered with the bonded composite material. Such inclusions may restore carious, decalcified, discolored, or poorly contoured areas.

Care is taken when choosing the area which will benefit from enameloplasty. Usually, a fissure should be removed by normal preparation procedures if it penetrates to more than one third the thickness of the enamel in the area. If one third or less of the enamel depth is involved, the fissure may be removed by enameloplasty without preparing or extending the tooth preparation. This procedure is applicable also to supplemental grooves (fissured or not) extending up cusp inclines. If the ends of these grooves were included in the tooth preparation, the cusp could be weakened to the extent that it would need to be capped. Provided that these areas are “saucered” by enameloplasty, the cusp strength can be retained and

a smooth union effected between the restorative material and the enamel margin because the grooved enamel is eliminated.

Another instance in which enameloplasty is indicated is the presence of a shallow fissure that approaches or crosses a lingual or facial ridge. This fissure, if extended under tooth extension principles, would involve two surfaces of the tooth. Use of the enameloplasty procedure often can confine the tooth preparation to one surface and produce a smooth union of the tooth surface and restorative material. An example would be the lingual fissure of a mandibular first molar that terminates on the occlusolingual ridge. Conventional extension should terminate when approximately 2 mm of the tooth structure remains between the bur and the lingual surface, and the remainder of the fissure is then reshaped, provided that the terminal portion of the fissure is no more than one third of the enamel in depth. Otherwise, the tooth preparation must be extended onto the lingual surface.

Enameloplasty may be applied to teeth in which no preparation is anticipated. Extreme prudence must be exercised, however, in the selection of these areas and the depth of enamel removed. This procedure should not be used unless the fissure can be made into a groove with a saucer base by a minimal reduction of enamel, and unless centric contacts can be maintained. For composite preparations, it may be appropriate to seal shallow fissures with sealant or composite material, without any mechanical alteration to the fissure.⁹ In the past, prophylactic odontotomy procedures were used, and these involved minimally preparing developmental or structural imperfections of the enamel, such as pits and fissures, and filling the preparation with amalgam to prevent caries from developing in these sites.¹⁵ Prophylactic odontotomy is no longer advocated as a preventive measure.

Step 1: Outline Form and Initial Depth

The first step in initial tooth preparation is determining and developing the outline form while establishing the initial depth.

DEFINITION

Establishing the outline form means (1) placing the preparation margins in the positions they will occupy in the final preparation except for finishing enamel walls and margins and (2) preparing an initial depth of 0.2 to 0.5 mm pulpally of the DEJ position or 0.8 mm pulpally to normal root-surface position (no deeper initially whether in the tooth structure, air, old restorative material, or caries unless the occlusal enamel thickness is minimal, and greater dimension is necessary for the strength of the restorative material) (Fig. 5-13). The deeper dimension is necessary when placing secondary retention. The outline form must be visualized before any mechanical alteration to the tooth is begun.

PRINCIPLES

The three general principles on which outline form is established regardless of the type of tooth preparation being prepared are as follows: (1) all unsupported or weakened (friable) enamel usually should be removed, (2) all faults should be included, and (3) all margins should be placed in a position to allow finishing of the margins of the restoration. The third

principle has ramifications that differ for pit-and-fissure preparations compared with smooth-surface preparations.

FACTORS

In determining the outline form of a proposed tooth preparation, certain conditions or factors must first be assessed. These conditions affect the outline form and often dictate the extensions. The extent of the caries lesion, defect, or faulty old restoration affects the outline form of the proposed tooth preparation because the objective is to extend to sound tooth structure except in a pulpal direction. The one exception is that occasionally, a tooth preparation outline for a new restoration contacts or extends slightly into a sound, existing restoration (e.g., a new MO abutting a sound DO). This approach is sometimes an acceptable practice (i.e., to have a margin of a new restoration placed into an existing, sound restoration).

In addition to these factors, esthetic and occlusal conditions affect the proposed preparation. Esthetic considerations not only affect the choice of restorative material but also the design of the tooth preparation in an effort to maximize the esthetic result of the restoration. Correcting or improving occlusal relationships also may necessitate altering the tooth preparation to accommodate such changes, even when the involved tooth structure is not faulty (i.e., a cuspal form may need to be altered to effect better occlusal relationships). Likewise, the adjacent tooth contour may dictate specific preparation extensions that secure appropriate proximal relationships and provide the restored tooth with optimal form and strength. Lastly, the desired cavosurface marginal configuration of the proposed restoration affects the outline form. Restorative materials that need beveled margins require tooth preparation outline form extensions that must anticipate the final cavosurface position and form after the bevels have been placed.

FEATURES

Generally, the typical features of establishing proper outline form and initial depth are (1) preserving cuspal strength, (2) preserving marginal ridge strength, (3) minimizing faciolingual extensions, (4) connecting two close (<0.5 mm apart) defects or tooth preparations, and (5) restricting the depth of the preparation into dentin.

Step 2: Primary Resistance Form

DEFINITION

Primary resistance form may be defined as the shape and placement of the preparation walls that best enable the remaining tooth structure and the restoration to withstand, without fracture, masticatory forces delivered principally in the long axis of the tooth. The relatively horizontal pulpal and gingival floors prepared perpendicular to the tooth's long axis help resist forces in the long axis of the tooth and prevent tooth fracture from wedging effects caused by opposing cusps.

PRINCIPLES

The fundamental principles involved in obtaining primary resistance form include (1) using a box shape with a relatively horizontal floor, which helps the tooth resist occlusal loading by virtue of being at right angles to the forces of mastication that are directed in the long axis of the tooth; (2) restricting the extension of the external walls to allow strong cusp and

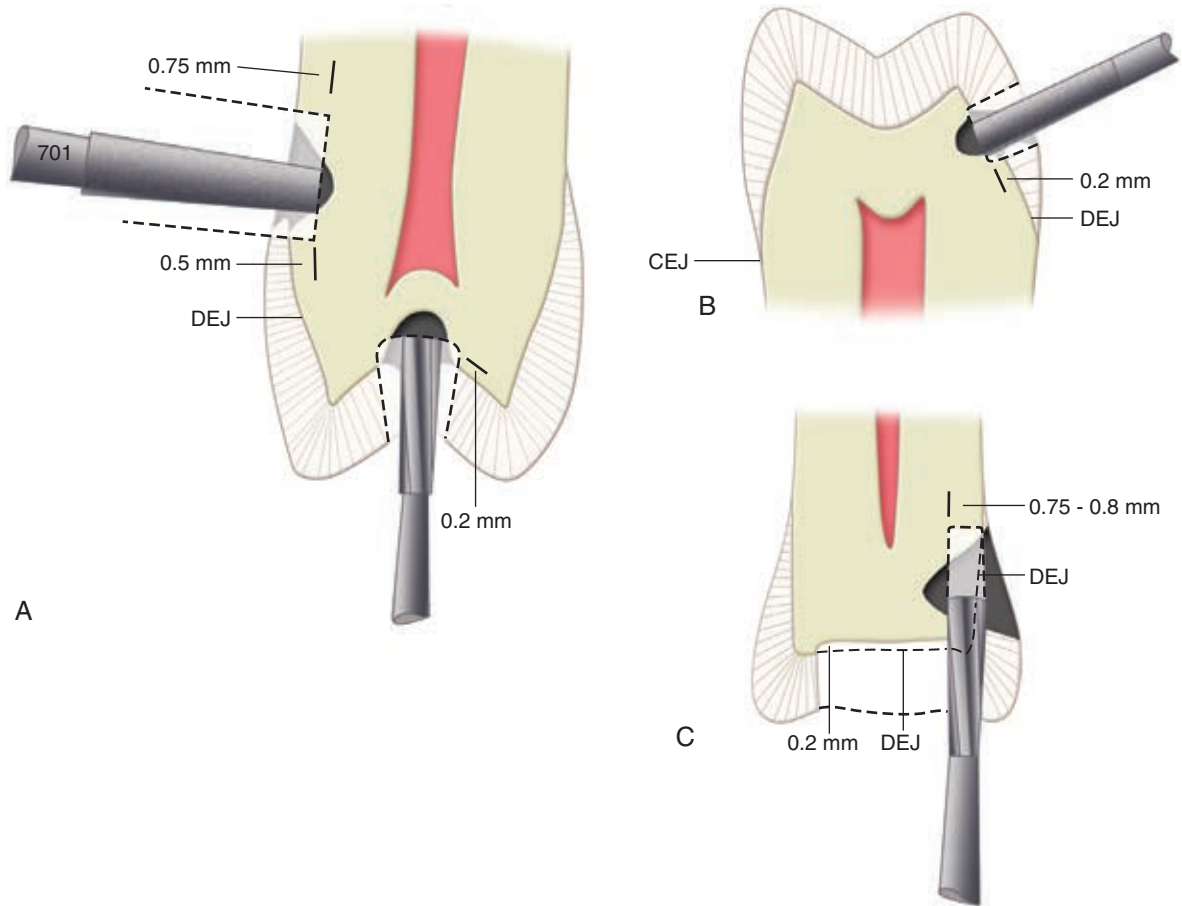


Fig. 5-13 Initial tooth preparation stage for conventional preparations. **A**, **B**, and **C**, Extensions in all directions are to sound tooth structure, while maintaining a specific limited pulpal or axial depth regardless of whether end (or side) of bur is in dentin, caries, old restorative material, or air. The dentinoenamel junction (DEJ) and the cementoenamel junction (CEJ) are indicated in **B**. In **A**, initial depth is approximately two-thirds of 3-mm bur head length, or 2 mm, as related to prepared facial and lingual walls, but is half the No. 245 bur head length, or 1.5 mm, as related to central fissure location.

ridge areas to remain with sufficient dentin support; (3) having a slight rounding of internal line angles to reduce stress concentrations in tooth structure; (4) reducing and covering (capping) weak cusps and enveloping or including enough of a weakened tooth within the restoration in extensive tooth preparations to prevent or resist fracture of the tooth by forces in the long axis and obliquely (laterally) directed forces (most resistance to oblique or lateral forces is attained later in the final tooth preparation stage); (5) providing enough thickness of restorative material to prevent its fracture under load; and (6) bonding the material to the tooth structure, when appropriate. Conventional and beveled preparation designs provide these resistance form principles. Modified tooth preparation designs are for small- to moderate-sized composite restorations and may not require uniform pulpal or minimal thickness for the material.

When developing the outline form in conventional Class I and II preparations, the end of the cutting instrument prepares a relatively horizontal pulpal wall of uniform depth into the tooth (see [Figs. 5-13, A and C](#)). The pulpal wall follows the original occlusal surface contours and the DEJ (these roughly paralleling each other). Similarly, in the proximal portion of conventional Class II preparations, the end of the cutting

instrument prepares a gingival wall (floor) that is horizontal and relatively perpendicular to these forces.

Minimally extended faciolingual walls conserve dentin, supporting the cusps and faciolingual ridges, maintaining as much strength of the remaining tooth structure as possible. This resistance is against the obliquely delivered forces and the forces in the tooth's long axis.

Internal and external angles within the tooth preparation are slightly rounded so that stresses in the tooth and restoration from masticatory forces are not as concentrated at these line angles.^{16,17} Rounding of internal line angles reduces the stress on the tooth, and resistance to fracture of the tooth is increased. Rounding of external angles within the tooth preparation (axiopulpal line angles) reduces the stress on some restorative materials (amalgam and ceramics), increasing resistance to fracture of the restorative material. A tooth weakened by extensive caries deserves consideration of the fourth principle [reducing and capping weakened cusps or extending to include cusps entirely] in obtaining the primary resistance form during tooth preparation. In extensive caries, facial or lingual extension of pulpal or gingival walls indicates (1) reduction of weak cusps for capping by the restorative material ([Fig. 5-14](#)) or (2) extension of the gingival floors around

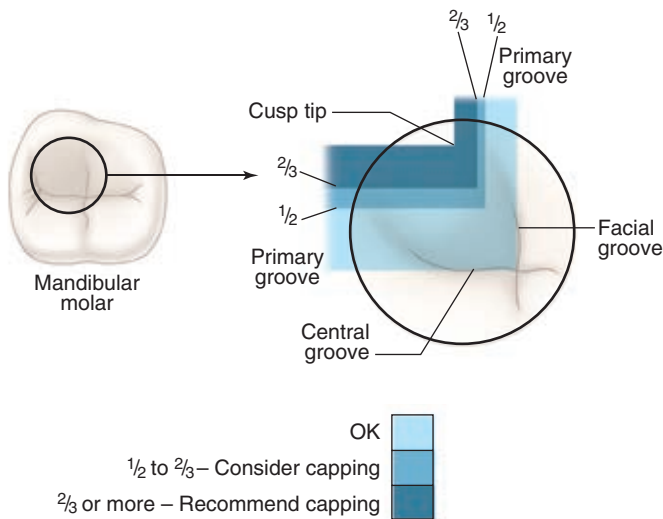


Fig. 5-14 Rule for cusp capping: If extension from a primary groove toward the cusp tip is no more than half the distance, no cusp capping should be done; if this extension is one half to two thirds of the distance, consider cusp capping; if the extension is more than two-thirds of the distance, usually cap the cusp.

axial tooth corners onto facial or lingual surfaces. Either of these features provides some resistance to forces in the long axis and to forces obliquely (laterally) directed. Reduction of cusps occurs as early as possible in the preparation to improve access and visibility. The decision to reduce a cusp is important and should be approached judiciously. The most important aspect in the evaluation of a suspicious cusp is the judgment of the amount of remaining dentin support. In addition, the cusp size and occlusal considerations may affect the decision. A basic general rule guides the reduction of cusps during initial tooth preparation: (1) cusp reduction should be considered when the outline form has extended half the distance from a primary groove to a cusp tip, and (2) cusp reduction usually is strongly recommended when the outline form has extended two-thirds the distance from a primary groove to a cusp tip. The exception to capping a cusp where extension has been two thirds from a primary groove toward the cusp tip is when the cusp is unusually large, when the operator judges that adequate cuspal strength (adequate dentin support) remains, or when a bonded restoration is being used and it is judged that bonding may provide for adequate remaining cuspal strength.¹⁸

In pulpless teeth, special consideration is applied in obtaining resistance form because of the weakened nature of the remaining structure.¹⁹ The weakened cusps may need to be reduced, enveloped, and covered with restorative material to prevent the cracking or splitting of the remaining tooth structure in accord with the fourth principle mentioned previously.

FACTORS

The need to develop resistance form in a preparation is a result of several factors. Certain conditions must be assessed to reduce the potential for fracture of either the restoration or the tooth. Foremost is the assessment of the occlusal contact on the restoration and the remaining tooth structure. The greater the occlusal force and contacts, the greater is the

potential for future fracture (e.g., the further posterior the tooth, the greater is the effective masticatory force because the tooth is closer to the temporomandibular joint [TMJ]).

The amount of remaining tooth structure also affects the need and type of resistance form. Very large teeth, even with extensive caries or defects, may require less consideration of resistance form, especially in regard to capping cusps, because the remaining tooth structure still has sufficient bulk to resist fracture. Weakened, friable tooth structure always should be removed in the preparation, but sometimes unsupported, but not friable, enamel may be left. This is usually for esthetic reasons in anterior teeth, especially on the facial surfaces of maxillary teeth where stresses are minimal and a bonded restoration typically is used.

The type of restorative material also dictates resistance form needs. The minimal occlusal thickness for amalgam for appropriate resistance to fracture is 1.5 mm; cast metal, 1 to 2 mm (depending on the region); and ceramics, 2 mm. The dimensional needs of composite depend more on the occlusal wear potential of the restored area. The thickness requirement is greater for posterior teeth than for anterior teeth. Composite can be used in thinner applications such as veneers or minor esthetic enhancements as long as the wear potential is considered.

The last factor relates to the enhancement of resistance form simply by bonding a restoration to the tooth. Bonding amalgam, composite, or ceramic to prepared tooth structure may increase the strength of the remaining unprepared tooth, reducing the potential for fracture.¹⁸ The benefits of the bonding procedures may permit the operator to leave a portion of the tooth in a more weakened state than usual or not to cap a cusp.

FEATURES

The design features of tooth preparation that enhance primary resistance form are as follows:

1. Relatively horizontal floors
2. Box-like shape
3. Inclusion of weakened tooth structure
4. Preservation of cusps and marginal ridges
5. Rounded internal line angles
6. Adequate thickness of restorative material
7. Reduction of cusps for capping, when indicated

Step 3: Primary Retention Form

DEFINITION

Primary retention form is the shape or form of the conventional preparation that prevents displacement or removal of the restoration by tipping or lifting forces for nonbonded restorations. In many respects, retention form and resistance form are accomplished at the same time (Fig. 5-15). The retention form developed during initial tooth preparation may be adequate to retain the restorative material in the tooth. Sometimes, however, additional retention features must be incorporated in the final stage of tooth preparation. Often, features that enhance the retention form of a preparation also enhance the resistance form (e.g., pins placed in a manner so that one portion of a tooth supports another portion of the tooth).

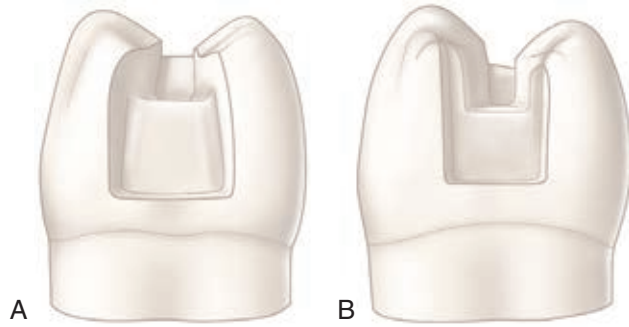


Fig. 5-15 Basic primary retention form in Class II tooth preparations for amalgam (A) with vertical external walls of proximal and occlusal portions converging occlusally and for inlay (B) with similar walls slightly diverging occlusally.

PRINCIPLES

Because retention needs are related to the restorative material used, the principles of primary retention form vary, depending on the material. For amalgam restorations in most Class I and all Class II conventional preparations, the material is retained in the tooth by developing external tooth walls that converge occlusally (see Fig. 5-15, A). In this way, when the amalgam is placed in the preparation and hardens, it cannot be dislodged without some type of fracture occurring. The occlusal convergence should not be excessive which would result in unsupported enamel rods at the cavosurface margin. In other conventional preparations for amalgam (e.g., Class III and V), the external walls diverge outwardly to provide strong enamel margins, and retention coves or grooves are prepared in the dentinal walls to provide the retention form (see Step 7: Secondary Resistance and Retention Forms).

Adhesive systems provide some retention by micromechanically bonding amalgam to tooth structure and reducing or eliminating microleakage.^{20,21} However, these effects appear to have little clinical value for tooth reinforcement. Studies show that bonded amalgams do not result in long-term reinforcement of teeth or improved resistance to fracture.²² Therefore, this book does not promote the use of bonded amalgam restorations.^{23,24}

Composite restorations primarily are retained in the tooth by a micromechanical bond that develops between the material and the etched and primed tooth structure. In such restorations, enamel and dentin are etched by an acid (when using an etch-and-rinse adhesive), and dentin is primed with an adhesive before placement of the composite. Additional retention may be accomplished when the surface area of the enamel available for bonding is increased by a beveled or flared (>90 degrees) enamel marginal configuration. Sometimes, tooth preparation for a composite restoration also requires the use of the mechanical retention form used in preparations for nonbonded restoration, which is considered part of the final stage of preparation.

Cast metal (usually a gold alloy) intracoronal restorations rely primarily on almost parallel vertical walls to provide retention of the casting in the tooth. During the initial tooth preparation, the preparation walls must be designed not only to provide for draw (for the casting to be placed into the tooth) but also to provide for an appropriate small angle of

divergence (2-5 degrees per wall) from the line of draw that would enhance retention form. The degree of divergence needed primarily depends on the length of the prepared walls: The greater the vertical height of the walls, the more divergence is permitted and recommended, but within the range described.

In inlay and onlay preparations for cast-metal restorations, the opposing vertical walls diverge outwardly by only a few degrees to each other and to a draw path that is usually perpendicular to the floor of the preparation (see Fig. 5-15, B). Close parallelism of prepared vertical walls is a principal retention form for cast-metal restorations, another being the use of a luting agent that bonds to tooth structure.

Step 4: Convenience Form

Convenience form is the shape or form of the preparation that provides for adequate observation, accessibility, and ease of operation in preparing and restoring the tooth. Occasionally, obtaining this form may necessitate the extension of distal, mesial, facial, or lingual walls to gain adequate access to the deeper portion of the preparation. The arbitrary extension of facial margins on anterior teeth usually is contraindicated, however, for esthetic reasons.

The occlusal divergence of vertical walls of tooth preparations for Class II cast restorations also may be considered convenience form. Extending proximal preparations beyond proximal contacts is another convenience form procedure. Although exceptions may be made to such an extension, preparing the proximal walls to obtain clearance with an adjacent proximal surface affords better access to finish the preparation walls and the restorative material and to place a matrix. For cast gold restorations, clearance with the adjacent proximal surface is mandatory to finish the preparation walls, make an accurate impression of the prepared tooth, and try-in the casting.

Final Tooth Preparation Stage

When the extensions and wall designs have fulfilled the objectives of initial tooth preparation, the preparation should be inspected carefully for other needs. With very conservative amalgam or composite restorations, the preparation may be complete after initial tooth preparation except for (1) desensitizing the prepared dentin walls for amalgam or (2) etching and priming the prepared walls for the adhesive for amalgam or composite. More involved lesions require additional steps (see steps 5 through 9 below) in the final tooth preparation stage.

Step 5: Removal of Any Remaining Enamel Pit or Fissure, Infected Dentin, or Old Restorative Material, If Indicated

DEFINITION

Removal of any remaining enamel pit or fissure, infected dentin, or old restorative material is the elimination of any infected carious tooth structure or faulty restorative material left in the tooth after initial tooth preparation. In preparations that remain in enamel, removal of any remaining enamel pit or fissure typically occurs as small, minimally extended excavations on isolated faulty areas of the pulpal floor.

In dentin, as caries progresses, an area of decalcification precedes the penetration of microorganisms. This area of decalcification often appears discolored compared with undisturbed dentin, and yet it does not exhibit the soft texture of caries. This dentin condition may be termed *affected dentin* and differs from *infected dentin* in that it has not lost structural integrity to the point which allows ready invasion by microorganisms. It is accepted and appropriate practice to allow affected dentin to remain in a prepared tooth.

The use of color alone to determine how much dentin to remove is unreliable. Often, soft, acute (rapid) caries manifests itself entirely within the normal range of color for dentin; the eye may not differentiate among infected, affected, or unaffected (normal) dentin. Distinctly discolored dentin, certainly affected, may simply be stained or sclerotic and is often comparable in hardness with surrounding unaffected (normal) dentin. A clinical description of exactly where infected dentin stops and affected dentin begins is practically impossible. It is an empiric decision made possible by practical knowledge and experience. The decision does not require exactness, for it is not necessary that all dentin invaded by microorganisms be removed. In shallow or moderately deep lesions, the removal of the masses of microorganisms and the subsequent sealing of the preparation by a restoration at best destroy those comparatively few remaining microorganisms and at worst reduce them to inactivity or dormancy.²⁵ Even in deep caries in which actual invasion of the pulp may have occurred, the recovery of the pulp requires only that a favorable balance be established for the pulp between the virulence of the organisms and the resistance of the host. This balance is often accomplished by removing all soft caries with its numerous organisms.²⁶ See Chapter 2 for caries detection and treatment modalities. However, leaving carious dentin at the DEJ area is unacceptable primarily because enamel requires an uncompromised attachment to dentin to be able to withstand the rigors of the oral environment (see Fig. 5-3).

After initial tooth preparation, the initial depths may result in old restorative material remaining on the pulpal or axial walls. Any remaining old restorative material should be removed if any of the following conditions are present: (1) the old material may affect negatively the esthetic result of the new restoration (i.e., old amalgam material left under a new composite restoration), (2) the old material may compromise the amount of needed retention (i.e., old glass ionomer material having a weaker bond to the tooth than the new composite restoration using enamel and dentin bonding), (3) radiographic evidence indicates caries is under the old material, (4) the tooth pulp was symptomatic pre-operatively, or (5) the periphery of the remaining old restorative material is not intact (i.e., some breach has occurred in the junction of the material with the adjacent tooth structure that may indicate caries under the old material). If none of these conditions is present, it is acceptable to leave the remaining old restorative material to serve as a base, rather than risk unnecessary excavation nearer to the pulp, which may result in pulpal irritation or exposure.

TECHNIQUES

When a pulpal or axial wall has been established at the proper initial tooth preparation position, and a small amount of infected carious material remains, only this material should be removed, leaving a rounded, concave area in the wall. The

level or position of the wall peripheral to the caries removal depression should not be altered.

In large preparations with extensive soft caries, the removal of infected dentin may be accomplished early in the initial tooth preparation. When the extensive caries is removed, the condition of the pulp and the remaining tooth structure has a definite bearing on the type of restoration placed. For this reason, it is more expedient to remove extensive caries early in the tooth preparation before time and effort are spent in doing a tooth preparation for a certain restorative material that is then deemed inadequate for satisfactory restoration of the tooth.

Another instance in which the removal of caries is indicated early in tooth preparation is when a patient has numerous teeth with extensive caries. In one appointment, infected dentin is removed from several teeth, and temporary restorations are placed. After all the teeth containing extensive caries are so treated, individual teeth are restored definitively. This procedure stops the progression of caries and is often referred to as a *caries-control procedure* (see Chapter 2).

With regard to the removal of the harder, heavily discolored dentin, opinions vary among the use of spoon excavators, round steel burs at very low speed, and round carbide burs rotating at high speeds. Several factors must be taken into consideration in the removal of this type of caries in deep-seated lesions, although basically the primary concern is for the pulp. Pulpal damage may result from the creation of frictional heat with the use of a bur. The pulp may become infected by forcing microorganisms into the dentinal tubules through excessive pressure with a spoon excavator, or it may be exposed when either instrument is used. The ideal method of removing this material would be one in which minimal pressure is exerted, frictional heat is minimized, and complete control of the instrument is maintained. Consideration of these factors usually favors the use of a round carbide bur, in a slow- or high-speed handpiece, with air coolant and slow speed. This technique gives the operator complete control of the instrument, minimizes pressure and heat generation, and permits adequate vision of the area being operated on. Examination of the area with an explorer after the removal of infected dentin is advisable, but this should be done judiciously to avoid perforation into the pulp. Caries that rapidly develops sometimes is relatively unstained, and unless the sense of touch is relied on to detect softness, the operator unintentionally may leave infected dentin. Ideally, removal of infected dentin should continue until the remaining dentin hardness approaches that of normal dentin. Heavy pressure should not be applied with an explorer, however, or any other instrument, on what is believed to be a thin layer of reasonably firm dentin next to a healthy pulp, to avoid creating unnecessary pulpal exposure.

Removal of remaining old restorative material, when indicated, also is accomplished with use of a round carbide bur, at slow speed (just above stall-out) with air or air-water coolant. The water spray (along with high-volume evacuation) is used when removing old amalgam material to reduce the amount of mercury vapor.

Step 6: Pulp Protection, If Indicated

Although the placement of liners and bases is not a step in tooth preparation, in the strict sense of the term, it is a step

in adapting the preparation for receiving the final restorative material. The reason for using liners or bases is to protect the pulp or to aid pulpal recovery or both. Pulpal irritation that occurs during or after operative procedures may result from (1) heat generated by rotary instruments, (2) some ingredients of various materials, (3) thermal changes conducted through restorative materials, (4) forces transmitted through materials to the dentin, (5) galvanic shock, and (6) the ingress of noxious products and bacteria through microleakage.²⁷

Because the ingress of bacteria is most commonly associated with various pulpal responses, more emphasis should be given to the complete sealing of the prepared dentinal tubules. Effective tubular sealing may prevent penetration of bacteria into the tubules and limit the retrograde diffusion of bacterial toxins toward the pulp.

Certain physical, chemical, and biologic factors should be considered in the selection of a liner or base. The material used should be one that, under the circumstances, more nearly satisfies the needs of the individual tooth and is based on an assessment of the anatomic, physiologic, and biologic response characteristics of the pulp and the physical and chemical properties of the considered material.

In the following discussion of liners and bases, the use of the term *liners* may include suspensions or dispersions of zinc oxide, calcium hydroxide, or resin-modified glass ionomer (RMGI) that can be applied to a tooth surface in a relatively thin film.²⁰ Liners also may provide (1) a barrier that protects the dentin from noxious agents from either the restorative material or oral fluids, (2) initial electrical insulation, or (3) some thermal protection.²⁸ *Bases* are materials, most commonly cements, that are used in thicker dimensions beneath permanent restorations to provide for mechanical, chemical, and thermal protection of the pulp. Examples of bases include zinc phosphate, zinc oxide–eugenol, polycarboxylate, and the most common, some type of glass ionomer (usually an RMGI).

A liner is used to medicate the pulp when suspected trauma has occurred. The desired pulpal effects include sedation and stimulation, the latter resulting in reparative dentin formation. The specific pulpal response desired dictates the choice of liner. If the removal of infected dentin does not extend deeper than 1 to 2 mm from the initially prepared pulpal or axial wall, usually no liner is indicated. If the excavation extends into or within 0.5 mm of the pulp, a calcium hydroxide liner usually is selected to stimulate reparative dentin (indirect pulp cap procedure).²⁹

Zinc oxide–eugenol and calcium hydroxide liners (chemo-setting types that harden) in thicknesses of approximately 0.5 mm or greater have adequate strength to resist condensation forces of amalgam and provide protection against short-term thermal changes.³⁰ *Calcium hydroxide liners must always be covered with an RMGI to prevent dissolution of the liner over time when used under amalgam restorations.* Generally, it is desirable to have approximately a 2-mm dimension of bulk between the pulp and a metallic restorative material. This bulk may include remaining dentin, liner, or base. Base materials offer pulpal protection from mechanical, thermal, and chemical irritants. For composite restorative materials, which are thermal insulators, the calcium hydroxide should be covered by an RMGI to protect the liner from dissolution from the etchant used for the composite placement.^{27,31} Very deep excavations may contain microscopic pulpal exposures that are not

visible to the naked eye. Hemorrhage is the usual evidence of a vital pulp exposure, but with microscopic exposures, such evidence may be lacking. Nevertheless, these exposures are large enough to allow direct pulpal access for bacteria and fluids. The ability of hard-setting calcium hydroxide materials to stimulate the formation of reparative dentin when it is in contact with pulpal tissue makes it the usual material of choice for application to very deep excavations and known pulpal exposures (direct pulp cap procedures).²⁹ Liners and bases in exposure areas should be applied without pressure.

Usually, an RMGI is used for “base” needs. These materials effectively bond to tooth structure, release fluoride, and have sufficient strength. They are easily placed and contoured, when necessary. Because of their chemical and micromechanical bond to tooth structure, retentive preparation features are not typically required. These materials are excellent for use under amalgam, gold, ceramic, and composite restorations.

The protective qualities of zinc phosphate, polycarboxylate, and glass ionomer cements are in proportion to the bulk of material used. A thin layer does not afford the protection of a thicker layer. The level to which a base is built should never compromise the desired tooth preparation depth, resulting in inadequate restorative material thickness.

Step 7: Secondary Resistance and Retention Forms

After any remaining enamel pit or fissure, infected dentin, or old restorative material (if indicated) has been removed, and pulpal protection has been provided by appropriate liners and bases, additional resistance and retention features may be deemed necessary for the preparation. Many compound and complex preparations require these additional features. When a tooth preparation includes occlusal and proximal surfaces, each of those areas should have independent retention and resistance features.

Because many preparation features that improve retention form also improve resistance form, and the reverse is true, they are presented together. The *secondary retention and resistance forms* are of two types: (1) mechanical preparation features and (2) treatments of the preparation walls with etching, priming, and adhesive materials. The second type is not really considered a part of tooth preparation but, rather, the first step for the insertion of the restorative material. Regardless, some general comments are presented about such treatments.

MECHANICAL FEATURES

A variety of mechanical alterations to the preparation enhance retention form, and these alterations require additional removal of tooth structure.

Retention Grooves and Coves

Vertically oriented retention grooves are used to provide additional retention for the proximal portions of some conventional tooth preparations. Horizontally oriented retention grooves are prepared in most Class III and Class V preparations for amalgam and in some root-surface tooth preparations for composite. Retention coves are placed for the incisal retention of Class III amalgams.

Historically, retention grooves in Class II preparations for amalgam restorations were recommended to increase retention of the proximal portion against movement proximally secondary to creep. Also, it was thought that they may increase the resistance form of the restoration against fracture at the junction of the proximal and occlusal portions. In vivo studies do not substantiate the necessity of these grooves in proximo-occlusal preparations with occlusal dovetail outline forms or in MOD preparations.^{4,32} They are recommended, however, for extensive tooth preparations for amalgam involving wide faciolingual proximal boxes, cusp capping, or both. Therefore, mastery of the techniques of optimal groove design and placement is indicated.

Preparation Extensions

Additional retention of the restorative material may be obtained by arbitrarily extending the preparation for molars onto the facial or lingual surface to include a facial or lingual groove. Such an extension, when performed for cast metal restorations, results in additional vertical, almost-parallel walls for retention. This feature also enhances resistance for the remaining tooth owing to envelopment.

Skirts

Skirts are preparation features used in cast gold restorations that extend the preparation around some, if not all, of the line angles of the tooth. When properly prepared, skirts provide additional, opposed vertical walls for added retention. The placement of skirts also significantly increases resistance form by enveloping the tooth, resisting fracture of the remaining tooth from occlusal forces.

Beveled Enamel Margins

Cast metal and some composite restorations include beveled marginal configurations. The bevels for cast metal may improve retention form slightly when opposing bevels are present but are used primarily to afford a better junctional relationship between the metal and the tooth. Enamel margins of some composite restorations may have a beveled or flared configuration to increase the surface area of etchable enamel and to maximize the effectiveness of the bond by etching more enamel rod ends.

Pins, Slots, Steps, and Amalgam Pins

When the need for increased retention form is unusually great, especially for amalgam restorations, several other features may be incorporated into the preparation. Pins and slots increase retention and resistance forms. Amalgam pins and properly positioned steps also improve retention form, but not to the extent of pins or slots.

PLACEMENT OF ETCHANT, PRIMER, OR ADHESIVE ON PREPARED WALLS

In addition to mechanical alterations to the tooth preparation, certain alterations to the preparation walls by actions of various materials also afford increased retention and resistance to fracture. Enamel and dentin surfaces may be treated with etchants or primers or both for certain restorative procedures.

Enamel Wall Etching

Enamel walls are etched for bonded restorations that use ceramic, composite, and amalgam materials. This procedure

consists of etching the enamel with an appropriate acid, resulting in a microscopically roughened surface to which the bonding material is mechanically bound.

Dentin Treatment

Dentinal surfaces may require etching and priming when using bonded ceramic, composite, or amalgam restorations. The actual treatment varies with the restorative material used, but for most composite restorations, a dentin bonding agent is recommended. Retention of indirect restorations may be enhanced by the luting agent used. Although not considered part of the tooth preparation, the cementation procedure does affect the retention of these restorations, and some cementing materials require pretreatment of the dentin, resulting in varying degrees of micromechanical bonding.

Step 8: Procedures for Finishing the External Walls of the Tooth Preparation

Finishing the external walls of the preparation entails consideration of degree of smoothness and cavosurface design because each restorative material has its maximal effectiveness when the appropriate conditions are developed for that specific material. Not all preparations require special finishing of the external walls at this stage because the walls already may have been finished during earlier steps in the preparation. This is particularly true for many composite preparations and most amalgam preparations.

Because most preparations have external walls in enamel, most of the following discussion relates to the appropriate finishing of enamel walls. Nevertheless, when a preparation has extended onto the root surface (no enamel present), the root-surface cavosurface angle should be either 90 degrees (for amalgam, composite, or ceramic restorations) or beveled (for intracoronal cast metal restorations). The 90-degree, root-surface margin provides a butt joint relationship between the restorative material and the cementum or dentin preparation wall, a configuration that provides appropriate strength to both.

DEFINITION

Finishing the preparation walls is the further development, when indicated, of a specific cavosurface design and degree of smoothness or roughness that produces the maximum effectiveness of the restorative material being used.

OBJECTIVES

The objectives of finishing the prepared walls are to (1) create an optimal marginal junction between the restorative material and the tooth structure, (2) afford a smooth marginal junction, and (3) provide maximal strength of the tooth and the restorative material at and near the margin. The following factors must be considered in the finishing of enamel walls and margins: (1) the direction of the enamel rods, (2) the support of the enamel rods at the DEJ and laterally (preparation side), (3) the type of restorative material to be placed in the preparation, (4) the location of the margin, and (5) the degree of smoothness or roughness desired.

Theoretically, the enamel rods radiate from the DEJ to the external surface of the enamel and are perpendicular to the tooth surface. All rods extend full length from dentin to the enamel surface. The rods converge from the DEJ toward

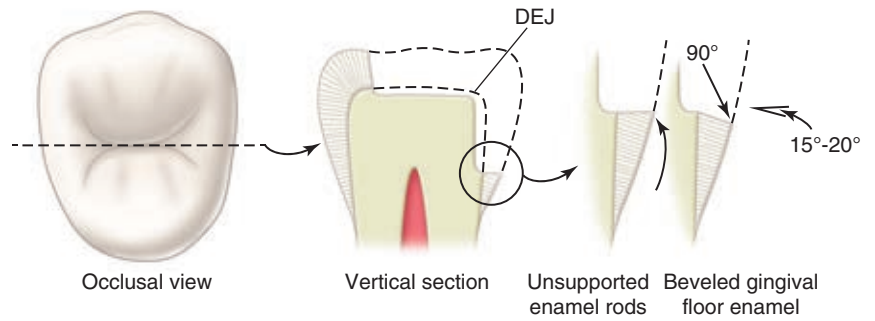


Fig. 5-16 Vertical section of Class II tooth preparation. Gingival floor enamel (and margin) is unsupported on dentin and friable unless removed.

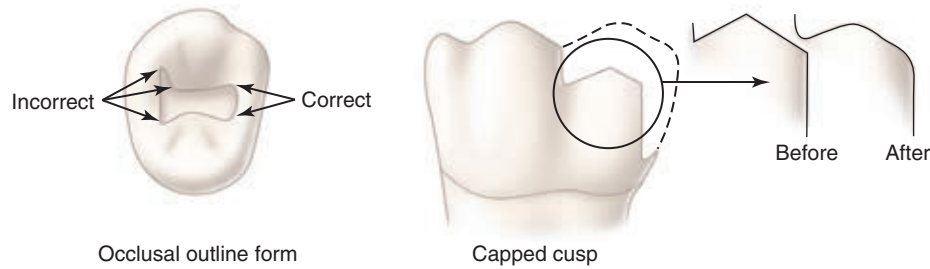


Fig. 5-17 The junctions of enamel walls (and respective margins) should be slightly rounded, whether obtuse or acute.

concave enamel surfaces and diverge outwardly toward convex surfaces. In general, the rods converge toward the center of developmental grooves and diverge toward the height of cusps and ridges (see Figs. 5-1, B and C). In the gingival third of enamel of the smooth surfaces in the permanent dentition, the rods incline slightly apically (Fig. 5-16).

In some instances, the rods of occlusal enamel seem to be harder than those of axial (mesial, facial, distal, lingual) enamel. This difference can be attributed to the amount of interlacing or twisting of the rods in the former compared with the straight rods of the latter. Enamel with such interlacing of the rods is termed *gnarled enamel*.

Enamel walls should be oriented such that all rods forming the prepared enamel wall have their inner ends resting on sound dentin. Enamel rods that do not run uninterrupted from the preparation margin to dentin tend to split off, leaving a V-shaped ditch along the cavosurface margin area of the restoration. This should not be interpreted to mean that all enamel walls should consist of full-length rods. The strongest enamel margin is one that is composed of full-length enamel rods supported on the preparation side by shorter enamel rods, all of which extend to sound dentin (see Fig. 5-11). The shorter enamel rods buttress the full-length enamel rods that form the margin, increasing the strength of the enamel margin.

An acute, abrupt change in an enamel wall outline form results in fracture potential, even though the enamel may have dentin support. The preparation outline and walls should have smooth curves or straight lines. When two enamel walls join, the resulting line angle may be “sharp.” If so, it should be slightly curved (“softened”). This slight rounding usually results in a similar curve at the margin. In other words, line angles formed by the junction of enamel walls should be slightly rounded whether they are obtuse or acute (Fig. 5-17).

FEATURES

Finishing of external walls has two primary features: (1) the design of the cavosurface angle and (2) the degree of smoothness or roughness of the wall. The design of the cavosurface angle depends on the restorative material being used. Because of the low edge strength of amalgam and ceramic, a 90-degree cavosurface angle produces maximal strength for these materials and the tooth. No bevels are placed at the cavosurface margin. On occlusal surfaces for Class I and Class II amalgam restorations, the incline planes of the cusp and the converging walls (for retentive purposes) of the preparation approximate the desirable 90 degree butt joint junction, even though the actual occlusal enamel margin may be greater than 90 degrees.

Beveling the external walls is a preparation technique used for some materials, such as intracoronal cast-gold or cast-metal and composite restorations.

Beveling can serve four useful purposes in the tooth preparation for a casting: (1) it produces a stronger enamel margin, (2) it permits a marginal seal in slightly undersized castings, (3) it provides marginal metal that is more easily burnished and adapted, and (4) it assists in adaptation of gingival margins of castings that fail to seat by a slight amount.

When amalgam is used, beveling is contraindicated except on the gingival floor of a Class II preparation when enamel is still present. In these instances, it is usually necessary to place a slight bevel (approximately 15-20 degrees) only on the enamel portion of the wall to remove unsupported enamel rods. This is necessary because of the gingival orientation of enamel rods in the cervical area of the tooth crown. This minimal bevel may be placed with an appropriate gingival margin trimmer hand instrument and, when placed, still results in a 90 degree amalgam marginal angle (see Fig. 5-16).

Sometimes, the unsupported enamel rods are removed simply by an explorer tip pulled along the margin.

Beveling enamel margins in composite preparations is indicated primarily for larger restorations that have increased retention needs. The use of a beveled marginal form with a composite tooth preparation may be advocated because the potential for retention is increased by increasing the surface area of enamel available for etch and having a more effective area of etch obtained by etching the cut ends of the enamel rods. Other advantages of beveling composites are as follows: (1) adjacent, minor defects can be included with a bevel, (2) esthetic quality may be enhanced by a bevel creating an area of gradual increase in composite thickness from the margin to the bulk of the restoration, and (3) the marginal seal may be enhanced.

The degree of desired smoothness or roughness is the second consideration in finishing the external walls. The advent of high-speed cutting procedures has produced two pertinent factors related to finishing the enamel walls: (1) the lessening of tactile sense and (2) the rapid removal of tooth structure. High speed can lead to over-extension of margins, grooved walls, or rounded cavosurface angles, especially on proximal margins. If this method is used, plain-cut fissure burs produce the finest surface.³³ These burs produce a smoother surface than crosscut burs, diamonds, or carborundum stones.³⁴ An excellent finish is achieved with this type of bur at lower rotational speeds.

In instances when proximal margins are left at minimal extension for esthetic reasons, rotating instruments (burs, stones, wheels, or disks) may not be usable because of lack of proper access. In such locations, hand instruments may need to be used. The planing action of a sharp hand instrument can result in a smooth enamel wall, although it may not be as smooth as that achieved with other instruments.³⁵ Hand instruments such as enamel hatchets and margin trimmers may be used in planing enamel walls, cleaving enamel, and establishing enamel bevels.

The restorative material used is the primary factor dictating the desired smoothness or roughness of an enamel wall. The prepared walls of inlay or onlay preparations require a smooth surface to permit undistorted impressions and close adaptation of the casting to the enamel margins.³⁶ In areas of sufficient access, fine sandpaper disks can create a smooth surface; however, proper use of hand instruments, plain fissure burs, finishing carbide burs, or fine diamond stones also creates satisfactory enamel margins. Prepared walls and margins of composite restorations can be roughened, usually by a coarse diamond rotary instrument, to provide increased surface area for bonding. Likewise when using amalgam restorative materials, a smooth preparation wall is not as desirable as for cast restorations. When amalgam materials are used, it has been shown that a rougher prepared wall markedly improves resistance to marginal leakage.³⁷ This observation does not mean, however, that finishing of the enamel wall should be ignored, but it does indicate that no strict rule for the selection of the finishing instrument can be applied in all instances.

Step 9: Final Procedures: Cleaning, Inspecting, and Desensitizing

The usual procedure in cleaning is to free the preparation of visible debris with water from the syringe and then to remove

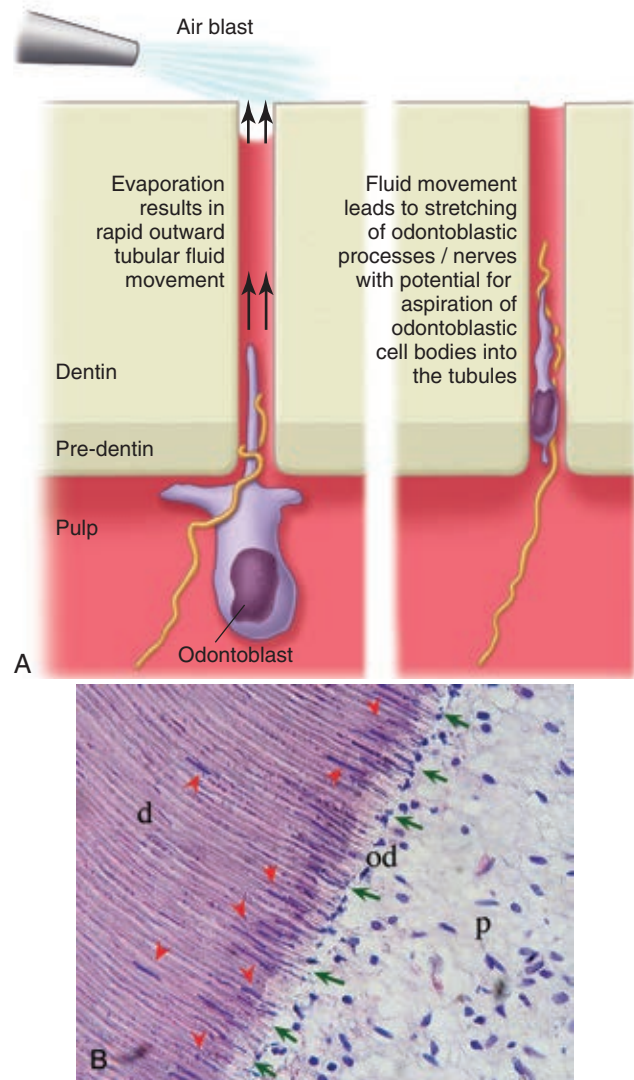


Fig. 5-18 **A**, Excessive drying of tooth preparations can cause odontoblasts to be aspirated into dentinal tubules. **B**, Nuclei are seen as dark rods in dentinal tubules. Red arrows indicate the nuclei of the aspirated odontoblasts. Green arrows indicate location of the odontoblasts prior to them being sucked into the tubules. *d*, dentin; *od*, odontoblasts; *p*, pulp. (**B**, From Mitsiadis TA, De Bari C, About I: Apoptosis in development and repair-related human tooth remodeling: A view from the inside. *Exp Cell Res* 314(4):869–877, 2008.)

the visible moisture with a few light bursts of air from the air syringe. In some instances, debris clings to walls and angles despite the aforementioned efforts, and it may be necessary to loosen this material with an explorer or small cotton pellet. After all of the visible debris has been removed, the excess moisture is removed. It is important not to dehydrate the tooth by overuse of air as this may damage the odontoblasts associated with the desiccated tubules (Fig. 5-18). When the preparation has been cleaned adequately, it is visually inspected to confirm complete debridement.

Composite restorations require some treatment of the preparation before insertion of the restorative material. This treatment usually includes etching enamel and dentin and

placing a resin-based adhesive. The smear layer usually is either altered or removed, and a hybrid layer is formed, which is characterized by an intermingling of the resin adhesive with collagen fibrils of the intertubular dentin. This creates a strong mechanical bond between the composite and dentin. It has been identified that the bond to dentin deteriorates over time as a result of hydrolysis of the adhesive resin component of the hybrid layer and proteolytic degradation of the collagen component of the hybrid layer.³⁸ Ongoing dental research has sought to optimize the long-term stability of the hybrid layer. For example, *in vivo* studies have shown that chlorhexidine (2 weight percent [wt%] solution) application to etched dentin is able to limit the activity of local collagenolytic enzymes (matrix metalloproteinases [MMPs]), which are able to degrade the exposed collagen matrix, and thus may help stabilize the hybrid layer, at least in Class I preparations for the short-term.³⁹ Long-term hybrid layer stability as a result of chlorhexidine use has not been demonstrated. These findings, as well as the decision to incorporate chlorhexidine or other dentin protease inhibitors as a final preparation step for hybrid layer stabilization, are to be considered in light of clinical studies that reveal that the clinical performance of composite resin systems that did not use chlorhexidine is comparable with that of amalgam.⁴⁰ In addition to the dentin bond, strong mechanical bonding occurs between the composite and the etched enamel, when enamel is present.

In accomplishing the final procedures before insertion of the restorative material, disinfection of the preparation may be considered. Although in the past, the term *sterilization* was used in the discussion of this topic, *disinfection* is a more accurate term to describe the objective. Chlorhexidine (2 wt%) solutions may be used in preparations for disinfection purposes in addition to the enzyme inhibition step mentioned above. The dentin tubule lumen, varying from 1 to 4 μm in diameter at varying distances between the DEJ and the pulp, presents a pathway for the entrance of microorganisms. Investigators have verified the presence of microorganisms in the dentin tubules beneath preparation walls. This fact in no way indicates, however, that caries is progressing or that failures will automatically result. It has been contended that caries in dentin stops or gradually ceases as soon as the caries lesion is closed to the oral environment, even if microorganisms remain in dentin.⁴¹ Investigators have noted that the number of bacteria in the dentin tubules is relatively small compared with the numerous microorganisms found in the superficial carious lesion. The question is whether these remaining organisms are capable of extending caries under the environmental circumstances of a restored tooth.²⁶

The possible infection of the pulp is always a consideration when bacteria remain in a channel that terminates in the pulp chamber. In this respect, the resistance of vital tissue to the ingress of bacteria must be considered. The precipitation of mineral in the dentinal tubules beneath a caries lesion (giving it a transparent appearance) creates a physical barrier to bacterial ingress. In addition to this host defense mechanism, the presence of reparative dentin deposited as a result of pulpal insult constitutes a significant deterrent to bacterial progress. Bacteria may be in a dormant condition as the result of the more sealed environment of a restored tooth.

Assuming that a surface disinfectant is successful, it is doubtful that the disinfection can exist for any appreciable length of time because of the difference between the thermal

coefficients of expansion of the tooth and filling materials.^{42,43} Although differing in amounts, marginal leakage has been shown for most restorative materials.^{32,44,45} A large percentage of non-disinfected restorations exhibit no caries on the internal wall as a result of this oral fluid penetration; it is possible that the natural defense mechanism of the tooth or the germicidal action of the restorative material destroys any invading bacteria. Some protection from further carious action is afforded by some restorative materials.⁴⁶ The germicidal or protective effect ranges from the fluoride content of some materials to the deposition of corrosive products at the interface of the preparation wall in an amalgam. Zinc oxide–eugenol cement has significant germicidal properties over an extended period. The use of desensitizers (for non-bonded restorations) and dentin bonding agents (for bonded restorations) to limit post-operative sensitivity has been recognized.

Occlusion of the dentinal tubules limits the potential for tubular fluid movement and resultant sensitivity. Desensitizers are effective disinfectants, provide crosslinking of any exposed dentin matrix and occlude (“plug”) the dentinal tubules by crosslinking tubular proteins.⁴⁷ Preparations designed for amalgam restoration should be desensitized with a solution that contains 5% glutaraldehyde and 35% 2-hydroxyethyl methacrylate (HEMA) before amalgam placement.^{47,48} Desensitizers may be used before cementing restorations with nonbonding luting agents. Desensitizers may be used immediately after etching and before priming of the dentin, if desired. All bonded restorations (composites, amalgams, glass ionomer materials, and bonded indirect restorations) use various adhesive systems that not only bond the material to the tooth but also seal the prepared tooth structure.

Additional Concepts in Tooth Preparation

Any new techniques which are advocated for the restoration of teeth should be assessed on the basis of the fundamentals of tooth preparation presented in this chapter. Understanding these fundamental principles makes the assessment of new approaches easier and wiser. Because amalgam and composite restorations are done more often than other operative procedures, most of the proposed new ways to restore teeth relate to these types of restorations.

Preparations for Amalgam Restorations

Several other restorative techniques have been advocated for use with amalgam restorations. These preparation techniques should be evaluated in light of the following pre-requisites for amalgam success: (1) 90-degree junctions of amalgam with tooth structure, (2) mechanical retention form, and (3) adequate thickness for the amalgam material.

Amalgam Box-Only Tooth Preparations

Box-only tooth preparations for amalgam may be advocated for some posterior teeth in which a proximal surface requires restoration, but the occlusal surface is not faulty. A proximal box is prepared and specific retention form is provided, but

no occlusal step is included. Such restorations are more conservative in that less tooth structure is removed. That conservation of tooth structure must be weighed against possible loss of retention form provided by the occlusal step of a typical Class II amalgam preparation. Proximal retention grooves may be indicated as part of this preparation design.

Amalgam Tunnel Tooth Preparations

In an effort to be conservative of tooth structure removal, other investigators advocate a tunnel tooth preparation. This preparation joins an occlusal lesion with a proximal lesion by means of a prepared tunnel under the involved marginal ridge. In this way, the marginal ridge remains essentially intact. In assessing this technique, the adequacy of preparation access may be controversial. Developing appropriately formed preparation walls and excavating caries may be compromised by lack of access and visibility. Whether or not the marginal ridge is preserved in a strong state also is controversial, especially since the dentinal support (essential for enamel longevity) of the marginal ridge is no longer present. This technique is controversial and is not supported in this textbook.

Adhesive Amalgam Restorations

Other techniques advocated for amalgam restorations use adhesive systems.^{21,49,50} Some of these materials mechanically bond the amalgam material to tooth structure. Others seal the prepared tooth structure with an adhesive resin before amalgam placement.⁵¹ The technique for the adhesive resin liner is different in that the adhesive is placed and polymerized before the amalgam placement. Although the proposed bonding techniques vary for bonded amalgams, the essential procedure is to prepare the tooth in a fashion similar to typical amalgam preparations except that more weakened, remaining tooth structure may be retained. Next, the preparation walls are treated or covered with specific adhesive lining materials that mechanically bond to the tooth and the amalgam. The amalgam is condensed into this adhesive material before polymerization, and a bond develops between the amalgam and adhesive. Because studies demonstrate no long-term benefit with regards to tooth reinforcement, this book does not promote the use of bonded amalgams.²²⁻²⁴

Preparations for Composite Restorations

Other concepts relate to the use of composite to restore teeth. Some newer concepts relating to preparations for composite restorations are presented in Chapters 8 to 12. In these chapters, more conservative preparations and preparations relating to expanded uses of composite, such as for esthetic enhancements, the conservative composite restoration of posterior occlusal surfaces, preventive resin restoration, veneers, and ceramic inlays cemented with composite materials, are presented.

Understanding the requirements of successful composite restorations is essential when assessing any proposed modifications. For a composite restoration to be successful, (1) marginal enamel may be beveled or have a flared form, and all should be etched; (2) dentin bonding systems should be used; and (3) non-enamel (root surface) external walls should provide butt-joint shapes, when necessary, and have

appropriately placed mechanical retention form, when indicated (see Table 5-1).

Composite Box-Only Tooth Preparations

The box-only preparations for composite restorations are similar to the preparations for amalgam restorations except that the box form is less distinct, having “roughed-out” marginal configurations rather than refined, 90-degree butt joints. The prepared tooth structure (enamel and dentin) is etched, primed, or both, which provides the retention form of the material in the tooth.

Composite Tunnel Tooth Preparations

The tunnel preparation, as described earlier, also has been advocated for composite restorations. Usually, it also is advocated to use an RMGI liner under the composite, and some investigators suggest that this preparation design be partially or completely restored with a glass ionomer restorative material. The same disadvantages exist as with amalgam tunnel restorations, and this technique is not recommended in this textbook.

Summary

This chapter has addressed the principles of tooth preparation. What should be apparent at this time is that a tooth preparation is determined by many factors, and each time a tooth is to be restored, each of these factors must be assessed. Tooth preparation for composite restorations is simpler and more conservative than for amalgam restorations because of the physical requirements necessary for amalgam (see Table 5-1). If the principles of tooth preparation are followed, the success of any restoration is greatly increased. No two tooth preparations are the same.

Numerous factors may need to be considered before initiating a tooth preparation. Box 5-2 lists many of these factors, but it is not an all-inclusive list. The increasing bond strengths of enamel and dentin bonding materials are likely to result in significant emphasis on adhesive restorations. Likewise, the improved ability to bond to tooth structure is likely to

Box 5-2 Factors to Consider before Tooth Preparation

Extent of Caries	Extent of Defect
Occlusion	Pulpal protection
Pulpal involvement	Contours
Esthetics	Economics
Patient's age	Patient's risk status
Patient's home care	Bur design
Gingival status	Radiographic assessment
Anesthesia	Other treatment factors
Bone support	Patient cooperation
Patient's desires	Fracture lines
Material limitations	Tooth anatomy
Operator skill	Ability to isolate area
Enamel rod direction	
Extent of old restorative material	

continue to alter the entire tooth preparation procedure. When materials can be bonded effectively to a tooth while restoring the inherent strength of the tooth, the need for refined tooth preparations is reduced.

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Instruments and Equipment for Tooth Preparation

Terrence E. Donovan, R. Scott Eidson

Hand Instruments for Cutting

Removal and shaping of tooth structure are essential aspects of restorative dentistry. Initially, this was a difficult process accomplished entirely by the use of hand instruments. The introduction of rotary, powered cutting equipment was a truly major advance in dentistry. From the time of the first hand-powered dental drill to the present-day electric and air-driven handpiece, tremendous strides have been made in the mechanical alteration of tooth structure and in the ease with which teeth can be restored. Modern high-speed equipment has eliminated the need for many hand instruments for tooth preparation. Nevertheless, hand instruments remain an essential part of the armamentarium for restorative dentistry.

The early hand-operated instruments—with their large, heavy handles (Fig. 6-1) and inferior (by present standards) metal alloys in the blades—were cumbersome, awkward to use, and ineffective in many situations. As the commercial manufacture of hand instruments increased, and dentists began to express ideas about tooth preparation, it became apparent that some scheme for identifying these instruments was necessary. Among his many contributions to modern dentistry, Black is credited with the first acceptable nomenclature for and classification of hand instruments.¹ His classification system enabled dentists and manufacturers to communicate more clearly and effectively about instrument design and function.

Modern hand instruments, when properly used, produce beneficial results for the operator and the patient. Some of these results can be satisfactorily achieved only with hand instruments and not with rotary instruments. Preparation form dictates some circumstances in which hand instruments are to be used, whereas accessibility dictates others.

Terminology and Classification

Categories

The hand instruments used in the dental operatory may be categorized as (1) cutting (excavators, chisels, and others)

or (2) non-cutting (amalgam condensers, mirrors, explorers, probes).¹ Excavators may be subdivided further into ordinary hatchets, hoes, angle formers, and spoons. Chisels are primarily used for cutting enamel and may be subdivided further into straight chisels, curved chisels, bin-angle chisels, enamel hatchets, and gingival margin trimmers. Other cutting instruments may be subdivided as knives, files, scalers, and carvers. In addition to the cutting instruments, a large group of noncutting instruments (see Fig. 14-21, *D* and *E*) is also in use.

Design

Most hand instruments, regardless of use, are composed of three parts: handle, shank, and blade (Fig. 6-2). For many non-cutting instruments, the part corresponding to the blade is termed *nib*. The end of the nib, or working surface, is known as *face*. The blade or nib is the working end of the instrument and is connected to the handle by the shank. Some instruments have a blade on both ends of the handle and are known as double-ended instruments. The blades are of many designs and sizes, depending on their functions.

Handles are available in various sizes and shapes. Early hand instruments had handles of quite large diameter and were grasped in the palm of the hand. A large, heavy handle is not always conducive to delicate manipulation. In North America, most instrument handles are small in diameter (5.5 mm) and light. They are commonly eight-sided and knurled to facilitate control. In Europe, the handles are often larger in diameter and tapered.

Shanks, which serve to connect the handles to the working ends of the instruments, are normally smooth, round, and tapered. They often have one or more bends to overcome the tendency of the instrument to twist while in use when force is applied.

Enamel and dentin are difficult substances to cut and require the generation of substantial forces at the tip of the instrument. Hand instruments must be balanced and sharp. Balance allows for the concentration of force onto the blade without causing rotation of the instrument in the operator's



Fig. 6-1 Designs of some early hand instruments. These instruments were individually handmade, variable in design, and cumbersome to use. Because of the nature of the handles, effective sterilization was a problem.

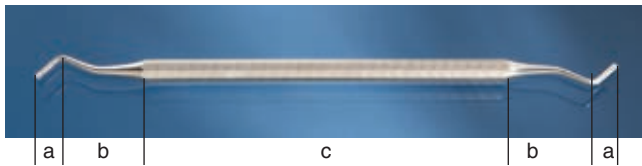


Fig. 6-2 Double-ended instrument illustrating three component parts of hand instruments: blade (a), shank (b), and handle (c). (Modified from Boyd LRB: Dental instruments: A pocket guide, ed 4, St. Louis, 2012, Saunders.)

grasp. Sharpness concentrates the force onto a small area of the edge, producing a high stress.

Balance is accomplished by designing the angles of the shank so that the cutting edge of the blade lies within the projected diameter of the handle and nearly coincides with the projected axis of the handle (Fig. 6-3; see also Fig. 6-2). For optimal anti-rotational design, the blade edge must not be off-axis by more than 1 to 2 mm. All dental instruments and equipment need to satisfy this principle of balance.

Shank Angles

The functional orientation and length of the blade determine the number of angles in the shank necessary to balance the instrument. Black classified instruments on the basis of the number of shank angles as mon-angle (one), bin-angle (two), or triple-angle (three).² Instruments with small, short blades may be easily designed in mon-angle form while confining the cutting edge within the required limit. Instruments with longer blades or more complex orientations may require two or three angles in the shank to bring the cutting edge close to the long axis of the handle. Such shanks are termed *contra-angled*.



Fig. 6-3 Instrument shank and blade design (with primary cutting edge positioned close to handle axis to produce balance). The complete instrument formula (four numbers) is expressed as the blade width (1) in 0.1-mm increments, cutting edge angle (2) in centigrades, blade length (3) in millimeters, and blade angle (4) in degrees.

Names

Black classified all of the instruments by name.² In addition, for hand-cutting instruments, he developed a numeric formula to characterize the dimensions and angles of the working end (see the next section for details of the formula). Black's classification system by instrument name categorized instruments by (1) function (e.g., scaler, excavator), (2) manner of use (e.g., hand condenser), (3) design of the working end (e.g., spoon excavator, sickle scaler), or (4) shape of the shank (e.g., mon-angle, bin-angle, contra-angle).² These names were combined to form the complete description of the instrument (e.g., bin-angle spoon excavator).

Formulas

Cutting instruments have formulas describing the dimensions and angles of the working end. These are placed on the handle using a code of three or four numbers separated by dashes or spaces (e.g., 10–8.5–8–14) (see Fig. 6-3). The first number indicates the width of the blade or primary cutting edge in tenths of a millimeter (0.1 mm) (e.g., 10 = 1 mm). The second number of a four-number code indicates the primary cutting edge angle, measured from a line parallel to the long axis of the instrument handle in clockwise centigrades. The angle is expressed as a percent of 360 degrees (e.g., 85 = 85% × 360 degrees = 306 degrees). The instrument is positioned so that this number always exceeds 50. If the edge is locally perpendicular to the blade, this number is normally omitted, resulting in a three-number code. The third number (second number of a three-number code) indicates the blade length in

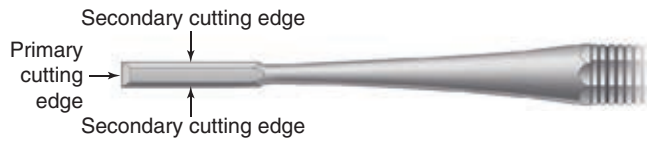


Fig. 6-4 Chisel blade design showing primary and secondary cutting edges.



Fig. 6-5 Examples of hand instruments called excavators (with corresponding instrument formulas). **A**, Bi-beveled ordinary hatchet (3–2–28). **B**, Hoe ($4\frac{1}{2}$ – $1\frac{1}{2}$ –22). **C**, Angle former (12–85–5–8).

millimeters (e.g., 8 = 8 mm). The fourth number (third number of a three-number code) indicates the blade angle, relative to the long axis of the handle in clockwise centigrade (e.g., 14 = 50 degrees). For these measurements, the instrument is positioned such that this number is always 50 or less. The most commonly used hand instruments, including those specified in this text, are shown in Figures 6-5 through 6-9 with their formulas indicated.

In some instances, an additional number on the handle is the manufacturer's identification number. It should not be confused with the formula number. This identification number is included simply to assist the specific manufacturer in cataloging and ordering.

Bevels

Most hand cutting instruments have on the end of the blade a single bevel that forms the primary cutting edge. Two additional edges, called *secondary cutting edges*, extend from the primary edge for the length of the blade (Fig. 6-4). Bi-beveled instruments such as ordinary hatchets have two bevels that form the cutting edge (Fig. 6-5, A).

Certain single-beveled instruments such as spoon excavators (Fig. 6-6) and gingival margin trimmers (Fig. 6-7, B and C) are used with a scraping or lateral cutting motion. Others such as enamel hatchets (see Fig. 6-7, A) may be used with a planing or direct cutting motion and a lateral cutting motion. For such single-beveled designs, the instruments must be made in pairs, with the bevels on opposite sides of the blade. Such instruments are designated as right beveled or left beveled and are indicated by appending the letter R or L to

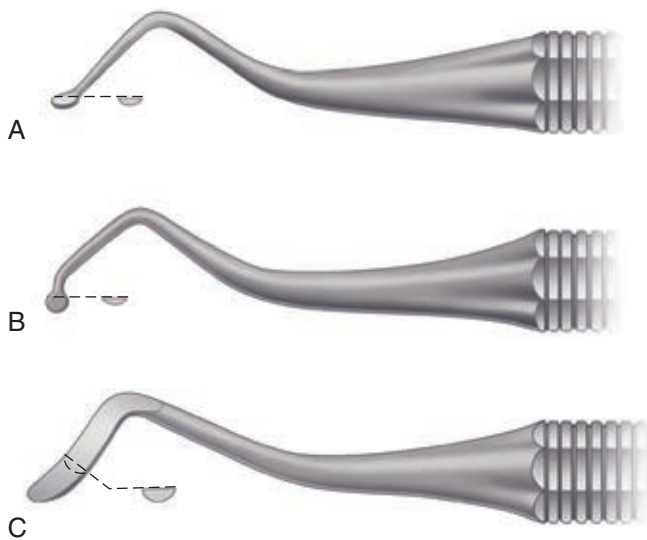


Fig. 6-6 Examples of hand instruments called spoon excavators (with corresponding instrument formulas). **A**, Bin-angle spoon (13–7–14). **B**, Triple-angle spoon (13–7–14). **C**, Spoon (15–7–14).

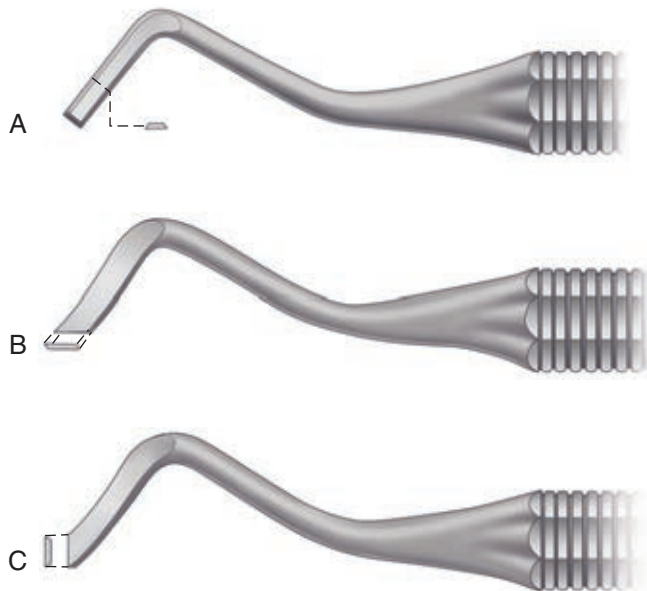


Fig. 6-7 Examples of hand instruments called chisels (with corresponding instrument formulas). **A**, Enamel hatchet (10–7–14). **B**, Gingival margin trimmer ($12\frac{1}{2}$ –100–7–14). **C**, Gingival margin trimmer ($12\frac{1}{2}$ –100–7–14).

the instrument formula. To determine whether the instrument has a right or left bevel, the primary cutting edge is held down and pointing away, and if the bevel appears on the right side of the blade, it is the right instrument of the pair. This instrument, when used in a scraping motion, is moved from right to left. The opposite holds true for the left instrument of the pair. One instrument is suited for work on one side of the preparation, and the other is suited for the opposite side of the preparation.

Most instruments are available with blades and shanks on both ends of the handle. Such instruments are termed

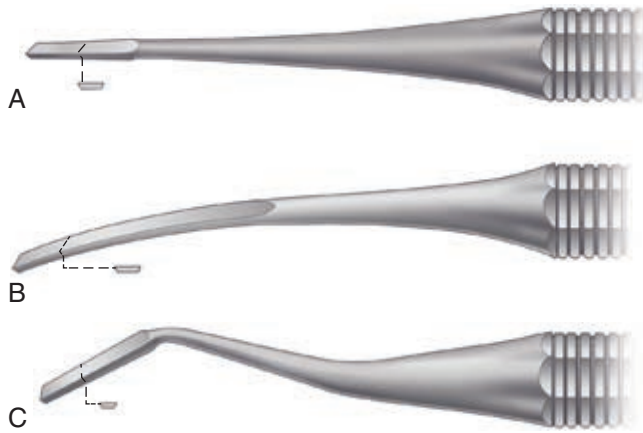


Fig. 6-8 Examples of hand instruments called chisels (with corresponding instrument formulas). **A**, Straight (12-7-0). **B**, Wedelstaedt ($11\frac{1}{2}$ -15-3). **C**, Bin-angle (10-7-8).

double-ended. In many cases, the right instrument of the pair is on one end of the handle, and the left instrument is on the other end. Sometimes, similar blades of different widths are placed on double-ended instruments. Single-ended instruments may be safer to use, but double-ended instruments are more efficient because they reduce instrument exchange.

Instruments having the cutting edge perpendicular to the axis of the handle (Fig. 6-8), such as bin-angle chisels (see Fig. 6-8, C), instruments with a slight blade curvature (Wedelstaedt chisels) (see Fig. 6-8, B), and hoes (see Fig. 6-5, B), are single-beveled and not designated as rights or lefts but as having a mesial bevel or a distal bevel. If when one observes the inside of the blade curvature (or the inside of the angle at the junction of the blade and shank) the primary bevel is not visible, the instrument has a distal bevel. Conversely, if the primary bevel can be seen (from the same viewpoint), the instrument has a mesial or reverse bevel (see Fig. 6-8).

As previously described, instruments such as chisels and hatchets have three cutting edges, one primary and two secondary. These allow cutting in three directions, as the need presents. The secondary edges permit more effective cutting than the primary edge in several instances. They are particularly effective in work on the facial and lingual walls of the proximal portion of a proximo-occlusal tooth preparation. The operator should not forget the usefulness of these secondary cutting edges because they enhance the use of the instrument.

Applications

The cutting instruments are used to cut the hard or soft tissues of the mouth. Excavators are used for removal of caries and refinement of the internal parts of the preparation. Chisels are used primarily for cutting enamel.

Excavators

The four subdivisions of excavators are (1) ordinary hatchets, (2) hoes, (3) angle-formers, and (4) spoons. An ordinary hatchet excavator has the cutting edge of the blade directed in the same plane as that of the long axis of the handle and is bi-beveled (see Fig. 6-5, A). These instruments are used

primarily on anterior teeth for preparing retentive areas and sharpening internal line angles, particularly in preparations for direct gold restorations.

The hoe excavator has the primary cutting edge of the blade perpendicular to the axis of the handle (see Fig. 6-5, B). This type of instrument is used for planing tooth preparation walls and for forming line angles. It is commonly used in Class III and V preparations for direct gold restorations. Some sets of cutting instruments contain hoes with longer and heavier blades, with the shanks contra-angled. These are intended for use on enamel or posterior teeth.

A special type of excavator is the angle-former (see Fig. 6-5, C). It is used primarily for sharpening line angles and creating retentive features in dentin in preparation for gold restorations. It also may be used in placing a bevel on enamel margins. It is non-angled and has the primary cutting edge at an angle (other than 90 degrees) to the blade. It may be described as a combination of a chisel and a gingival margin trimmer. It is available in pairs (right and left).

Spoon excavators (see Fig. 6-6) are used for removing caries and carving amalgam or direct wax patterns. The blades are slightly curved, and the cutting edges are either circular or claw-like. The circular edge is known as a discoid, whereas the claw-like blade is termed *cleoid* (Fig. 6-9, C and D). The shanks may be bin-angled or triple-angled to facilitate accessibility.

Chisels

Chisels are intended primarily for cutting enamel and may be grouped as (1) straight, slightly curved, or bin-angle; (2) enamel hatchets; and (3) gingival margin trimmers. The straight chisel has a straight shank and blade, with the bevel on only one side. Its primary edge is perpendicular to the axis of the handle. It is similar in design to a carpenter's chisel (see Fig. 6-8, A). The shank and blade of the chisel also may be slightly curved (Wedelstaedt design) (see Fig. 6-8, B) or may be bin-angled (see Fig. 6-8, C). The force used with all these chisels is essentially a straight thrust. A right or left type is not needed in a straight chisel because a 180-degree turn of the instrument allows for its use on either side of the preparation. The bin-angle and Wedelstaedt chisels have the primary cutting edges in a plane perpendicular to the axis of the handle and may have either a distal bevel or a mesial (reverse) bevel. The blade with a distal bevel is designed to plane a wall that faces the blade's inside surface (see Fig. 6-5, A and B). The blade with a mesial bevel is designed to plane a wall that faces the blade's outside surface (see Fig. 6-8, B and C).

The enamel hatchet is a chisel similar in design to the ordinary hatchet except that the blade is larger, heavier, and beveled on only one side (see Fig. 6-7, A). It has its cutting edges in a plane that is parallel with the axis of the handle. It is used for cutting enamel and comes as right or left types for use on opposite sides of the preparation.

The gingival margin trimmer is designed to produce a proper bevel on gingival enamel margins of proximo-occlusal preparations. It is similar in design to the enamel hatchet except the blade is curved (similar to a spoon excavator), and the primary cutting edge is at an angle (other than perpendicular) to the axis of the blade (see Fig. 6-7, B and C). It is made as right and left types. It also is made so that a right and left pair is either a mesial pair or a distal pair. When the second number in the formula is 90 to 100, the pair is used

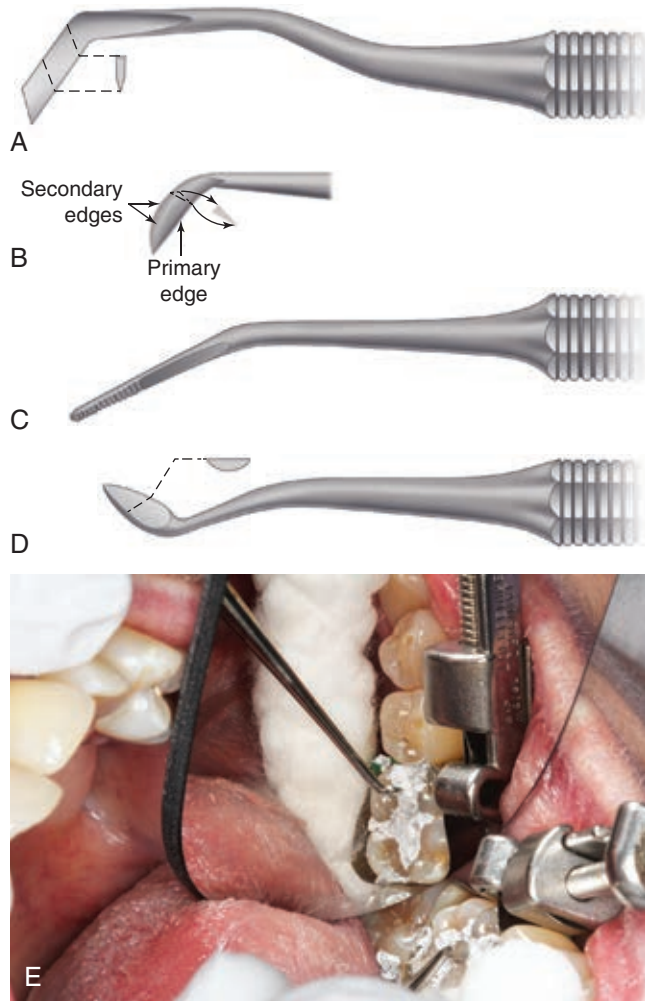


Fig. 6-9 Examples of other hand instruments for cutting. **A**, Finishing knife. **B**, Alternative finishing knife design emphasizing secondary cutting edges. **C**, Dental file. **D**, Cleoid blade. **E**, Discoid blade carving amalgam.

on the distal gingival margin. When this number is 75 to 85, the pair is used to bevel the mesial margin. The 100 and 75 pairs are for inlay–onlay preparations with steep gingival bevels. The 90 and 85 pairs are for amalgam preparations with gingival enamel bevels that decline gingivally only slightly. Among other uses for these instruments is the rounding or beveling of the axiopulpal line angle of two-surface preparations.

Other Cutting Instruments

Other hand cutting instruments such as the knife, file, and discoid–cleoid instrument are used for trimming restorative material rather than for cutting tooth structure. Knives, known as *finishing knives*, *amalgam knives*, or *gold knives*, are designed with a thin, knife-like blade that is made in various sizes and shapes (see Fig. 6-9, *A* and *B*). Knives are used for trimming excess restorative material on the gingival, facial, or lingual margins of a proximal restoration or trimming and contouring the surface of a Class V restoration. Sharp secondary edges on the heel aspect of the blade are useful in a scrape–pull mode.

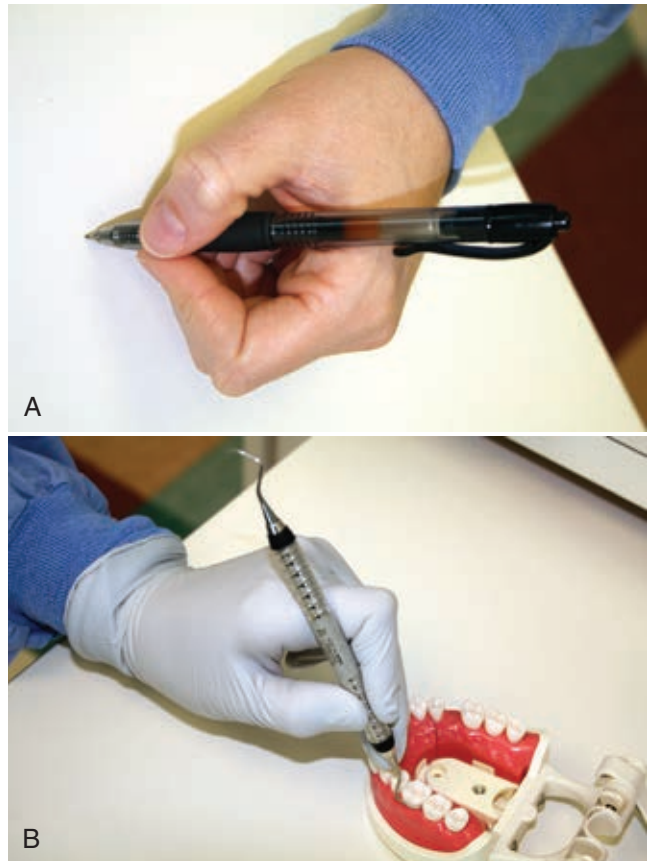


Fig. 6-10 Pen grasps. **A**, Conventional pen grasp. Side of middle finger is on writing instrument. **B**, Modified pen grasp. Correct position of middle finger is near the “topside” of the instrument for good control and cutting pressure. The rest is tip (or tips) of ring finger (or ring and little fingers) on tooth (or teeth) of same arch.

Files (see Fig. 6-9, *C*) also can be used to trim excess restorative material. They are particularly useful at gingival margins. The blades of the file are extremely thin, and the teeth of the instrument on the cutting surfaces are short and designed to make the file a push instrument or a pull instrument. Files are manufactured in various shapes and angles to allow access to restorations.

The discoid–cleoid (see Fig. 6-9, *D* and *E*) instrument is used principally for carving occlusal anatomy in unset amalgam restorations. It also may be used to trim or burnish inlay–onlay margins. The working ends of this instrument are larger than the discoid or cleoid end of an excavator.

Hand Instrument Techniques

Four grasps are used with hand instruments: (1) modified pen, (2) inverted pen, (3) palm-and-thumb, and (4) modified palm-and-thumb. The conventional pen grasp is not an acceptable instrument grasp (Fig. 6-10, *A*).

Modified Pen Grasp

The grasp that permits the greatest delicacy of touch is the modified pen grasp (see Fig. 6-10, *B*). As the name implies, it is similar, but not identical, to that used in holding a pen. The



Fig. 6-11 Inverted pen grasp. Palm faces more toward operator. The rest is similar to that shown for modified pen grasp (see Fig. 6-10, B).

pads of the thumb and of the index and middle fingers contact the instrument, while the tip of the ring finger (or tips of the ring and little fingers) is placed on a nearby tooth surface of the same arch as a rest. The palm of the hand generally is facing away from the operator. The pad of the middle finger is placed near the topside of the instrument; by this finger working with the wrist and the forearm, cutting or cleaving pressure is generated on the blade. The instrument should not be allowed to rest on or near the first joint of the middle finger as in the conventional pen grasp (see Fig. 6-10, A). Although this latter position may appear to be more comfortable, it limits the application of pressure. A balanced instrument design allows the application of suitable force without the instrument tending to rotate in the fingers (see Fig. 6-3).

Inverted Pen Grasp

The finger positions of the inverted pen grasp are the same as for the modified pen grasp. The hand is rotated, however, so that the palm faces more toward the operator (Fig. 6-11). This grasp is used mostly for tooth preparations employing the lingual approach on anterior teeth.

Palm-and-Thumb Grasp

The palm-and-thumb grasp is similar to that used for holding a knife while paring an apple. The handle is placed in the palm of the hand and grasped by all the fingers, while the thumb is free of the instrument, and the rest is provided by supporting the tip of the thumb on a nearby tooth of the same arch or on a firm, stable structure. For suitable control, this grasp requires careful use during cutting. An example of an appropriate use is holding a handpiece for cutting incisal retention for a Class III preparation on a maxillary incisor (Fig. 6-12).

Modified Palm-and-Thumb Grasp

The modified palm-and-thumb grasp may be used when it is feasible to rest the thumb on the tooth being prepared or the adjacent tooth (Fig. 6-13). The handle of the instrument is held by all four fingers, whose pads press the handle against the distal area of the palm and the pad and first joint of the thumb. Grasping the handle under the first joints of the ring



Fig. 6-12 Palm-and-thumb grasp. This grasp has limited use, such as preparing incisal retention in a Class III preparation on a maxillary incisor. The rest is tip of thumb on tooth in same arch.

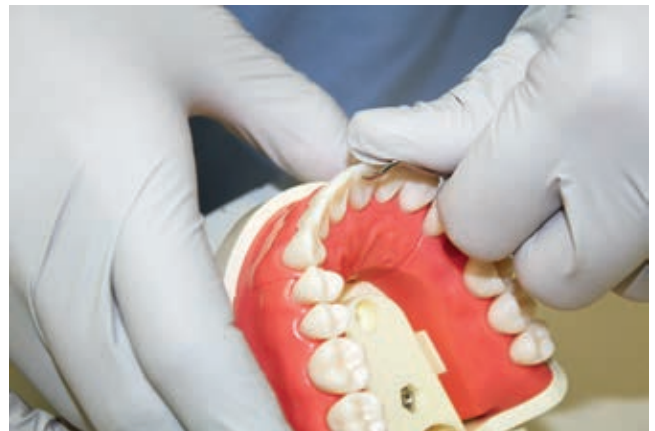


Fig. 6-13 Modified palm-and-thumb grasp. This modification allows greater ease of instrument movement and more control against slippage during thrust stroke compared with palm-and-thumb grasp. The rest is tip of thumb on tooth being prepared or adjacent tooth. Note how the instrument is braced against pad and end joint of thumb.

finger and little finger provides stabilization. This grip fosters control against slippage.

The modified pen grasp and the inverted pen grasp are used practically universally. The modified palm-and-thumb grasp usually is employed in the area of the maxillary arch and is best adopted when the dentist is operating from a rear-chair position.

Rests

A proper instrument grasp must include a firm rest to steady the hand during operating procedures. When the modified pen grasp and the inverted pen grasp are used, rests are established by placing the ring finger (or both ring and little fingers) on a tooth (or teeth) of the same arch and as close to the operating site as possible (see Figs. 6-10 and 6-11). The closer the rest areas are to the operating area, the more reliable they are. When the palm-and-thumb grasps are used, rests are created by placing the tip of the thumb on the tooth being

operated on, on an adjacent tooth, or on a convenient area of the same arch (see Figs. 6-12 and 6-13).

In some instances, it is impossible to establish a rest on tooth structure, and soft tissue must be used. Neither soft tissue rests nor distant hard tissue rests afford reliable control, and they reduce the force or power that can be used safely.

Occasionally, it is impossible to establish normal finger rests with the hand holding the instrument. Under these circumstances, instrument control may be gained using the forefinger of the opposite hand on the shank of the instrument or using an indirect rest (i.e., the operating hand rests on the opposite hand, which rests on a stable oral structure).

Guards

Guards are hand instruments or other items, such as interproximal wedges, used to protect soft tissue from contact with sharp cutting or abrasive instruments (see Fig. 6-10, B).

Contemporary Powered Cutting Equipment

Rotary Power Cutting Equipment

Powered rotary cutting instruments, known as *dental handpieces*, are the most commonly used instruments in contemporary dentistry. Dentistry as practiced today would not be possible without the use of powered cutting instruments. Current dental handpieces are now highly efficient and sophisticated instruments that have evolved from their beginnings in the early 1950s. Many evolutionary changes to handpieces have dramatically improved their use and efficiency over the years. Changes in ergonomic design, weight, and balance have made handpieces more comfortable to use for longer periods. This improved design can minimize arm and shoulder fatigue in the clinician. Better visibility with incorporation of durable fiberoptics greatly improves the clinician's ability to see more detail with less eye strain. Development of LED (light-emitting diode) technology has improved the quality of light to be more akin to daylight and has vastly enhanced bulb life. Noise levels, which have a considerable impact on the long-term hearing health of clinicians and their staff, have been reduced. The durability of the handpiece that undergoes frequent sterilization has been improved significantly over the years, thus avoiding material degradation. New bearing materials and cartridges have been developed to enhance their service longevity and to contribute to noise level reductions. Chucking mechanisms have evolved such that pushbuttons, instead of bur tools, are used to release and change burs.

Two technologies are used today for dental handpieces, and each has unique characteristics and benefits. The air-driven handpiece was, for many years, the mainstay for cutting teeth in dentistry. The electric motor-driven handpiece is now becoming increasingly popular for use in all cutting applications in dentistry. The technologies for both air-driven and electric systems continue to evolve, and both systems remain very popular for everyday use in operative dentistry procedures.

Electric and air-driven systems have both advantages and disadvantages. Air-driven systems are less costly on initial startup and are less expensive with regard to replacing

turbines compared with electric handpieces. Air-driven handpieces weigh less than electric handpieces, and this quality may be the most significant adjustment for clinicians who make the change from air-driven handpieces to electric handpieces. The size of the head of the air-driven handpiece is usually smaller. The advantages of electric handpieces are that they are quieter than air-driven handpieces, they cut with high torque with very little stalling, they maintain high bur concentricity, and they offer high-precision cutting. Cutting with electric handpieces is smoother and more like milling, whereas cutting with the air-driven handpiece is more like chopping the tooth with the bur. Another advantage of electric handpieces is that they offer multiple attachments for the motor that can be used for different cutting applications such as denture adjustments and endodontic instrumentation. Some disadvantages of air-driven handpieces are that they create a loud, high-pitched noise that can affect the hearing of the operator and the staff over years. The torque and concentricity of the air turbines degrade in a relatively short period. Air-driven handpieces need turbine replacement and repairs more frequently. More vibration and bur chatter are associated with air-driven handpieces. Some disadvantages of electric handpieces are the initial setup expense and weight and balance issues for some clinicians.

Rotary Speed Ranges for Different Cutting Applications

The rotational speed of an instrument is measured in revolutions per minute (rpm). Three speed ranges are generally recognized: low or slow speeds (<12,000 rpm), medium or intermediate speeds (12,000–200,000 rpm), and high or ultra-high speeds (>200,000 rpm). The terms *low-speed*, *medium-speed*, and *high-speed* are used preferentially in this textbook. Most useful instruments are rotated at either low speed or high speed. Electric handpiece motors generate up to 200,000 rpm of rotation. This speed is significantly less than the 400,000 rpm generated by air-driven handpieces. However, the electric handpiece motor has attachments with speed increase multipliers that can increase rotation in ratios of 5:1 or 4:1, which makes them effective in the same range as air-driven handpieces. The difference in the amount of cutting power is substantial in electric handpieces. Electric handpieces can produce up to 60 watts of cutting power versus less than 20 watts by air-driven handpieces. The extra cutting power in electric handpieces allow the constant torque necessary to cut various restorative materials and tooth structure regardless of the load. Unlike in the air-driven handpiece, the bur in the electric handpiece can resist slowing down or stopping as the load is increased.

The crucial factor for some purposes is the surface speed of the instrument, that is, the velocity at which the edges of the cutting instrument pass across the surface being cut. This speed is proportional to the rotational speed and the diameter of the instrument, with large instruments having higher surface speeds at any given rate of rotation.

Although intact tooth structure can be removed by an instrument rotating at low speeds, it is a traumatic experience for the patient and the dentist. Low-speed cutting is ineffective, is time-consuming, and requires a relatively heavy force application; this results in heat production at the operating site and produces vibrations of low frequency and high

amplitude. Heat and vibration are the main sources of patient discomfort.³ At low speeds, burs have a tendency to roll out of the tooth preparation and mar the proximal margin or tooth surface. In addition, carbide burs do not last long because their brittle blades are easily broken at low speeds. Many of these disadvantages of low-speed operation do not apply when the objective is some procedure other than cutting tooth structure. The low-speed range is used for cleaning teeth, caries excavation, and finishing and polishing procedures. At low speeds, tactile sensation is better, and generally, overheating of cut surfaces is less likely. The availability of a low-speed option provides a valuable adjunct for many dental procedures.

At high speed, the surface speed needed for efficient cutting can be attained with smaller and more versatile cutting instruments. This speed is used for tooth preparation and removing old restorations. Other advantages are the following: (1) diamond and carbide cutting instruments remove tooth structure faster and with less pressure, vibration, and heat generation; (2) the number of rotary cutting instruments needed is reduced because smaller sizes are more universal in application; (3) the operator has better control and greater ease of operation; (4) instruments last longer; (5) patients are generally less apprehensive because annoying vibrations and operating time are decreased; and (6) several teeth in the same arch can be treated at the same appointment (as they should be).

Variable control to regulate the speed makes the handpiece more versatile. This feature allows the operator to obtain easily the optimal speed for the size and type of rotating instrument at any stage of a specific operation. All electric handpieces have an adjustable rheostat that can easily set the maximum rpms to specific situations for different operative procedures. Air-driven handpieces can be controlled, but usually the control is more difficult and less precise, since the operator's pressure on the foot-operated rheostat controls the speed of the handpiece.

For infection control, all dental handpieces are now sterilized, but the process is associated with some challenges. Continual sterilization can produce degradation in clinical performance (longevity, power, turbine speed, fiberoptic transmission, eccentricity, noise, chuck performance, visibility angle, interocclusal clearance, water spray pattern).⁴ Most handpieces require re-oiling after sterilization, and excess oil may be sprayed during the start-up operation. Several companies offer automated equipment to precisely clean and lubricate the handpiece after each use. It is recommended to run the handpiece for a few seconds before initiating dental procedures in which the deposition of oil spray onto tooth structure might interfere with processes such as dental adhesion.

Laser Equipment

Lasers are devices that produce beams of coherent and very-high-intensity light. Numerous current and potential uses of lasers in dentistry have been identified that involve the treatment of soft tissues and the modification of hard tooth structures.^{5,6} The word *laser* is an acronym for "light amplification by stimulated emission of radiation." A crystal or gas is excited to emit photons of a characteristic wavelength that are amplified and filtered to make a coherent light beam. The effects of the laser depend on the power of the beam and the extent to which the beam is absorbed.

Current laser units are relatively expensive compared with air-driven and electric motor cutting instruments and must be used frequently in a dental practice to justify the expense. At the moment, lasers are used primarily for either soft tissue applications or hard tissue surface modification. They can be used for tooth preparations, however, it is more difficult to generate a defined margin or tooth preparation surface than with conventional rotary instruments. Lasers are inefficient and awkward for removing large amounts of enamel or dentin, and that process with a laser has the potential to generate unwanted amounts of heat. They cannot be used to remove existing amalgam or ceramic dental restorations. No single laser type is suitable for all potential laser applications. Lasers may never replace a high-speed dental handpiece. For several years, the use of lasers to prepare teeth held great promise; however, that promise has failed to materialize. Currently, available laser instruments have proven to be relatively inefficient and impractical for tooth preparation and have not achieved widespread popularity. Although lasers can be extremely useful for soft tissue surgery, current versions are of limited value for tooth preparation.

Other Equipment

Alternative methods of cutting enamel and dentin have been assessed periodically. In the mid-1950s, air-abrasive cutting was tested, but several clinical problems precluded general acceptance. Most importantly, no tactile sense was associated with air-abrasive cutting of tooth structure. This made it difficult for the operator to determine the cutting progress within the tooth preparation. Additionally, the abrasive dust interfered with visibility of the cutting site and tended to mechanically etch the surface of the dental mirror. Preventing the patient or office personnel from inhaling abrasive dust posed an additional difficulty.

Contemporary air abrasion equipment (Fig. 6-14) is helpful for stain removal, debriding pits and fissures before sealing, and micromechanical roughening of surfaces to be bonded (enamel, cast metal alloys, or porcelain).⁷ This approach works well when organic material is being removed and when only



Fig. 6-14 Example of contemporary air abrasion unit for removal of superficial enamel defects or stains, debriding pits and fissures for sealant application, or roughening surfaces to be bonded or luted. (Courtesy Danville Materials, Inc., San Ramon, CA.)

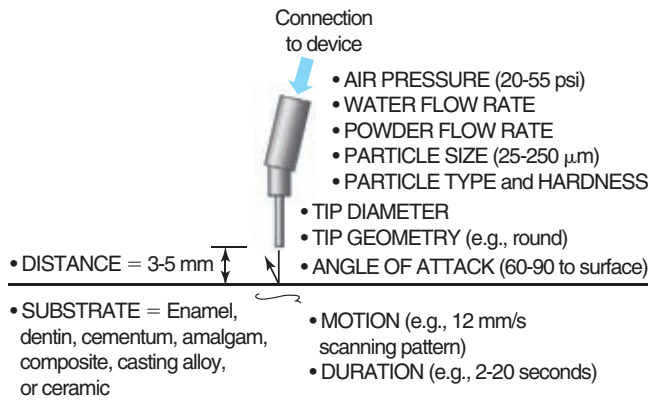


Fig. 6-15 Schematic representation of range of variables associated with any type of air abrasion equipment. The cleaning or cutting action is a function of kinetic energy imparted to the actual surface, and this is affected by variables concerning the particle size, air pressure, angulation with surface, type of substrate, and method of clearance. (Courtesy of B. Kunselman [Master's thesis, 1999], School of Dentistry, University of North Carolina, Chapel Hill, NC.)

a limited amount of enamel or dentin is involved. Although promoted for caries excavation, air abrasion cannot produce well-defined preparation wall and margin details that are possible with conventional rotary cutting techniques. Generally, the finest stream of abrading particles still generates an effective cutting width that is far greater than the width of luted cement margins or the errors tolerable in most caries excavations. Roughening of surfaces to be bonded, luted, or repaired is an advantage and can occur intraorally or extraorally, depending on the situation. Roughening by air abrasion by itself is not a substitute for acid-etching techniques. Roughening improves bonding. Acid-etching alone or after roughening, however, always produces a better bond than air abrasion alone.⁸

Air abrasion techniques rely on the transfer of kinetic energy from a stream of powder particles on the surface of tooth structure or a restoration to produce a fractured surface layer, resulting in roughness for bonding or disruption for cutting. The energy transfer event is affected by many things, including powder particle, pressure, angulation, surface composition, and clearance angle variables (Fig. 6-15). The most common error made by operators of air abrasion units is holding the tip at the wrong distance from the surface for the desired action. Greater distances significantly reduce the energy of the stream.⁹ Short distances may produce unwanted cutting actions, such as when only surface stain removal is being attempted. The potential for unwanted cutting is a significant problem when employing an air-polishing device (e.g., Prophy Jet) to clean the surfaces of dentin and enamel.¹⁰⁻¹³ When used properly, however, units designed for air polishing tooth surfaces can be quite efficient and effective (Fig. 6-16).

Rotary Cutting Instruments

The individual instruments intended for use with dental handpieces are manufactured in hundreds of sizes, shapes, and types. This variation is, in part, a result of the need for



Fig. 6-16 Example of air abrasion equipment used for tooth cleaning showing the Prophy tip and handle attached by a flexible cord to the control unit with the reservoir of powder and source of water (left). (Courtesy of DENTSPLY International, York, PA.)



Fig. 6-17 Normal designation of three parts of rotary cutting instruments.

specialized designs for particular clinical applications or to fit particular handpieces, but much of the variation also results from individual preferences on the part of dentists. Since the introduction of high-speed techniques in clinical practice, a rapid evolution of technique and an accompanying proliferation of new instrument designs have occurred. Nevertheless, the number of instruments essential for use with any one type of handpiece is comparatively small, especially in the case of high-speed turbine handpieces.

Common Design Characteristics

Despite the great variation among rotary cutting instruments, they share certain design features. Each instrument consists of three parts: (1) shank, (2) neck, and (3) head (Fig. 6-17). Each has its own function, influencing its design and the materials used for its construction. The term *shank* has different meanings as applied to rotary instruments and to hand instruments.

Shank Design

The *shank* is the part that fits into the handpiece, accepts the rotary motion from the handpiece, and provides a bearing surface to control the alignment and concentricity of the instrument. The shank design and dimensions vary with the handpiece for which it is intended. The American Dental Association (ADA) Specification No. 23 for dental excavating burs includes five classes of instrument shanks.¹⁴ Three of these (Fig. 6-18)—the straight handpiece shank, the latch-type angle handpiece shank, and the friction-grip angle handpiece shank—are commonly encountered. The shank portion of the straight handpiece instrument is a simple cylinder. It is

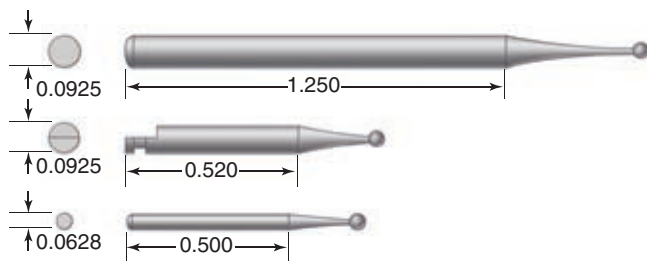


Fig. 6-18 Characteristics and typical dimensions (in inches) of three common instrument shank designs for straight handpiece (A), latch-angle handpiece (B), and friction-grip angle handpiece type (C).

held in the handpiece by a metal chuck that accepts a range of shank diameters. Precise control of the shank diameter is not as crucial as for other shank designs. Straight handpiece instruments are now rarely used for preparing teeth except for caries excavation. They are commonly used, however, for finishing and polishing completed restorations.

The more complicated shape of the latch-type shank reflects the different mechanisms by which these instruments are held in the handpiece. Their shorter overall length permits substantially improved access to posterior regions of the mouth compared with straight handpiece instruments. Handpieces that use latch-type burs normally have a metal bur tube within which the instruments fit as closely as possible, while still permitting easy interchange. The posterior portion of the shank is flattened on one side so that the end of the instrument fits into a D-shaped socket at the bottom of the bur tube, causing the instrument to be rotated. Latch-type instruments are not retained in the handpiece by a chuck but, rather, by a retaining latch that slides into the groove found at the shank end of the instrument. This type of instrument is used predominantly at low and medium speed ranges for finishing procedures. At these speeds, the small amount of potential wobble inherent in the clearance between the instrument and the handpiece bur tube is controlled by the lateral pressure exerted during cutting procedures. At higher speeds, the latch-type shank design is inadequate to provide a true-running instrument head, and as a result, an improved shank design is required for these speeds.

The friction-grip shank design was developed for use with high-speed handpieces. This design is smaller in overall length than the latch-type instruments, providing a further improvement in access to the posterior regions of the mouth. The shank is a simple cylinder manufactured to close dimensional tolerances. As the name implies, friction-grip instruments originally were designed to be held in the handpiece by friction between the shank and a plastic or metal chuck. Newer handpiece designs have metal chucks that close to make a positive contact with the bur shank. Careful dimensional control on the shanks of these instruments is important because for high-speed use, even minor variations in shank diameter can cause substantial variation in instrument performance and problems with insertion, retention, and removal.

Neck Design

As shown in Fig. 6-17, the *neck* is the intermediate portion of an instrument that connects the head to the shank. It corresponds to the part of a hand instrument that is referred

to as *shank*. Except in the case of the larger, more massive instruments, the neck normally tapers from the shank diameter to a smaller size immediately adjacent to the head. The main function of the neck is to transmit rotational and translational forces to the head. At the same time, it is desirable for the operator to have the greatest possible visibility of the cutting head and the greatest manipulative freedom. For this reason, the neck dimensions represent a compromise between the need for a large cross-section to provide strength and a small cross-section to improve access and visibility.

Head Design

The *head* is the working part of the instrument, the cutting edges or points that perform the desired shaping of tooth structure. The shape of the head and the material used to construct it are closely related to its intended application and technique of use. The heads of instruments show greater variation in design and construction than either of the other main portions. For this reason, the characteristics of the head form the basis on which rotary instruments are usually classified.

Many characteristics of the heads of rotary instruments could be used for classification. Most important among these is the division into bladed instruments and abrasive instruments. Material of construction, head size, and head shape are additional characteristics that are useful for further subdivision. Bladed and abrasive instruments exhibit substantially different clinical performances, even when operated under nearly identical conditions. This appears to result from differences in the mechanism of cutting that are inherent in their designs.

Dental Burs

The term *bur* is applied to all rotary cutting instruments that have bladed cutting heads. This includes instruments intended for finishing metal restorations and surgical removal of bone and instruments primarily intended for tooth preparation.

Historical Development of Dental Burs

The earliest burs were hand-made. They were not only expensive but also variable in dimension and performance. The shapes, dimensions, and nomenclature of modern burs are directly related to those of the first machine-made burs introduced in 1891.¹⁵ Early burs were made of steel. Steel burs perform well, cutting human dentin at low speeds, but dull rapidly at higher speeds or when cutting enamel. When burs are dulled, the reduced effectiveness in cutting creates increased heat and vibration.

Carbide burs, which were introduced in 1947, have largely replaced steel burs for tooth preparation. Steel burs now are used mainly for finishing procedures. Carbide burs perform better than steel burs at all speeds, and their superiority is greatest at high speeds. All carbide burs have heads of cemented carbide in which microscopic carbide particles, usually tungsten carbide, are held together in a matrix of cobalt or nickel. Carbide is much harder than steel and less prone to dulling during cutting.

In most burs, the carbide head is attached to a steel shank and neck by welding or brazing. The substitution of steel

for carbide in the portions of the bur where greater wear resistance is not required has several advantages. It permits the manufacturer more freedom of design in attaining the characteristics desired in the instrument and allows economy in the cost of materials of construction.

Although most carbide burs have the joint located in the posterior part of the head, others are sold that have the joint located within the shank and have carbide necks and heads. Carbide is stiffer and stronger than steel, but it is also more brittle. A carbide neck subjected to a sudden blow or shock fractures, whereas a steel neck bends. A bur that is even slightly bent produces increased vibration and overcutting as a result of increased runout. Although steel necks reduce the risk of fracture during use, they may cause severe problems if bent. Either type can be satisfactory, and other design factors are varied to take maximal advantage of the properties of the material used.

Bur Classification Systems

To facilitate the description, selection, and manufacture of burs, it is highly desirable to have some agreed-on shorthand designation, which represents all variables of a particular head design by some simple code. In the United States, dental burs traditionally have been described in terms of an arbitrary numerical code for head size and shape (e.g., 2 = 1-mm diameter round bur; 57 = 1-mm diameter straight fissure bur; 34 = 0.8-mm diameter inverted cone bur).¹⁶ Despite the complexity of the system, it is still in common use. Other countries developed and used similarly arbitrary systems. Newer classification systems such as those developed by the International Dental Federation (Federation Dentaire Internationale) and International Standards Organization (ISO) tend to use separate designations for shape (usually a shape name) and size (usually a number giving the head diameter in tenths of a millimeter) (e.g., round 010; straight fissure plain 010; inverted cone 008).^{17,18}

Shapes

The term *bur shape* refers to the contour or silhouette of the head. The basic head shapes are round, inverted cone, pear, straight fissure, and tapered fissure (Fig. 6-19). A *round bur* is spherical. This shape customarily has been used for initial entry into the tooth, extension of the preparation, preparation of retention features, and caries removal.

An *inverted cone bur* is a portion of a rapidly tapered cone with the apex of the cone directed toward the bur shank. Head

length is approximately the same as the diameter. This shape is particularly suitable for providing undercuts in tooth preparations.

A *pear-shaped bur* is a portion of a slightly tapered cone with the small end of the cone directed toward the bur shank. The end of the head either is continuously curved or is flat with rounded corners where the sides and flat end intersect. An elongated pear bur (length three times the width) is advocated for tooth preparations for amalgam.

A *straight fissure bur* is an elongated cylinder. Some dentists advocate this shape for amalgam tooth preparation. Modified burs of this design with slightly curved tip angles are available. A tapered fissure bur is a portion of a slightly tapered cone with the small end of the cone directed away from the bur shank. This shape is used for tooth preparations for indirect restorations, for which freedom from undercuts is essential for successful withdrawal of patterns and final seating of the restorations. Tapered fissure burs can have a flat end with the tip corners slightly rounded.

Among these basic shapes, variations are possible. Fissure and inverted cone burs may have half-round or domed ends. Taper and cone angles may vary. The ratio of head length to diameter may be varied. In addition to shape, other features may be varied, such as the number of blades, spiral versus axial patterns for blades, and continuous versus crosscut blade edges.

Sizes

In the United States, the number designating bur size also traditionally has served as a code for head design. This numbering system for burs was originated by the S.S. White Dental Manufacturing Company in 1891 for their first machine-made burs. It was extensive and logical, so other domestic manufacturers found it convenient to adopt it for their burs as well. As a result, for more than 60 years, a general uniformity existed for bur numbers in the United States. Table 6-1 shows the correlation of bur head sizes with dimensions and shapes. The table includes not only many bur sizes that are still in common use but also others that have become obsolete.

The original numbering system grouped burs by 9 shapes and 11 sizes. The $\frac{1}{2}$ and $\frac{1}{4}$ designations (both very small round burs) were added later when smaller instruments were included in the system. All original bur designs had continuous blade edges. Later, when crosscut burs were found to be more effective for cutting dentin at low speeds, crosscut versions of many bur sizes were introduced. This modification was indicated by adding 500 to the number of the equivalent noncrosscut size. A No. 57 with crosscut was designated No. 557. Similarly, a 900 prefix was used to indicate a head design intended for end cutting only. Except for differences in blade design, a No. 957, No. 557, and No. 57 bur all had the same head dimensions. These changes occurred gradually over time without disrupting the system. The sizes in common use in 1955 are shown in Table 6-2. The system changed rapidly thereafter, but where the numbers are still used, the designs and dimensions remain the same.

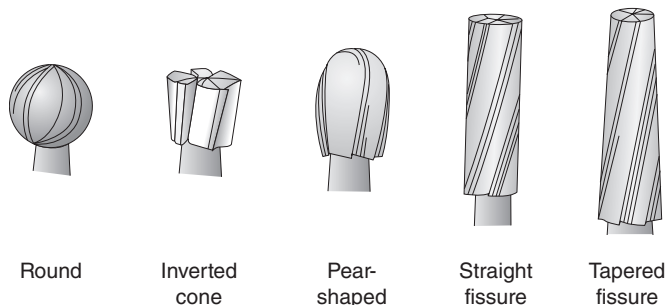


Fig. 6-19 Basic bur head shapes. (From Finkbeiner BL, Johnson CS: Mosby's comprehensive dental assisting, St. Louis, 1995, Mosby.)

Modifications in Bur Design

As available handpiece speeds increased after 1950, particularly after the high-speed turbine handpieces were introduced,

Table 6-1 Original Bur Head Sizes (1891–1954)

Head Shapes	Head Diameters in Inches (mm*)												
	0.020	0.025	0.032	0.039	0.047	0.055	0.063	0.072	0.081	0.090	0.099	0.109	0.119
	(0.5)	(0.6)	(0.8)	(1.0)	(1.2)	(1.4)	(1.6)	(1.8)	(2.1)	(2.3)	(2.5)	(2.8)	(3.0)
Round	¼	½	1	2	3	4	5	6	7	8	9	10	11
Wheel	—	11½	12	13	14	15	16	17	18	19	20	21	22
Cone	—	22½	23	24	25	26	27	28	29	30	31	32	33
Inverted cone	—	33½	34	35	36	37	38	39	40	41	42	43	44
Bud	—	44½	45	46	47	48	49	50	51	—	—	—	—
Straight fissure (flat end)	55¼	55½	56	57	58	59	60	61	62	—	—	—	—
Straight fissure (pointed end)	—	66½	67	68	69	70	71	72	73	—	—	—	—
Pear	—	77½	78	79	80	81	82	83	84	85	86	87	88
Oval	—	88½	89	90	91	92	93	94	95	—	—	—	—

*Millimeter values rounded to the nearest 0.1 mm.
 Courtesy of H.M. Moylan, S.S. White Dental Manufacturing Company, Lakewood, NJ.

Table 6-2 Standard Bur Head Sizes—Carbide and Steel (1955–Present)

Head Shapes	Head Diameters in Inches (mm*)													
	0.020	0.025	0.032	0.040	0.048	0.056	0.064	0.073	0.082	0.091	0.100	0.110	0.120	0.130
	(0.5)	(0.6)	(0.8)	(1.0)	(1.2)	(1.4)	(1.6)	(1.9)	(2.1)	(2.3)	(2.5)	(2.8)	(3.0)	(3.3)
Round	¼	½	1	2	3	4	5	6	7	8	9	10	11	—
Wheel	—	11½	12	—	14	—	16	—	—	—	—	—	—	—
Inverted cone	—	33½	34	35	36	37	38	39	40	—	—	—	—	—
Plain fissure	—	55½	56	57	58	59	60	61	62	—	—	—	—	—
Round crosscut	—	—	—	502	503	504	505	506	—	—	—	—	—	—
Straight fissure crosscut	—	—	556	557	558	559	560	561	562	563	—	—	—	—
Tapered fissure crosscut	—	—	—	700	701	—	702	—	703	—	—	—	—	—
End cutting fissure	—	—	—	957	958	959	—	—	—	—	—	—	—	—

*Millimeter values rounded to the nearest 0.1 mm.
 Note: Non-standard burs are not shown in this table.

a new cycle of modification of bur sizes and shapes occurred. Numerous other categories have arisen as new variations in blade number or design have been created. Some of the numbers assigned to the burs were selected arbitrarily. With the introduction of new bur sizes and elimination of older sizes, much of the logic in the system has no longer been maintained, and many dentists and manufacturers no longer recognize the original significance of the numbers used for burs. The number of standard sizes that have continued in use has been reduced. This has been most obvious in the decreased popularity of large-diameter burs. The cutting effectiveness of carbide burs is greatly increased at high speeds.¹⁹ This is particularly true of the small-diameter sizes, which did not have sufficient peripheral speed for efficient cutting when used at lower rates of rotation. As the effectiveness of small burs has increased, they have replaced larger burs in many procedures. Three other major trends in bur design are discernible: (1)

reduced use of crosscuts, (2) extended heads on fissure burs, and (3) rounding of sharp tip angles.

Crosscuts are needed on fissure burs to obtain adequate cutting effectiveness at low speeds, but they are not needed at high speeds. Because crosscut burs used at high speeds tend to produce unduly rough surfaces, many of the crosscut sizes originally developed for low-speed use have been replaced by non-crosscut instruments of the same dimension for high-speed use.²⁰ In many instances, the non-crosscut equivalents were available; a No. 57 bur might be used at high speed, whereas a No. 557 bur was preferred for low-speed use. Non-crosscut versions of the 700 series burs have become popular, but their introduction precipitated a crisis in the bur numbering system because no number traditionally had been assigned to burs of this type.

Carbide fissure burs with extended head lengths two to three times those of the normal tapered fissure burs of similar

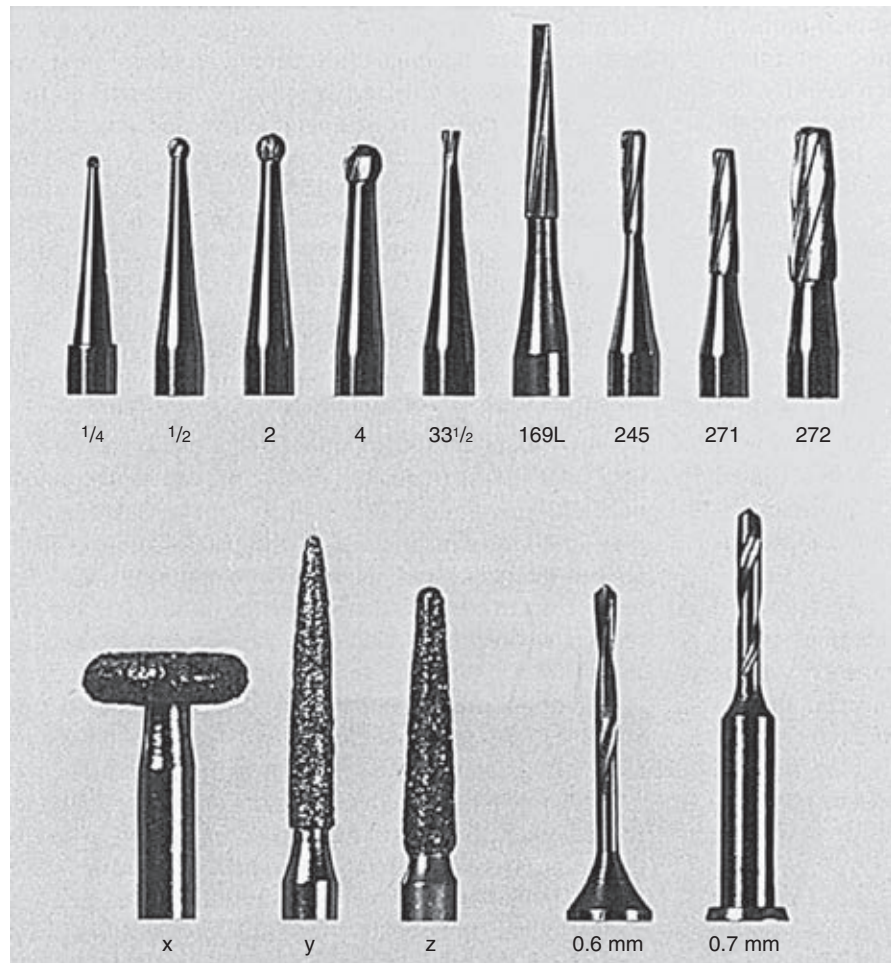


Fig. 6-20 Burs used in recommended procedures. Bur sizes $\frac{1}{4}$, $\frac{1}{2}$, 2, 4, $33\frac{1}{2}$, and 169L are standard carbide burs available from various sources. The 245, 271, and 272 burs are non-standard carbide burs that do not conform to the current American Dental Association (ADA) standard numbering system. They are designed to combine rounded corners with flat ends and are available from several manufacturers. The diamond instruments shown are wheel (Star No. 110) (x), flame (Star No. 265-8F) (y), and tapered cylinder (R & R No. 770 \times 7) (z). Two sizes of twist drill are illustrated. Particular drills often are provided as specified by manufacturers of pin-retention systems.

diameter have been introduced. Such a design would never have been practical using a brittle material such as carbide if the bur were to be used at low speed. The applied force required to make a bur cut at speeds of 5000 to 6000 rpm would normally be sufficient to fracture such an attenuated head. The extremely light applied pressures needed for cutting at high speed permit many modifications of burs, however, that would have been impractical at low speed.

The third major trend in bur design has been toward rounding of the sharp tip corners. Early contributions to this trend were made by Markley and also Sockwell.⁸ Because teeth are relatively brittle, the sharp angles produced by conventional burs can result in high stress concentrations and increase the tendency of the tooth to fracture. Bur heads with rounded corners result in lower stresses in restored teeth, enhance the strength of the tooth by preserving vital dentin, and facilitate the adaptation of restorative materials. Carbide burs and diamond instruments of these designs last longer because no sharp corners to chip and wear are present. Such burs facilitate tooth preparation with desired features of a flat preparation floor and rounded internal line angles.

Many of these new and modified bur designs simplify the techniques and reduce the effort needed for optimal results. Although the development of new bur sizes and shapes has increased greatly the number of different types in current use, the number actually required for clinical effectiveness has

been reduced. Most instruments recommended in this text for the preparation of teeth are illustrated in Fig. 6-20. The selection includes standard head designs and modified designs of the types just discussed. Table 6-3 lists the significant head dimensions of these standard and modified burs.

A problem related to the dimensions and designations of rotary dental instruments worldwide arose because each country developed its own system of classification. Dentists in the United States often were not aware of the problem because they predominantly used domestic products, and all U.S. manufacturers used the same system. The rapid rate at which new bur designs were introduced during the transition to high-speed techniques threatened to cause a complete breakdown in the numbering system. As different manufacturers developed and marketed new burs of similar design almost simultaneously, the risk of similar burs being given different numbers or different burs being given the same number increased. Combined with the growing use of foreign products in the United States, this situation has led to more interest in the establishment of international standards for dimensions, nomenclature, and other characteristics.

Progress toward the development of an international numbering system for basic bur shapes and sizes under the auspices of the ISO (International Standards Organization) has been slow. For other design features, the trend instead seems to be toward the use of individual manufacturer's code

Table 6-3 Names and Key Dimensions of Recommended Burs

Manufacturer's Size Number	ADA Size Number	ISO Size Number	Head Diameter (mm)	Head Length (mm)	Taper Angle (degrees)	Shape
¼	¼	005	0.50	0.40	—	Round
½	½	006	0.60	0.48	—	Round
2	2	010	1.00	0.80	—	Round
4	4	014	1.40	1.10	—	Round
33½	33½	006	0.60	0.45	12	Inverted cone
169	169	009	0.90	4.30	6	Tapered fissure
169L*	169L	009	0.90	5.60	4	Elongated tapered fissure
329	329	007	0.70	0.85	8	Pear, normal length
330	330	008	0.80	1.00	8	Pear, normal length
245 [†]	330L	008	0.80	3.00	4	Pear, elongated
271 [†]	171	012	1.20	4.00	6	Tapered fissure
272 [†]	172	016	1.60	5.00	6	Tapered fissure

*Similar to the No. 169 bur except for greater head length.

[†]These burs differ from the equivalent ADA size by being flat ended with rounded corners. The manufacturer's number has been changed to indicate this difference.

[†]Similar to the No. 330 bur except for greater head length.

ADA, American Dental Association; ISO, International Standard Organization.

numbers. Throughout the remaining text, the traditional U.S. numbers are used, where possible. The few exceptions are shown in Fig. 6-20 and Table 6-3.

Additional Features in Head Design

Numerous factors other than head size and shape are involved in determining the clinical effectiveness of a bur design.^{21,22} Figure 6-21 shows a lateral view and a cross-sectional view of a No. 701 crosscut tapered fissure bur in which several of these factors are illustrated. The lateral view (see Fig. 6-21, A) shows neck diameter, head diameter, head length, taper angle, blade spiral angle, and crosscut size and spacing as they apply to this bur size. Of these features, head length and taper angle are primarily descriptive and may be varied within limits consistent with the intended use of the bur. This bur originally was designed for use at low speeds in preparing teeth for cast restorations. The taper angle is intended to approximate the desired occlusal divergence of the lateral walls of the preparations, and the head length must be long enough to reach the full depth of the normal preparation. These factors do not otherwise affect the performance of the bur.

Neck diameter is important functionally because a neck that is too small results in a weak instrument unable to resist lateral forces. Too large a neck diameter may interfere with visibility and the use of the part of the bur head next to the neck and may restrict access for coolants. As the head of a bur increases in length or diameter, the moment arm exerted by lateral forces increases, and the neck needs to be larger.

Compared with these factors, two other design variables, the spiral angle and crosscutting, have considerably greater influence on bur performance. There is a tendency toward reduced spiral angles on burs intended exclusively for high-speed operation in which a large spiral is not needed to produce a smoother preparation and a smaller angle, which produces more efficient cutting.

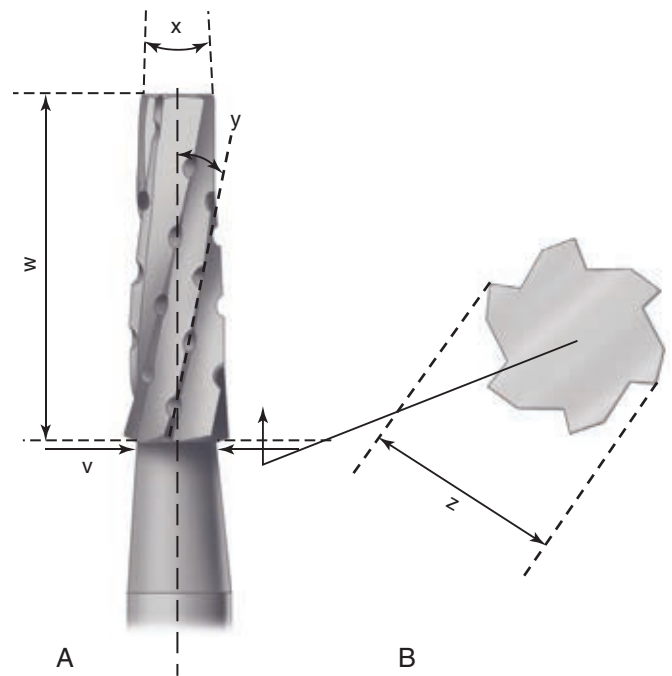


Fig. 6-21 Design features of bur heads (illustrated using No. 701 bur). A, Lateral view—neck diameter (v), head length (w), taper angle (x), and spiral angle (y). B, End view—head diameter (z).

As noted previously, crosscut bur designs have notches in the blade edges to increase cutting effectiveness at low and medium speeds. A certain amount of perpendicular force is required to make a blade grasp the surface and start cutting as it passes across the surface. The harder the surface, the duller the blade, and the greater its length, the more is the force required to initiate cutting. By reducing the total length of bur blade that is actively cutting at any one time, the

crosscuts effectively increase the cutting pressure resulting from rotation of the bur and the perpendicular pressure holding the blade edge against the tooth.

As each crosscut blade cuts, it leaves small ridges of tooth structure standing behind the notches. Because the notches in two succeeding blades do not line up with each other, the ridges left by one blade are removed by the following one at low or medium speeds. At the high speed attained with air-driven handpieces, however, the contact of the bur with the tooth is not continuous, and usually only one blade cuts effectively.²³ Under these circumstances, although the high cutting rate of crosscut burs is maintained, the ridges are not removed, and a much rougher cut surface results.²⁰

A cross-sectional view of the same No. 701 bur is shown in Figure 6-21, B. This cross-section is made at the point of largest head diameter and is drawn as seen from the shank end. The bur has six blades uniformly spaced with depressed areas between them. These depressed areas are properly known as *flutes*. The number of blades on a bur is always even because even numbers are easier to produce in the manufacturing process, and instruments with odd numbers of blades cut no better than those with even numbers. The number of blades on an excavating bur may vary from 6 to 8 to 10. Burs intended mainly for finishing procedures usually have 12 to 40 blades. The greater the number of blades, the smoother is the cutting action at low speeds. Most burs are made with at least 6 blades because they may need to be used in this speed range. In the high-speed range, no more than one blade seems to cut effectively at any one time, and the remaining blades are, in effect, spares. The tendency for the bur to cut on a single blade is often a result of factors other than the bur itself. Nevertheless, it is important that the bur head be as symmetrical as possible. Two terms are in common use to measure this characteristic of bur heads: *concentricity* and *runout*.

Concentricity is a direct measurement of the symmetry of the bur head itself. It measures how closely a single circle can be passed through the tips of all of the blades. Concentricity is an indication of whether one blade is longer or shorter than the others. It is a static measurement not directly related to function. *Runout* is a dynamic test measuring the accuracy with which all blade tips pass through a single point when the instrument is rotated. It measures not only the concentricity of the head but also the accuracy with which the center of rotation passes through the center of the head. Even a perfectly concentric head exhibits substantial runout if the head is off center on the axis of the bur, the bur neck is bent, the bur is not held straight in the handpiece chuck, or the chuck is eccentric relative to the handpiece bearings. The runout can never be less than the concentricity, and it is usually substantially greater. *Runout* is the more significant term clinically because it is the primary cause of vibration during cutting and is the factor that determines the minimum diameter of the hole that can be prepared by a given bur. Because of runout errors, burs normally cut holes measurably larger than the head diameter.

Bur Blade Design

The actual cutting action of a bur (or a diamond) occurs in a very small region at the edge of the blade (or at the point of a diamond chip). In the high-speed range, this effective

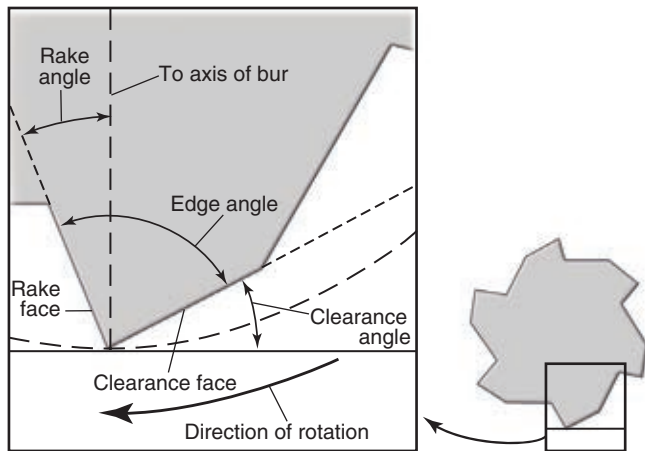


Fig. 6-22 Bur blade design. Schematic cross-section viewed from shank end of head to show rake angle, edge angle, and clearance angle.

portion of the individual blade is limited to no more than a few thousandths of a centimeter adjacent to the blade edge. Figure 6-22 is an enlarged schematic view of this portion of a bur blade. Several terms used in the discussion of blade design are illustrated.

Each blade has two sides—the *rake face* (toward the direction of cutting) and the *clearance face*—and three important angles—the *rake angle*, the *edge angle*, and the *clearance angle*. The optimal angles depend on such factors as the mechanical properties of the blade material, the mechanical properties of the material being cut, the rotational speed and diameter of the bur, and the lateral force applied by the operator to the handpiece and to the bur.

The rake angle is the most important design characteristic of a bur blade. For cutting hard, brittle materials, a negative rake angle minimizes fractures of the cutting edge, increasing the tool life. A rake angle is said to be negative when the rake face is ahead of the radius (from cutting edge to axis of bur), as illustrated in Figure 6-22. Increasing the edge angle reinforces the cutting edge and reduces the likelihood for the edge of the blade to fracture. Carbide bur blades have higher hardness and are more wear-resistant, but they are more brittle than steel blades and require greater edge angles to minimize fractures. The three angles cannot be varied independently of each other. An increase in the clearance angle causes a decrease in the edge angle. The clearance angle eliminates rubbing friction of the clearance face, provides a stop to prevent the bur edge from digging into the tooth structure excessively, and reduces the radius of the blade back of the cutting edge to provide adequate flute space or clearance space for the chips formed ahead of the following blade.

Carbide burs normally have blades with slight negative rake angles and edge angles of approximately 90 degrees. Their clearance faces either are curved or have two surfaces to provide a low clearance angle near the edge and a greater clearance space ahead of the following blade.

Diamond Abrasive Instruments

The second major category of rotary dental cutting instruments involves abrasive cutting rather than blade cutting. Abrasive instruments are based on small, angular particles of

a hard substance held in a matrix of softer material. Cutting occurs at numerous points where individual hard particles protrude from the matrix, rather than along a continuous blade edge. This difference in design causes definite differences in the mechanisms by which the two types of instruments cut and in the applications for which they are best suited.

Abrasive instruments are generally grouped as diamond or other instruments. Diamond instruments have had great clinical impact because of their long life and great effectiveness in cutting enamel and dentin. Diamond instruments for dental use were introduced in the United States in 1942 at a time before carbide burs were available and at a time when interest in increased rotational speeds was beginning to expose the limitations of steel burs. The earliest diamond instruments were substitutes for previously used abrasive points of other types used for grinding and finishing.²⁴ Their vastly superior performance in these applications led to their immediate acceptance. The shortage of burs as a result of wartime demands emphasized the relative durability of diamond instruments for cutting enamel and promoted the development of operative techniques employing them.

Terminology

Diamond instruments consist of three parts: (1) a metal blank, (2) the powdered diamond abrasive, and (3) a metallic bonding material that holds the diamond powder onto the blank (Fig. 6-23). The blank in many ways resembles a bur without blades. It has the same essential parts: head, neck, and shank.

The shank dimensions, similar to those for bur shanks, depend on the intended handpiece. The neck is normally a

tapered section of reduced diameter that connects the shank to the head, but for large disk-shaped or wheel-shaped instruments, it may not be reduced below the shank diameter. The head of the blank is undersized compared with the desired final dimensions of the instrument, but its size and shape determine the size and shape of the finished instrument. Dimensions of the head make allowance for a fairly uniform thickness of diamonds and bonding material on all sides. Some abrasive instruments are designed as a mandrel and a detachable head. This is much more practical for abrasive disks that have very short lifetimes.

The diamonds employed are industrial diamonds, either natural or synthetic, that have been crushed to powder, then carefully graded for size and quality. The shape of the individual particle is important because of its effect on the cutting efficiency and durability of the instrument, but the careful control of particle size is probably of greater importance. The diamonds generally are attached to the blank by electroplating a layer of metal on the blank while holding the diamonds in place against it. Although the electroplating holds the diamonds in place, it also tends to cover much of the diamond surfaces. Some proprietary techniques do allow greater diamond exposure and more effective cutting.

Classification

Diamond instruments currently are marketed in myriad head shapes and sizes (Table 6-4) and in all of the standard shank designs. Most of the diamond shapes parallel those for burs (Fig. 6-24). This great diversity arose, in part, as a result of the relative simplicity of the manufacturing process. Because it is possible to make diamond instruments in almost any shape for which a blank can be manufactured, they are produced in many highly specialized shapes, on which it would be impractical to place cutting blades. This has been a major factor in establishing clinical uses for these points, which are not in direct competition with burs.

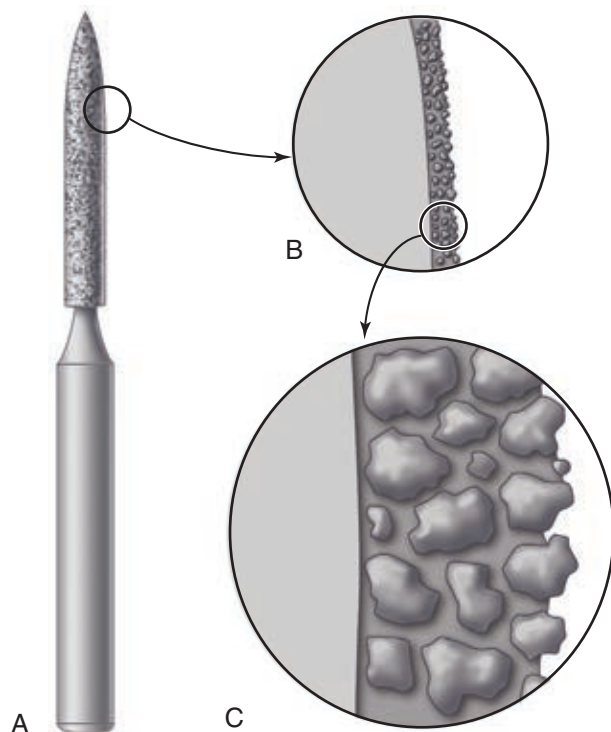


Fig. 6-23 Diamond instrument construction. **A**, Overall view. **B**, Detail of abrasive layer. **C**, Detail of particle bonding.

Table 6-4 Standard Categories of Shapes and Sizes for Diamond Cutting Instruments

Head Shapes	Profile Variations
Round	—
Football	Pointed
Barrel	—
Cylinder	Flat-, bevel-, round- or, safe-end
Inverted cone	—
Taper	Flat-, round-, or safe-end
Flame	—
Curettage	—
Pear	—
Needle	“Christmas tree”
Interproximal	Occlusal anatomy
Donut	—
Wheel	—

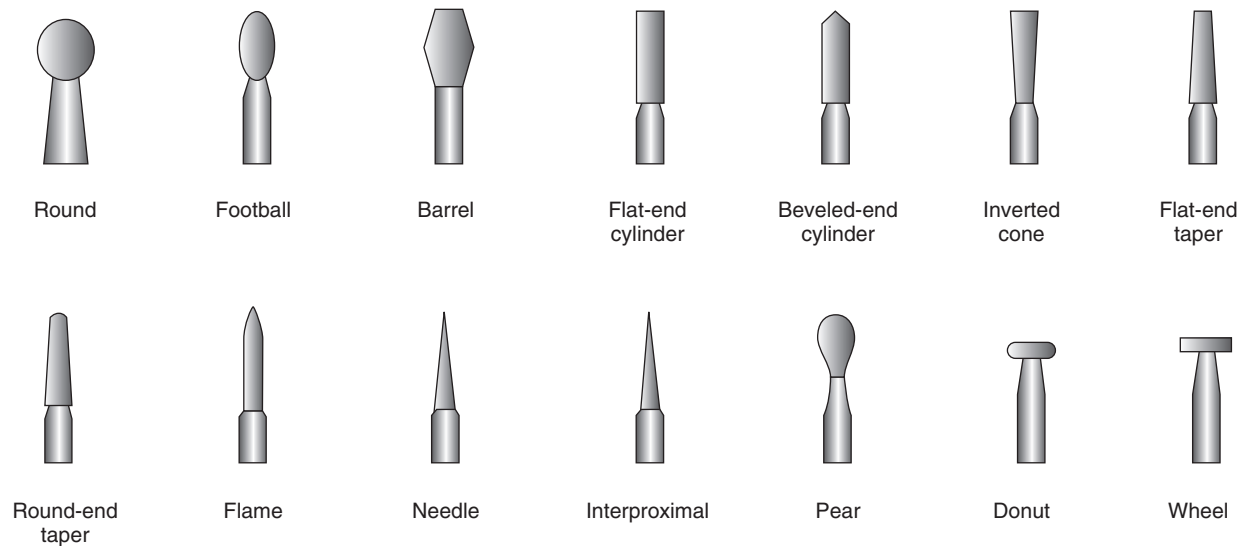


Fig. 6-24 Characteristic shapes and designs for a range of diamond cutting instruments.

Head Shapes and Sizes

Diamond instruments are available in a wide variety of shapes and in sizes that correspond to all except the smallest-diameter burs. The greatest difference lies in the diversity of other sizes and shapes in which diamond instruments are produced. Even with many subdivisions, the size range within each group is large compared with that found among the burs. More than 200 shapes and sizes of diamonds are currently marketed.

Because of their design with an abrasive layer over an underlying blank, the smallest diamond instruments cannot be as small in diameter as the smallest burs, but a wide range of sizes is available for each shape. No one manufacturer produces all sizes, but each usually offers an assortment of instruments, including the popular sizes and shapes. Because of the lack of uniform nomenclature for diamond instruments, it is often necessary to select them by inspection to obtain the desired size and shape. It is essential to indicate the manufacturer when attempting to describe diamond instruments by catalogue number.

Diamond Particle Factors

The clinical performance of diamond abrasive instruments depends on the size, spacing, uniformity, exposure, and bonding of the diamond particles. Increased pressure causes the particles to dig into the surface more deeply, leaving deeper scratches and removing more tooth structure.

Diamond particle size is commonly categorized as coarse (125–150 μm), medium (88–125 μm), fine (60–74 μm), and very fine (38–44 μm) for diamond preparation instruments.²⁴ These ranges correspond to standard sieve sizes for separating particle sizes. When using large particle sizes, the number of abrasive particles that can be placed on a given area of the head is decreased. For any given force that the operator applies, the pressure on each particle tip is greater. The resulting pressure also is increased if diamond particles are more widely spaced so that fewer are in contact with the surface at any one time. The final clinical performance of diamond instruments is strongly affected by the technique used to take advantage of the design factors for each instrument.

Diamond finishing instruments use even finer diamonds (10–38 μm) to produce relatively smooth surfaces for final finishing with diamond polishing pastes. Surface finishes of less than 1 μm are considered clinically smooth (see the section on composites in [online Chapter 18](#)) and can be routinely attained by using a series of progressively finer polishing steps.

Proper diamond instrument speed and pressure are the major factors in determining service life.²⁵ Properly used diamond instruments last almost indefinitely. Almost the only cause of failure of diamond instruments is loss of the diamonds from critical areas. This loss results from the use of excess pressure in an attempt to increase the cutting rate at inadequate speeds.²⁶

Other Abrasive Instruments

Many types of abrasive instruments are used in dentistry in addition to diamond instruments. At one time, they were extensively used for tooth preparation, but their use is now primarily restricted to shaping, finishing, and polishing restorations in the clinic and in the laboratory.

Classification

In these instruments, as in the diamond instruments, the cutting surfaces of the head are composed of abrasive particles held in a continuous matrix of softer material. Other than this and their use of standard shank designs, diamond instruments have little similarity in their construction. They may be divided into two distinct groups—*molded instruments* and *coated instruments*. Each uses various abrasives and matrix materials.

Molded abrasive instruments have heads that are manufactured by molding or pressing a uniform mixture of abrasive and matrix around the roughened end of the shank or cementing a premolded head to the shank. In contrast to diamond instruments, molded instruments have a much softer matrix and wear during use. The abrasive is distributed throughout the matrix so that new particles are exposed by the wear. These instruments are made in a full range of shapes and sizes. The

mounted heads are often termed *points* and *stones*. Hard and rigid molded instrument heads use rigid polymer or ceramic materials for their matrix and commonly are used for grinding and shaping procedures. Other molded instrument heads use flexible matrix materials, such as rubber, to hold the abrasive particles. These are used predominantly for finishing and polishing procedures. Molded unmounted disks or wheelstones are attached by a screw to a mandrel of suitable size for a given handpiece that has a threaded hole in the end. This design permits the instruments to be changed easily and discarded economically.

The coated abrasive instruments are mostly disks that have a thin layer of abrasive cemented to a flexible backing. This construction allows the instrument to conform to the surface contour of a tooth or restoration. Most flexible disks are designed for reversible attachment to a mandrel. Coated abrasive instruments may be used in the finishing and smoothing procedures of certain enamel walls (and margins) of tooth preparations for indirect restorations but most often in finishing procedures for restorations.

The abrasives are softer and are less wear resistant than diamond powder, and as a result, they tend to lose their sharp edges and their cutting efficiency with use. When this happens to coated instruments, they are discarded. In contrast, molded instruments are intended to partially regenerate through the gradual loss of their worn outer layers but may require that the operator reshape them to improve their concentricity. This is accomplished by applying a truing or shaping stone against the rotating instrument.

Materials

The matrix materials usually are phenolic resins or rubber. Some molded points may be sintered, but most are resin bonded. A rubber matrix is used primarily to obtain a flexible head on instruments to be used for polishing. A harder, non-flexible rubber matrix is often used for molded silicon carbide (SiC) disks. The matrix of coated instruments is usually one of the phenolic resins.

Synthetic or natural abrasives may be used, including silicon carbide, aluminum oxide, garnet, quartz, pumice, and cuttlebone. The hardness of the abrasive has a major effect on the cutting efficiency. The Mohs hardness values for important dental abrasives are shown in Table 6-5. SiC usually is used in molded rounds, tree or bud shapes, wheels, and cylinders of various sizes. These points are normally gray-green, available in various textures, and usually fast cutting (except on enamel) and produce a moderately smooth surface. Molded unmounted disks are black or a dark color, have a soft matrix, wear more rapidly than stones, and produce a moderately rough surface texture. These disks are termed *carborundum disks* or *separating disks*. Aluminum oxide is used for the same instrument designs as those for silicon carbide disks. Points are usually white, rigid, fine textured, and less porous and produce a smoother surface than SiC.

Garnet (reddish) and quartz (white) are used for coated disks that are available in a series of particle sizes and range from coarse to medium-fine for use in initial finishing. These abrasives are hard enough to cut tooth structure and all restorative materials, with the exception of some porcelains. Pumice is a powdered abrasive produced by crushing foamed volcanic glass into thin glass flakes. The flakes cut effectively, but they

Table 6-5 Hardness Values of Restorative Materials, Tooth Structure, and Abrasives

	Knoop Hardness	Brinell Hardness	Mohs Hardness
Dentin	68	48	3–4
Enamel	343	300	5
Dental composite	41–80	60–80	5–7
Dental amalgam	110	—	4–5
Gold alloy (type III)	—	110	—
Feldspathic porcelain	460	—	6–7
Pumice	—	—	6
Cuttlebone	—	—	7
Garnet	—	—	6.5–7
Quartz	800	600	7
Aluminum oxide	1500	1200	9
Silicon carbide	2500	—	9.5
Diamond	>7000	>5000	10

break down rapidly. Pumice is used with rubber disks and wheels, usually for initial polishing procedures. Cuttlebone is derived from the cuttlefish, a relative of squid and octopus. It is becoming scarce and gradually is being replaced by synthetic substitutes. It is a soft white abrasive, used only in coated disks for final finishing and polishing. It is soft enough that it reduces the risk of unintentional damage to tooth structure during the final stages of finishing.

Cutting Mechanisms

For cutting, it is necessary to apply sufficient pressure to make the cutting edge of a blade or abrasive particle dig into the surface. Local fracture occurs more easily if the strain rate is high (high rotary instrument surface speed) because the surface that is being cut responds in a brittle fashion. The process by which rotary instruments cut tooth structure is complex and not fully understood. The following discussion of cutting addresses cutting evaluations, cutting instrument design, proposed cutting mechanisms, and clinical recommendations for cutting.

Evaluation of Cutting

Cutting can be measured in terms of effectiveness and efficiency. Certain factors may influence one, but not the other.²⁷ Cutting effectiveness is the rate of tooth structure removal (mm/min or mg/s). Effectiveness does not consider potential side effects such as heat or noise. Cutting efficiency is the percentage of energy actually producing cutting. Cutting efficiency is reduced when energy is wasted as heat or noise. It is possible to increase effectiveness while decreasing efficiency. A dull bur may be made to cut faster than a sharp bur by applying a greater pressure, but experience indicates that this results in a great increase in heat production and reduced efficiency.²⁸

It is generally agreed that increased rotational speed results in increased effectiveness and efficiency. Adverse effects associated with increased speeds are heat, vibration, and noise. Heat has been identified as a primary cause of pulpal injury. Air-water sprays do not prevent the production of heat, but do serve to remove it before it causes a damaging increase in temperature within the tooth.

Bladed Cutting

The following discussion focuses on rotary bladed instruments but also is applicable to bladed hand instruments. Tooth structure, similar to other materials, undergoes brittle and ductile fracture. Brittle fracture is associated with crack production, usually by tensile loading. Ductile fracture involves plastic deformation of material, usually proceeding by shear. Extensive plastic deformation also may produce local work hardening and encourage brittle fracture. Low-speed cutting tends to proceed by plastic deformation before tooth structure fracture. High-speed cutting, especially of enamel, proceeds by brittle fracture.

The rate of stress application (or strain rate) affects the resultant properties of materials. In general, the faster the rate of loading, the greater are the strength, hardness, modulus of elasticity, and brittleness of a material. A cutting instrument with a large diameter and high rotational speed produces a high surface speed and a high stress (or strain) rate.

Many factors interact to determine which cutting mechanism is active in a particular situation. The mechanical properties of tooth structure, the design of the cutting edge or point, the linear speed of the instrument's surface, the contact force applied, and the power output characteristics of the handpiece influence the cutting process in various ways.^{19,29}

For the blade to initiate the cutting action, it must be sharp, must have a higher hardness and modulus of elasticity than the material being cut, and must be pressed against the surface with sufficient force. The high hardness and modulus of elasticity are essential to concentrate the applied force on a small enough area to exceed the shear strength of the material being cut. As shown in Figure 6-25, sheared segments accumulate in a distorted layer that slides up along the rake face of the blade until it breaks or until the blade disengages from the surface as it rotates. These chips accumulate in the clearance space between blades until washed out or thrown out by centrifugal force.

Mechanical distortion of tooth structure ahead of the blade produces heat. Frictional heat is produced by the rubbing

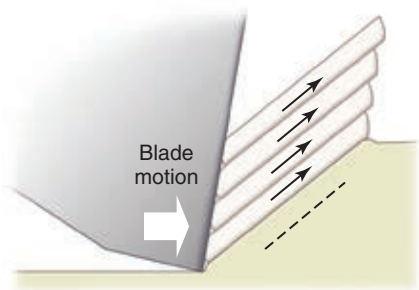


Fig. 6-25 Schematic representation of bur blade (*end view*) cutting a ductile material by shearing mechanism. Energy is required to deform the material removed and produce new surface.

action of the cut chips against the rake face of the blade and the blade tip against the cut surface of the tooth immediately behind the edge. This can produce extreme temperature increases in the tooth and the bur in the absence of adequate cooling. The transfer of heat is not instantaneous, and the reduced temperature increase observed in teeth cut at very high speeds may be caused, in part, by the removal of the heated surface layer of the tooth structure by a following blade before the heat can be conducted into the tooth.

Abrasive Cutting

The following discussion is pertinent to all abrasive cutting situations, but diamond instruments are used as the primary example.¹² The cutting action of diamond abrasive instruments is similar in many ways to that of bladed instruments, but key differences result from the properties, size, and distribution of the abrasive. The very high hardness of diamonds provides superior resistance to wear. A diamond instrument that is not abused has little or no tendency to dull with use. Individual diamond particles have very sharp edges, are randomly oriented on the surface, and tend to have large negative rake angles.

When diamond instruments are used to cut ductile materials, some material is removed as chips, but much material flows laterally around the cutting point and is left as a ridge of deformed material on the surface (Fig. 6-26). Repeated deformation work hardens the distorted material until irregular portions become brittle, break off, and are removed. This type of cutting is less efficient than that by a blade; burs are generally preferred for cutting ductile materials such as dentin.

Diamonds cut brittle materials by a different mechanism. Most cutting results from tensile fractures that produce a series of subsurface cracks (Fig. 6-27). Diamonds are most efficient when used to cut brittle materials and are superior to burs for the removal of dental enamel. Diamond abrasives are commonly used for milling in computer-aided design/computer-assisted manufacturing (CAD/CAM) or copy-milling applications (see section on machined restorations in Online Chapter 18).

Cutting Recommendations

Overall, the requirements for effective and efficient cutting include using a contra-angle handpiece, air-water spray for cooling, high operating speed (> 200,000 rpm), light pressure,

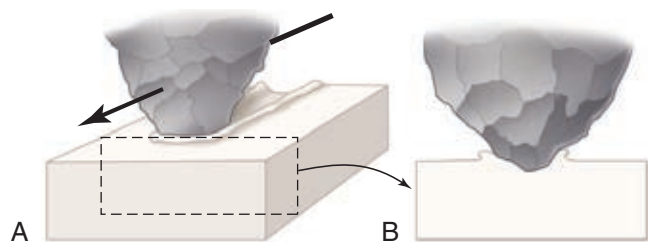


Fig. 6-26 Schematic representation of an abrasive particle cutting ductile material. **A**, Lateral view. **B**, Cross-sectional view. Material is displaced laterally by passage of an abrasive particle, work hardened, and subsequently removed by other particles.

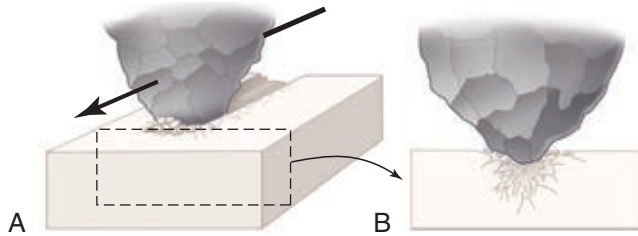


Fig. 6-27 Schematic representation of abrasive particle cutting brittle material. **A**, Lateral view. **B**, Cross-sectional view. Subsurface cracks caused by the passage of abrasive particles intersect, undermining small pieces of material, which are removed easily by following abrasive particles.

and a carbide bur or diamond instrument. Carbide burs are better for end cutting, produce lower heat, and have more blade edges per diameter for cutting. They are used effectively for punch cuts to enter tooth structure, intracoronal tooth preparation, amalgam removal, small preparations, and secondary retention features. Diamond instruments have higher hardness, and coarse diamonds have high cutting effectiveness. Diamonds are more effective than burs for intracoronal and extracoronal tooth preparations, beveling enamel margins on tooth preparations, and enameloplasty.

Hazards with Cutting Instruments

Almost everything done in a dental office involves some risk to the patient, the dentist, or the auxiliaries. For the patient, pulpal dangers arise from tooth preparation and restoration procedures. Soft tissue dangers are also present. Everyone is potentially susceptible to eye, ear, and inhalation dangers. Careful adherence to normal precautions can, however, eliminate or minimize most risks associated with the use of cutting instruments.

Pulpal Precautions

The use of cutting instruments can harm the pulp by exposure to mechanical vibration, heat generation, desiccation and loss of dentinal tubule fluid, or transection of odontoblastic processes. As the thickness of remaining dentin decreases, the pulpal insult (and response) from heat or desiccation increases. Slight to moderate injury produces a localized, protective pulpal response in the region of the cut tubules. In severe injury, destruction extends beyond the cut tubules, often resulting in pulpal abscess and death of the pulp. These pulpal sequelae (recovery or necrosis) take 2 weeks to 6 months or longer, depending on the extent and degree of the trauma. Although a young pulp is more prone to injury, it also recovers more effectively compared with an older pulp, in which the recuperative powers are slower and less effective.

Enamel and dentin are good thermal insulators and protect the pulp if the quantity of heat is not too great and the remaining thickness of tissue is adequate. The longer the time of cutting and the higher the local temperature produced, the greater is the threat of thermal trauma. The remaining tissue is effective in protecting the pulp in proportion to the square of its thickness. Steel burs produce more heat than carbide

burs because of inefficient cutting. Burs and diamond instruments that are dull or plugged with debris do not cut efficiently, resulting in heat production. When used without coolants, diamond instruments generate more damaging heat compared with carbide burs.

The most common instrument coolants are air and air-water sprays. Air alone as a coolant is not effective in preventing pulpal damage because it needlessly desiccates dentin and damages odontoblasts. Air has a much lower heat capacity than water and is much less efficient in absorbing unwanted heat. An air coolant alone should be used only when visibility is a problem, such as during the finishing procedures of tooth preparations. At such times, air coolant combined with lower speed and light, intermittent application should be used to enhance vision and minimize trauma. Air-water spray is universally used to cool, moisten, and clear the operating site during normal cutting procedures. In addition, the spray lubricates, cleans, and cools the cutting instrument, increasing its efficiency and service life. A well-designed and properly directed air-water spray also helps keep the gingival crevice open for better visualization when gingival extension is necessary. The use of a water spray and its removal by an effective high-volume evacuator are especially important when old amalgam restorations are removed because they decrease mercury vapor release and increase visibility.

During normal cutting procedures, a layer of debris, described as a smear layer, is created that covers the cut surfaces of the enamel and dentin. The smear layer on dentin is moderately protective because it occludes the dentinal tubules and inhibits the outward flow of tubular fluid and the inward penetration of microleakage contaminants. The smear layer is, however, still porous. When air alone is applied to dentin, local desiccation may produce fluid flow and affect the physiologic status of the odontoblastic processes in the underlying dentin. Air is applied only to the extent of removing excess moisture, leaving a glistening surface.

Soft Tissue Precautions

The lips, tongue, and cheeks of the patient are the most frequent areas of soft tissue injury. The handpiece should never be operated unless good access to and visualization of the cutting site are available. A rubber dam is helpful in isolating the operating site. When the dam is not used, the dental assistant can retract the soft tissue on one side with a mouth mirror, cotton roll, or evacuator tip. The dentist usually can manage the other side with a mirror or cotton roll or both. If the dentist must work alone, the patient can help by holding a retraction-type saliva ejector evacuator tip, after it is positioned in the mouth.

With air-driven handpieces, the rotating instrument does not stop immediately when the foot control is released. The operator must wait for the instrument to stop or be extremely careful when removing the handpiece from the mouth so as not to lacerate soft tissues. The large disk is one of the most dangerous instruments used in the mouth. Such disks are seldom indicated intraorally. They should be used with light, intermittent application and with extreme caution.

With electric handpieces, patients have been severely burned when these handpieces have overheated during dental procedures (Fig. 6-28). Some patients suffered third-degree burns that required reconstructive surgery. Burns may not be



Fig. 6-28 This patient suffered burn from the overheated bearing of an electric handpiece. Because the patient was anesthetized, he was unaware of the burn as it occurred from the overheated handpiece.

apparent to the operator or the patient until after the tissue damage has occurred because the anesthetized patient cannot feel the tissue burning and the handpiece housing insulates the operator from the heated attachment. Although the reported burns have occurred during cutting of tooth and bone, tooth extraction and other dental surgical procedures, overheating could occur during any dental procedure.

With high-speed and low-speed air-driven handpieces, sluggish handpiece performance will alert the dental practitioner to maintenance issues such as a dull bur or worn or clogged gears or bearings. A poorly maintained electric handpiece does not provide a similar warning that maintenance is needed. Instead, if an electric handpiece is worn out, damaged, or clogged, the electric motor sends increased power to the handpiece head or attachment in order to maintain handpiece performance. This increased power can rapidly generate heat at the head of the handpiece attachment. Because the heat buildup is so rapid and is efficiently conducted through the metal handpiece, a burn occurring in the patient may be the first indication of handpiece problems. Adhering to strict maintenance guidelines recommended by the manufacturers is critical to prevent overheating in electric handpieces. The clinician must be aware that improperly maintained, damaged, or worn-out devices have the potential to overheat without warning.

The dentist and the assistant always must be aware of the patient's response during the cutting procedures. A sudden reflex movement by the patient such as gagging, swallowing, or coughing could result in serious injury. If an accident does occur and soft tissue is damaged, the operator should remain calm and control any hemorrhage with a pressure pack. The patient should be told what has happened, and medical assistance should be obtained, if needed.

The chance of mechanical pulpal involvement may be greater if a hand excavator is used to remove the last portions of soft caries in a deep preparation. When the remaining dentinal wall is thin, the pressure exerted on the excavator may be sufficient to break into the pulp chamber. A round bur may be used at a low speed with light, intermittent pressure for caries removal. Air-driven handpieces should be operated just above stall-out speed to improve tactile sense for caries

removal. The dentist should proceed with caution and inspect the area frequently.

Eye Precautions

The operator, the assistant, and the patient should wear glasses with side shields to prevent eye damage from airborne particles during operative procedures using rotary instrumentation. When high speeds are used, particles of old restorations, tooth structure, bacteria, and other debris are discharged at high speeds from the patient's mouth. Sufficiently strong high-volume evacuation applied by the dental assistant near the operating site helps alleviate this problem. Protective glasses are always indicated when rotary instrumentation is being used. The dentist, being in the direct path of such particles, is more likely to receive injury than the assistant or the patient. If an eye is injured, it should be covered by a clean gauze pad until medical attention can be obtained.

In addition to routine airborne debris, airborne particles may be produced occasionally by matrix failure of molded abrasive cutting instruments. Hard matrix wheels may crack or shatter into relatively large pieces. Soft abrasive wheels or points may increase in temperature during use, causing the rubber matrix to debond explosively from the abrasive into fine particles.

Precautions must be taken to prevent eye injury from unusual light sources such as visible light-curing units and laser equipment. Dental personnel and patients should be protected from high-intensity visible light with the use of colored plastic shields (attached to the fiberoptic tip). Laser light can be inadvertently reflected from many surfaces in the dental operatory; the operatory should be closed, and everyone should wear protective goggles (see the earlier section on laser equipment).

Ear Precautions

Various sounds are known to affect people in different ways. Soft music or random sounds such as rainfall usually have a relaxing or sedative effect. Loud noises are generally annoying and may contribute to mental and physical distress. A noisy environment decreases the ability to concentrate, increases proneness to accidents, and reduces overall efficiency. Extremely loud noises such as explosions or continuous exposure to high noise levels can cause permanent damage to the hearing mechanism.

An objectionable high-pitched whine is produced by some air-driven handpieces at high speeds. Aside from the annoying aspect of this noise, hearing loss could result from continued exposure. Potential damage to hearing from noise depends on (1) the intensity or loudness (decibels [db]), (2) frequency (cycles per second [cps]) of the noise, (3) duration (time) of the noise, and (4) susceptibility of the individual. Older age, existing ear damage, disease, and medications are other factors that can accelerate hearing loss.

Normal ears require that the intensity of sound reach a certain minimal level before the ear can detect it. This is known as *auditory threshold*. It can vary with the frequency and exposure to other sounds. When subjected to a loud noise of short duration, a protective mechanism of the ear causes it to lose some sensitivity temporarily. This is described as

temporary threshold shift. If sufficient time is allowed between exposures, complete recovery occurs. Extended or continuous exposure is much more likely to result in a permanent threshold shift, with persistent hearing loss. The loss may be caused by all frequencies, but often high-frequency sounds affect hearing more severely. A certain amount of unnoticed noise (ambient noise level) is present even in a quiet room (20–40 db). An ordinary conversation averages 50 to 70 db in a frequency range of 500 to 2500 cps.

Air-driven handpieces with ball bearings, free running at 30-lb air pressure, may have noise levels of 70 to 94 db at high frequencies. Noise levels greater than 75 db in frequency ranges of 1000 to 8000 cps may cause hearing damage. Noise levels vary among handpieces produced by the same manufacturer. Handpiece wear and eccentric rotating instruments can cause increased noise. Protective measures are recommended when the noise level reaches 85 db with frequency ranges of 300 to 4800 cps. Protection is mandatory in areas where the level transiently reaches 95 db. The effect of excessive noise levels depends on exposure times. Normal use of a dental handpiece is one of intermittent application that generally is less than 30 minutes per day. Earplugs can be used to reduce the level of exposure, but these have several drawbacks. Room soundproofing helps and can be accomplished with absorbing materials used on walls and floors. Anti-noise devices also can be used to cancel unwanted sounds.

Inhalation Precautions

Aerosols and vapors are created by cutting tooth structure and restorative materials. Aerosols and vapors are a health hazard to all present. The aerosols are fine dispersions in air of water, tooth debris, microorganisms, or restorative materials. Cutting amalgams or composites produce submicron particles and vapor. The particles that may be inadvertently inhaled have the potential to produce alveolar irritation and tissue reactions. Vapor from cutting amalgams is predominantly mercury and should be eliminated, as much as possible, by careful evacuation near the tooth being operated on. The vapors generated during cutting or polishing by thermal decomposition of polymeric restorative materials (sealants, acrylic resin, composites) are predominantly monomers. They may be eliminated efficiently by careful intraoral evacuation during the cutting or polishing procedures.

A rubber dam protects the patient against oral inhalation of aerosols or vapors, but nasal inhalation of vapor and finer aerosol still may occur. Disposable masks worn by dental office personnel filter out bacteria and all but the finest particulate matter. Masks do not, however, filter out mercury or monomer vapors. The biologic effects of mercury hazards and appropriate office hygiene measures are discussed in online [Chapter 18](#) on Biomaterials.

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Preliminary Considerations for Operative Dentistry

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This chapter addresses routine chairside pre-operative procedures (before actual tooth preparation). Primarily, these procedures include patient and operator positions and isolation of the operating field.

Preoperative Patient and Dental Team Considerations

In preparation for a clinical procedure, it is important to ensure that patient and operator positions are properly selected, that instrument exchange between the dentist and the assistant is efficient, that proper illumination is present, and that magnification is used, if needed.

Patient and Operator Positions

Efficient patient and operator positions are beneficial for the welfare of both individuals. A patient who is in a comfortable position is more relaxed, has less muscle tension, and is more capable of cooperating with the dentist.

The practice of dentistry is demanding and stressful. Physical problems may arise if appropriate operating positions are neglected.¹ Most restorative dental procedures can be accomplished with the dentist seated. Positions that create unnecessary curvature of the spine or slumping of the shoulders should be avoided. Proper balance and weight distribution on both feet is essential when operating from a standing position. Generally, any uncomfortable or unnatural position that places undue strain on the body should be used only rarely.

Chair and Patient Positions

Chair and patient positions are important considerations. Dental chairs are designed to provide total body support in any chair position. An available chair accessory is an adjustable headrest cushion or an articulating headrest attached to the chair back. A contoured or lounge-type chair provides complete patient support and comfort. Most chairs also are equipped with programmable operating positions.

The most common patient positions for operative dentistry are almost supine or reclined 45 degrees (Fig. 7-1). The choice

of patient position varies with the operator, the type of procedure, and the area of the mouth involved in the operation. In the almost supine position, the patient's head, knees, and feet are approximately the same level. The patient's head should not be lower than the feet; the head should be positioned lower than the feet only in an emergency, as when the patient is in syncope.

Operating Positions

Operating positions can be described by the location of the operator or by the location of the operator's arms in relation to patient position. A right-handed operator uses essentially three positions—right front, right, and right rear. These are sometimes referred to as the 7-o'clock, 9-o'clock, and 11-o'clock positions (Fig. 7-2, A). For a left-handed operator, the three positions are the left front, left, and left rear positions, or the 5-o'clock, 3-o'clock, and 1-o'clock positions. A fourth position, direct rear position, or 12-o'clock position, has application for certain areas of the mouth. As a rule, the teeth being treated should be at the same level as the operator's elbow. The operating positions described here are for the right-handed operator; the left-handed operator should substitute left for right.

RIGHT FRONT POSITION

The right front position facilitates examination and treatment of mandibular anterior teeth (see Fig. 7-2, B), mandibular posterior teeth (especially on the right side), and maxillary anterior teeth. It is often advantageous to have the patient's head rotated slightly toward the operator.

RIGHT POSITION

In the right position, the operator is directly to the right of the patient (see Fig. 7-2, C). This position is convenient for operating on the facial surfaces of maxillary and mandibular right posterior teeth and the occlusal surfaces of mandibular right posterior teeth.

RIGHT REAR POSITION

The right rear position is the position of choice for most operations. The operator is behind and slightly to the right of

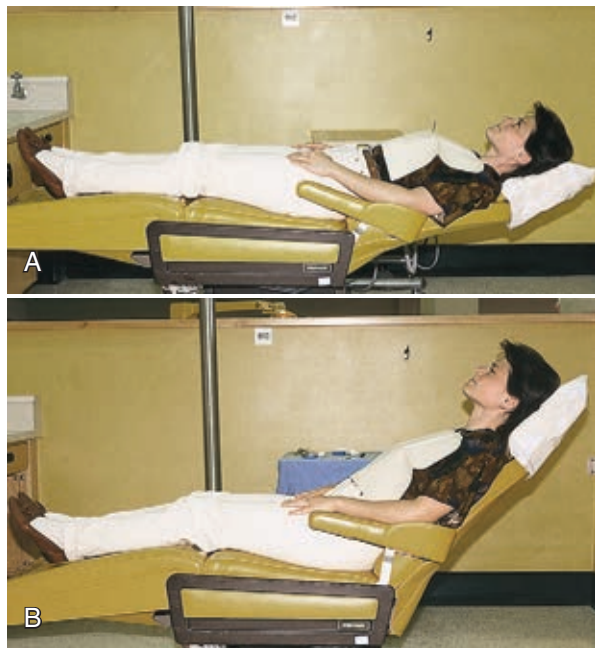


Fig. 7-1 Common patient positions. Both positions are recommended for sit-down dentistry. Use depends on the arch being treated. **A**, Supine. **B**, Reclined 45 degrees. (From Darby ML, Walsh MM: *Dental hygiene: Theory and practice*, ed 3, St. Louis, 2010, Saunders.)

the patient. The left arm is positioned around the patient's head (see Fig. 7-2, *D*). When operating from this position, the lingual and incisal (occlusal) surfaces of maxillary teeth are viewed in the mouth mirror. Direct vision may be used on mandibular teeth, particularly on the left side, but the use of a mouth mirror is advocated for visibility, light reflection, and retraction.

DIRECT REAR POSITION

The direct rear position is used primarily for operating on the lingual surfaces of mandibular anterior teeth. The operator is located directly behind the patient and looks down over the patient's head (see Fig. 7-2, *E*).

General Considerations

Several general considerations regarding chair and patient positions are important. The operator should not hesitate to rotate the patient's head backward or forward or from side to side to accommodate the demands of access and visibility of the operating field. Minor rotation of the patient's head is not uncomfortable to the patient and allows the operator to maintain his or her basic body position. As a rule, when operating in the maxillary arch, the maxillary occlusal surfaces should be oriented approximately perpendicular to the floor. When operating in the mandibular arch, the mandibular occlusal surfaces should be oriented approximately 45 degrees to the floor.

The operator's face should not come too close to the patient's face. The ideal distance, similar to that for reading a book, should be maintained. Another important aspect of proper operating position is to minimize body contact with the patient. A proper operator does not rest the forearms on

the patient's shoulders or the hands on the patient's face or forehead. The patient's chest should not be used as an instrument tray. From most positions, the left hand should be free to hold the mouth mirror to reflect light onto the operating field, to view the tooth preparation indirectly, or to retract the cheek or tongue. In certain instances, it is more appropriate to retract the cheek with one or two fingers of the left hand than to use a mouth mirror. It is often possible, however, to retract the cheek and reflect light with the mouth mirror at the same time.

When operating for an extended period, the operator can obtain a certain amount of rest and muscle relaxation by changing operating positions. Operating from a single position through the day, especially if standing, produces unnecessary fatigue. Changing positions, if only for a short time, reduces muscle strain and lessens fatigue.¹

Operating Stools

A variety of operating stools are available for the dentist and the dental assistant. The seat should be well padded with smooth cushion edges and should be adjustable up and down. The backrest should be adjustable forward and backward as well as up and down.

Some advantages of the seated work position are lost if the operator uses the stool improperly. The operator should sit back on the cushion, using the entire seat and not just the front edge. The upper body should be positioned so that the spinal column is straight or bent slightly forward and supported by the backrest of the stool. The thighs should be parallel to the floor, and the lower legs should be perpendicular to the floor. If the seat is too high, its front edge cuts off circulation to the user's legs. Feet should be flat on the floor.

The seated work position for the assistant is essentially the same as for the operator except that the stool is 4 to 6 inches higher for maximal visual access. It is important that the stool for the assistant have an adequate footrest so that a parallel thigh position can be maintained with good foot support. When properly seated, the operator and the assistant are capable of providing dental service throughout the day without an unnecessary decline in efficiency and productivity because of muscle tension and fatigue (Fig. 7-3).

Instrument Exchange

All instrument exchanges between the operator and the assistant should occur in the exchange zone below the patient's chin and a few inches above the patient's chest. Instruments should not be exchanged over the patient's face. During the procedure, the operator should anticipate the next instrument required, and inform the assistant accordingly; this allows the instrument to be brought into the exchange zone for a timely exchange.

During proper instrument exchange, the operator should not need to remove his or her eyes from the operating field. The operator should rotate the instrument handle forward to cue the assistant to exchange instruments. Any sharp instrument should be exchanged with appropriate deliberation. The assistant should take the instrument from the operator, rather than the operator dropping it into the assistant's hand, and vice versa. Each person should be sure that the other has a firm grasp on the instrument before it is released.

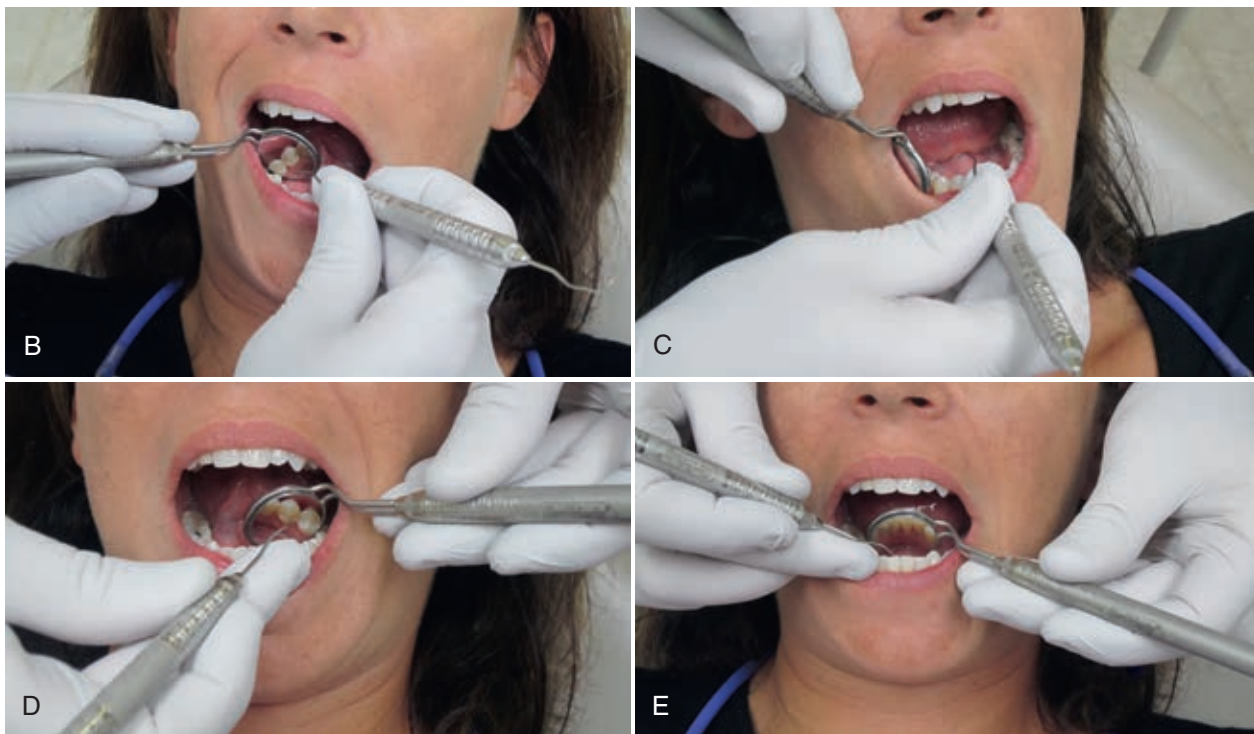
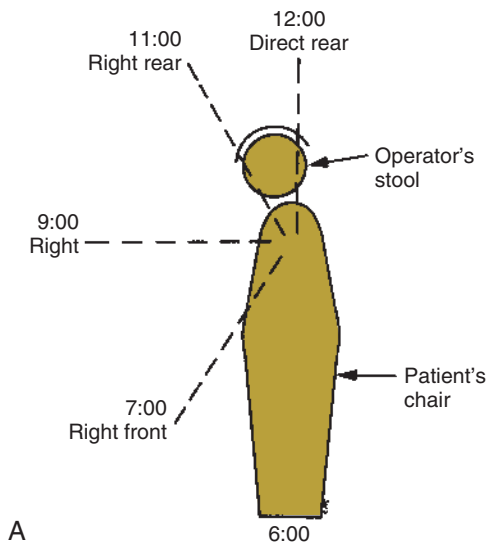


Fig. 7-2 Operating positions indicated by arm approach to the patient. **A**, Diagrammatic operator positions. **B**, Right front. **C**, Right. **D**, Right rear. **E**, Direct rear.

Magnification and Headlamp Illumination

Another key to the success of clinical operative dentistry is visual acuity. The operator must be able to see clearly to attend to the details of each procedure. The use of magnification facilitates attention to detail and does not adversely affect vision. Magnifying lenses have a fixed focal length that often requires the operator to maintain a proper working distance, which ensures good posture. Several types of magnification devices are available, including bifocal eyeglasses, loupes, and surgical telescopes (Fig. 7-4). The use of such magnification devices also provides some protection from eye injury. To

further improve visual acuity, headlamps are recommended in operative dentistry. Their greatest advantage is the light source being parallel to the clinician's vision, eliminating shadows at the operating field. Current headlamps use light-emitting diode (LED) technology and produce whiter light than conventional tungsten halogen light sources.

Isolation of the Operating Field

The goals of operating field isolation are moisture control, retraction, and harm prevention.



Fig. 7-3 Recommended seating positions for operator and chairside assistant, with the height of the operating field approximately at elbow level of the operator. (From Robinson DS, Bird DL: *Essentials of dental assisting*, ed 4, St. Louis, 2007, Saunders.)

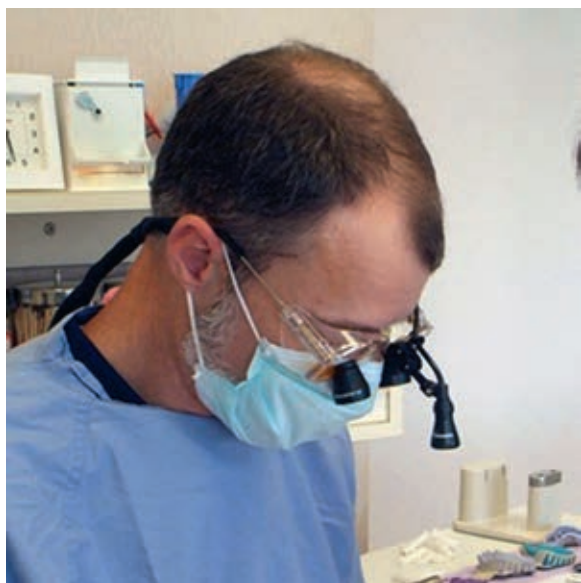


Fig. 7-4 Use of magnification with surgical telescopes.

Goals of Isolation

Moisture Control

Operative dentistry cannot be executed properly unless the moisture in the mouth is controlled. Moisture control refers to excluding sulcular fluid, saliva, and gingival bleeding from the operating field. It also involves preventing the spray from the handpiece and restorative debris from being swallowed or aspirated by the patient. The rubber dam, suction devices, and absorbents are variously effective in moisture control. Generally, the rubber dam is the recommended technique for moisture control. Raskin et al. and Fusayama have reported, however, that achieving effective isolation is more important than the specific technique used.^{2,3}

Retraction and Access

The details of a restorative procedure cannot be managed without proper retraction and access. Retraction and access provides maximal exposure of the operating site and usually involves having the patient maintain an open mouth and depressing or retracting the gingival tissue, tongue, lips, and cheek. The rubber dam, high-volume evacuator, absorbents, retraction cord, mouth prop, and other isolation devices such as the Isolite (Isolite Systems, Santa Barbara, CA) are used for retraction and access.

Harm Prevention

An important consideration of isolating the operating field is preventing harm to the patient during the operation.^{4,5} Excessive saliva and handpiece spray can alarm the patient. Small instruments and restorative debris can be aspirated or swallowed. Soft tissue can be damaged accidentally. The same devices used for moisture control and retraction contribute not only to harm prevention but also to patient comfort and operator efficiency. Harm prevention is achieved as much by the manner in which the devices are used as by the devices themselves.

Local Anesthesia

Local anesthetics play a role in eliminating the discomfort of dental treatment and controlling moisture by reducing salivary flow. Local anesthetics incorporating a vasoconstrictor also reduce blood flow, which helps control hemorrhage at the operating site.

Rubber Dam Isolation

In 1864, S.C. Barnum, a New York City dentist, introduced the rubber dam into dentistry. Use of the rubber dam ensures appropriate dryness of the teeth and improves the quality of clinical restorative dentistry.^{6,7} The rubber dam is used to define the operating field by isolating one or more teeth from the oral environment. The dam eliminates saliva from the operating site and retracts the soft tissue.

Advantages

The advantages of rubber dam isolation of the operating field are (1) a dry, clean operating field; (2) improved access and visibility; (3) potentially improved properties of dental materials; (4) protection of the patient and the operator; and (5) operating efficiency.

DRY, CLEAN OPERATING FIELD

For most procedures, rubber dam isolation is the preferred method of obtaining a dry, clean field. The operator can best perform procedures such as caries removal, proper tooth preparation, and insertion of restorative materials in a dry field. The time saved by operating in a clean field with good visibility may more than compensate for the time spent applying the rubber dam.⁸ When excavating a deep caries lesion and risking pulpal exposure, use of the rubber dam is strongly recommended to prevent pulpal contamination from oral fluids.

ACCESS AND VISIBILITY

The rubber dam provides maximal access and visibility. It controls moisture and retracts soft tissue. Gingival tissue is retracted mildly to enhance access to and visibility of the gingival aspects of the tooth preparation. The dam also retracts the lips, cheeks, and tongue. A dark-colored rubber dam provides a non-reflective background in contrast to the operating site. Because the dam remains in place throughout the operative procedure, access and visibility are maintained without interruption.

IMPROVED PROPERTIES OF DENTAL MATERIALS

The rubber dam prevents moisture contamination of restorative materials during insertion and promotes improved properties of dental materials. Amalgam restorative material does not achieve its optimum physical properties if used in a wet field.⁶ Bonding to enamel and dentin is unpredictable if the tooth substrate is contaminated with saliva, blood, or other oral fluids.^{9,10} Some studies have concluded that no difference exists between the use of the rubber dam and cotton roll isolation as long as control of sources of contamination is maintained during the restorative procedures.^{2,11-13}

PROTECTION OF THE PATIENT AND THE OPERATOR

The rubber dam protects the patient and the operator. It protects the patient from aspirating or swallowing small instruments or debris associated with operative procedures.¹⁴ A properly applied rubber dam protects soft tissue from irritating or distasteful medicaments (e.g., etching agents). The dam also offers some soft tissue protection from rotating burs and stones. Authors disagree on whether the rubber dam protects the patient from mercury exposure during amalgam removal.^{15,16} However, it is generally agreed that the rubber dam is an effective infection control barrier for the dental office.¹⁷⁻¹⁹

OPERATING EFFICIENCY

Use of the rubber dam allows for operating efficiency and increased productivity. Excessive conversation with the patient is discouraged. The rubber dam retainer (discussed later) helps provide a moderate amount of mouth opening during the procedure. (For additional mouth-opening aids, see the section on Mouth Props.) Quadrant restorative procedures are facilitated. Many state dental practice acts permit the assistant to place the rubber dam, thus saving time for the dentist. Christensen reported that use of a rubber dam increases the quality and quantity of restorative services.⁸

Disadvantages

Rubber dam use is low among private practitioners.²⁰⁻²² Time consumption and patient objection are the most frequently quoted disadvantages of the rubber dam. However, the rubber dam usually can be placed in less than 5 minutes. The advantages previously mentioned certainly outweigh the time spent with placement.

Certain situations may preclude the use of the rubber dam, including (1) teeth that have not erupted sufficiently to support a retainer, (2) some third molars, and (3) extremely malpositioned teeth. In addition, patients may not tolerate the rubber dam if breathing through the nose is difficult. In rare



Fig. 7-5 Rubber dam material as supplied in sheets. (From Boyd LRB: *Dental instruments: A pocket guide*, ed 4, St. Louis, 2012, Saunders.)

instances, the patient cannot tolerate a rubber dam because of psychological reasons or latex allergy.^{12,23} Latex-free rubber dam material is, however, currently available (Fig. 7-5). Jones and Reid reported that use of the rubber dam was well accepted by patients and operators.²⁴

Materials and Instruments

The materials and instruments necessary for the use of the rubber dam are available from most dental supply companies.

MATERIAL

Rubber dam material (latex and nonlatex), as with all rubber products, deteriorates over time, resulting in low tear strength. The dam material is available in 5 × 5 inch (12.5 × 12.5 cm) or 6 × 6 inch (15 × 15 cm) sheets. The thicknesses or weights available are thin (0.006 inch [0.15 mm]), medium (0.008 inch [0.2 mm]), heavy (0.010 inch [0.25 mm]), and extra heavy (0.012 inch [0.30 mm]). Light and dark dam materials are available, and darker colors are generally preferred for contrast. The rubber dam material has a shiny side and a dull side. Because the dull side is less light reflective, it is generally placed facing the occlusal side of the isolated teeth. A thicker dam is more effective in retracting tissue and more resistant to tearing; it is especially recommended for isolating Class V lesions in conjunction with a cervical retainer. The thinner material has the advantage of passing through the contacts easier, which is particularly helpful when contacts are tight.

FRAME

The rubber dam holder (frame) maintains the borders of the rubber dam in position. The Young holder is a U-shaped metal frame (Fig. 7-6) with small metal projections for securing the borders of the rubber dam.

RETAINER

The rubber dam retainer consists of four prongs and two jaws connected by a bow (Fig. 7-7). The retainer is used to anchor the dam to the most posterior tooth to be isolated. Retainers also are used to retract gingival tissue. Many different sizes and



Fig. 7-6 Young rubber dam frame (holder). (From Hargreaves KM, Cohen S: *Cohen's pathways of the pulp*, ed 10, St. Louis, 2011, Mosby.)

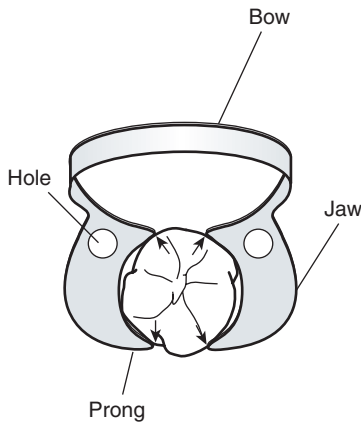


Fig. 7-7 Rubber dam retainer. Note four-point prong contact (arrows) with tooth. (From Daniel SJ, Harfst SA, Wilder RS: *Mosby's dental hygiene: Concepts, cases, and competencies*, ed 2, St. Louis, 2008, Mosby.)

shapes are available, with specific retainers designed for certain teeth (Fig. 7-8). Table 7-1 lists suggested retainer applications. When positioned on a tooth, a properly selected retainer should contact the tooth in its four line angles (see Fig. 7-7). This four-point contact prevents rocking or tilting of the retainer. Movement of the retainer on the anchor tooth can injure the gingiva and the tooth, resulting in postoperative soreness or sensitivity.²⁵ The prongs of some retainers are gingivally directed (inverted) and are helpful when the anchor tooth is only partially erupted or when additional soft tissue retraction is indicated (Fig. 7-9). The jaws of the retainer should not extend beyond the mesial and distal line angles of the tooth because (1) they may interfere with matrix and wedge placement, (2) gingival trauma is more likely to occur, and (3) a complete seal around the anchor tooth is more difficult to achieve.

Wingless and winged retainers are available (see Fig. 7-8). The winged retainer has anterior and lateral wings (Fig. 7-10).

Table 7-1 Suggested Retainers for Various Anchor Tooth Applications	
Retainer	Application
W56	Most molar anchor teeth
W7	Mandibular molar anchor teeth
W8	Maxillary molar anchor teeth
W4	Most premolar anchor teeth
W2	Small premolar anchor teeth
W27	Terminal mandibular molar anchor teeth requiring preparations involving the distal surface

FIESTA® Color Coded Matte Finish Winged and Wingless Clamps

<p>ANTERIOR</p>	<p>MOLAR</p> <p>Small lower Lower Lower</p>
<p>PREMOLAR</p> <p>Large bicuspid Bicuspid</p>	<p>Upper Small upper Upper and lower</p>
<p>SERRATED JAWS</p> <p>Serrations for improved retention</p> <p>Lower right molars/ Upper left molars Lower left molars/ Upper right molars</p>	<p>MOLAR - SPECIAL USE</p> <p>For irregularly shaped, structurally compromised or partially erupted molars</p> <p>Small Large</p>

Fig. 7-8 Selection of rubber dam retainers. Note retainers with wings. (Pictured: Color Coded Matte Finish Winged and Wingless Clamps.) (Courtesy Coltène/Whaledent Inc., Cuyahoga Falls, OH.)

The wings are designed to provide extra retraction of the rubber dam from the operating field and to allow attachment of the dam to the retainer before conveying the retainer (with dam) to the anchor tooth, after which the dam is removed from the lateral wings. As seen in Figure 7-10, the anterior wings can be cut away if they are not wanted.

The bow of the retainer (except the No. 212, which is applied after the rubber dam is in place) should be tied with dental floss (Fig. 7-11) approximately 12 inches (30 cm) in length before the retainer is placed in the mouth. For maximal protection, the tie may be threaded through both holes in the jaws of the retainer because the bow of the retainer could break. The floss allows retrieval of the retainer or its broken parts if they are accidentally swallowed or aspirated. It is sometimes necessary to re-contour the jaws of the retainer to the shape of the tooth by grinding with a mounted stone

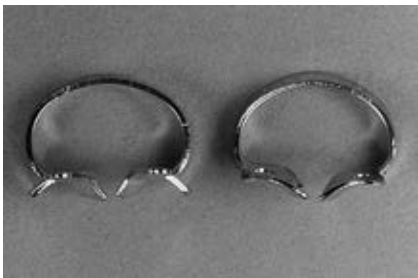


Fig. 7-9 Retainers with prongs directed gingivally are helpful when the anchor tooth is only partially erupted.

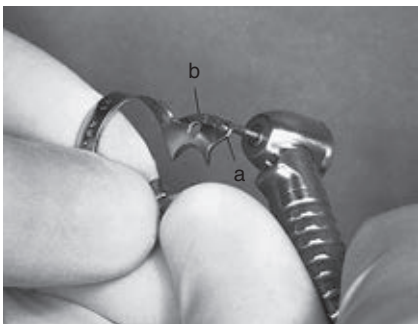


Fig. 7-10 Removing anterior wings (a) on molar retainer. Lateral wings (b) are for holding lip of stretched rubber dam hole.

(Fig. 7-12). A retainer usually is not required when the dam is applied for treatment of the anterior teeth except for the cervical retainer for Class V restorations.

PUNCH

The rubber dam punch is a precision instrument having a rotating metal table (disk) with holes of varying sizes and a tapered, sharp-pointed plunger (Fig. 7-13). Care should be exercised when changing from one hole to another. The plunger should be centered in the cutting hole so that the edges of the holes are not at risk of being chipped by the plunger tip when the plunger is closed. Otherwise, the cutting quality of the punch is ruined, as evidenced by incompletely cut holes. These holes tear easily when stretched during application over the retainer or tooth.

RETAINER FORCEPS

The rubber dam retainer forceps is used for placement and removal of the retainer from the tooth (Fig. 7-14).

NAPKIN

The rubber dam napkin, placed between the rubber dam and the patient's skin, has the following benefits:

1. It improves patient comfort by reducing direct contact of the rubber material with the skin.
2. It absorbs any saliva seeping at the corners of the mouth.
3. It acts as a cushion.



Fig. 7-12 Re-contouring jaws of retainer with mounted stone.

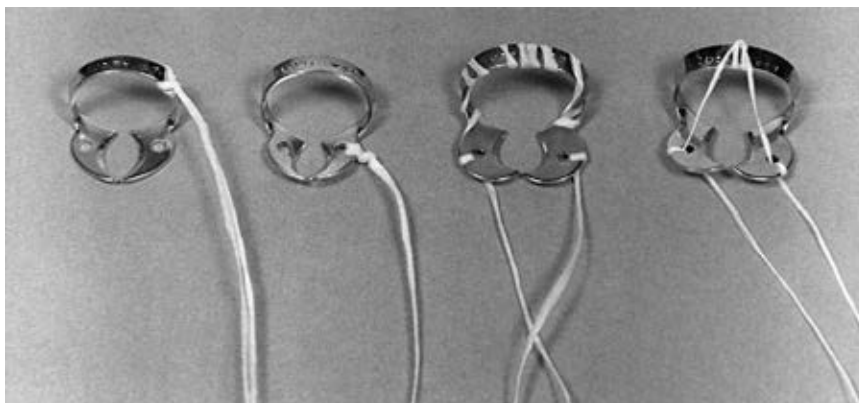


Fig. 7-11 Methods of tying retainers with dental floss.



Fig. 7-13 Rubber dam punches. (From Boyd LRB: *Dental instruments: A pocket guide*, ed 4, St. Louis, 2012, Saunders.)



Fig. 7-15 Disposable rubber dam napkin. (Courtesy Coltène/Whaledent Inc., Cuyahoga Falls, OH.)

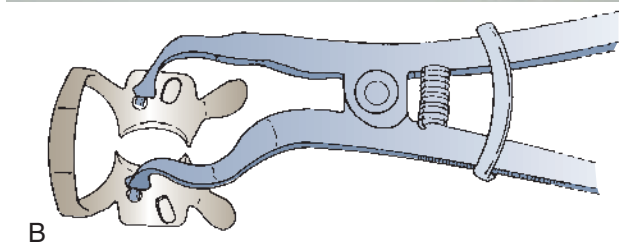


Fig. 7-14 Rubber dam forceps (A) engaging retainer (B). (A, From Boyd LRB: *Dental instruments: A pocket guide*, ed 4, St. Louis, 2012, Saunders. B, From Baum L, Phillips RW, Lund MR: *Textbook of operative dentistry*, ed 3, Philadelphia, 1995, Saunders.)

4. It provides a convenient method of wiping the patient's lips on removal of the dam.
5. The rubber dam napkin adds to the comfort of the patient, particularly when the dam must be used for long appointments (Fig. 7-15).

LUBRICANT

A water-soluble lubricant applied in the area of the punched holes facilitates the passing of the dam septa through the proximal contacts. A rubber dam lubricant is commercially available, but other lubricants such as shaving cream also are satisfactory. Applying the lubricant to both sides of the dam in the area of the punched holes aids in passing the dam through the contacts. Cocoa butter or petroleum jelly may be applied at the corners of the patient's mouth to prevent irritation. These two materials are not satisfactory rubber dam lubricants, however, because both are oil-based and not easily rinsed from the dam when the dam is placed.

ANCHORS (OTHER THAN RETAINERS)

Besides retainers, other anchors may also be used. The proximal contact may be sufficient to anchor the dam on the tooth

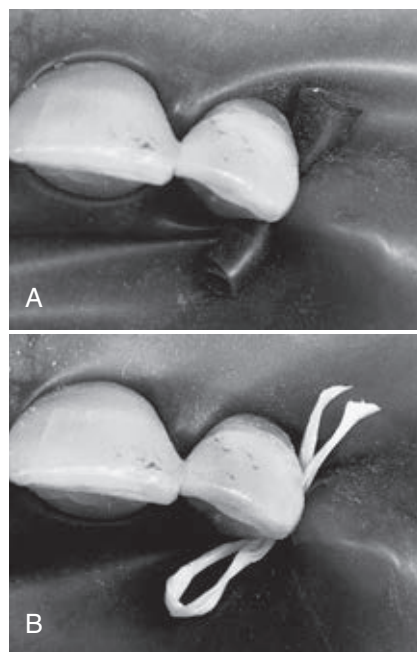


Fig. 7-16 A, Anchor formed from dental tape. B, Anchor formed from rubber dam material.

farthest from the posterior retainer (in the isolated field), eliminating the need for a second retainer (see Step 13 of Procedure 7-1). To secure the dam further anteriorly or to anchor the dam on any tooth where a retainer is contraindicated, waxed dental tape (or floss) or a small piece of rubber dam material (cut from a sheet of dam) or a rubber Wedjet (Hygenic, Akron, OH) may be passed through the proximal contact. When dental tape is used, it should be passed through the contact, looped, and passed through a second time (Fig. 7-16, A). The cut piece of dam material is first stretched, passed through the contact, and then released (see Fig. 7-16, B). When the anchor is in place, the tape, floss, dam material, or Wedjet should be trimmed to prevent interference with the operating site.

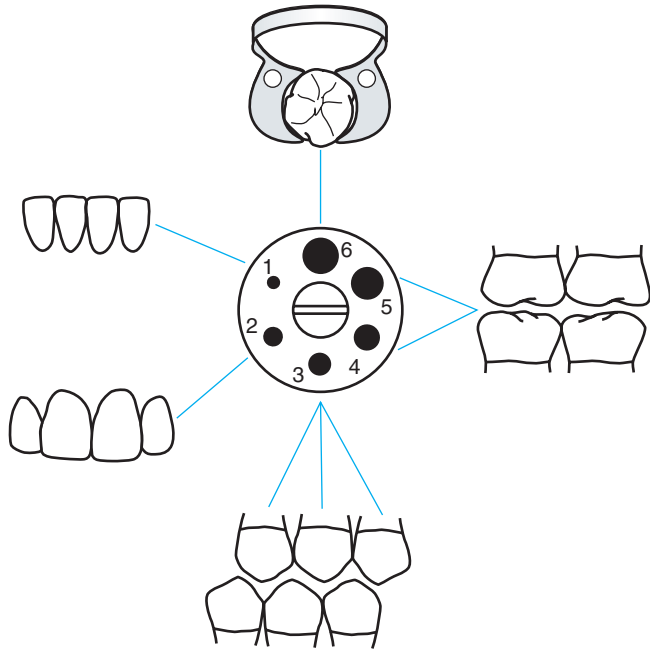


Fig. 7-17 Cutting table on rubber dam punch, illustrating use of hole size. (From Daniel SJ, Harfst SA, Wilder RS: *Mosby's dental hygiene: Concepts, cases, and competencies*, ed 2, St. Louis, 2008, Mosby.)

Hole Size and Position

Successful isolation of teeth and maintenance of a dry, clean operating field largely depend on hole size and position in the rubber dam.²⁶ Holes should be punched by following the arch form, making adjustments for malpositioned or missing teeth. Most rubber dam punches have either five or six holes in the cutting table. The smaller holes are used for the incisors, canines, and premolars and the larger holes for the molars. The largest hole generally is reserved for the posterior anchor tooth (Fig. 7-17). The following guidelines and suggestions can be helpful when positioning the holes:

- (Optional) Punch an identification hole in the upper left (i.e., the patient's left) corner of the rubber dam for ease of location of that corner when applying the dam to the holder.
- When operating on the incisors and mesial surfaces of canines, isolate from first premolar to first premolar. Metal retainers usually are not required for this isolation (Fig. 7-18, A). If additional access is necessary after isolating teeth, as described, a retainer can be positioned over the dam to engage the adjacent nonisolated tooth, but care must be exercised not to pinch the gingiva beneath the dam (see Fig. 7-18, B and C).
- When operating on a canine, it is preferable to isolate from the first molar to the opposite lateral incisor. To treat a Class V lesion on a canine, isolate posteriorly to include the first molar to provide access for placement of the cervical retainer on the canine.
- When operating on posterior teeth, isolate anteriorly to include the lateral incisor on the opposite side of the arch from the operating site. In this case, the hole for the lateral incisor is the most remote from the hole for the posterior anchor tooth. Anterior teeth included in the isolation

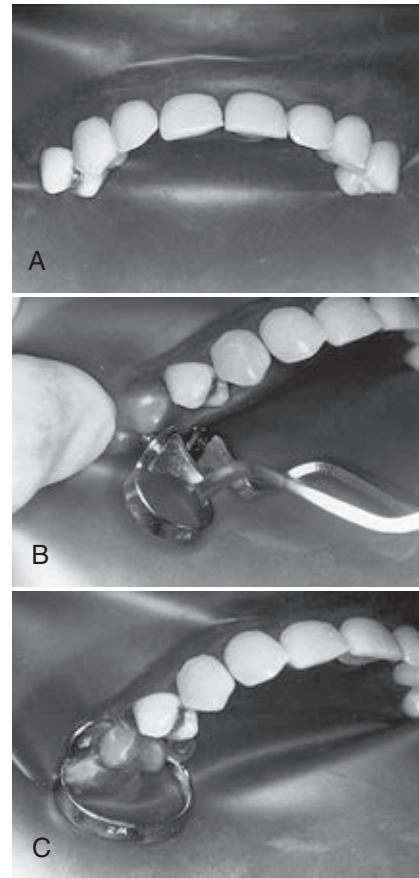


Fig. 7-18 A, Isolation for operating on incisors and mesial surface of canines. B and C, Increasing access by application of metal retainer over dam and adjacent nonisolated tooth.

- provide finger rests on dry teeth and better access and visibility for the operator and the assistant.
- When operating on premolars, punch holes to include one to two teeth distally, and extend anteriorly to include the opposite lateral incisor.
- When operating on molars, punch holes as far distally as possible, and extend anteriorly to include the opposite lateral incisor.
- Isolation of a minimum of three teeth is recommended except when endodontic therapy is indicated, and in that case, only the tooth to be treated is isolated. The number of teeth to be treated and the tooth surface influence the pattern of isolation.
- The distance between holes is equal to the distance from the center of one tooth to the center of the adjacent tooth, measured at the level of the gingival tissue. When the distance between holes is excessive, the dam material is excessive and wrinkles between teeth. Conversely, too little distance between holes causes the dam to stretch, resulting in space around the teeth and leakage. When the distance is correct, the dam intimately adapts to the teeth and covers and slightly retracts the interdental tissue.
- When the rubber dam is applied to maxillary teeth, the first holes punched (after the optional identification hole) are for the central incisors. These holes are positioned approximately 1 inch (25 mm) from the superior border of the dam (Fig. 7-19, A), providing sufficient material to

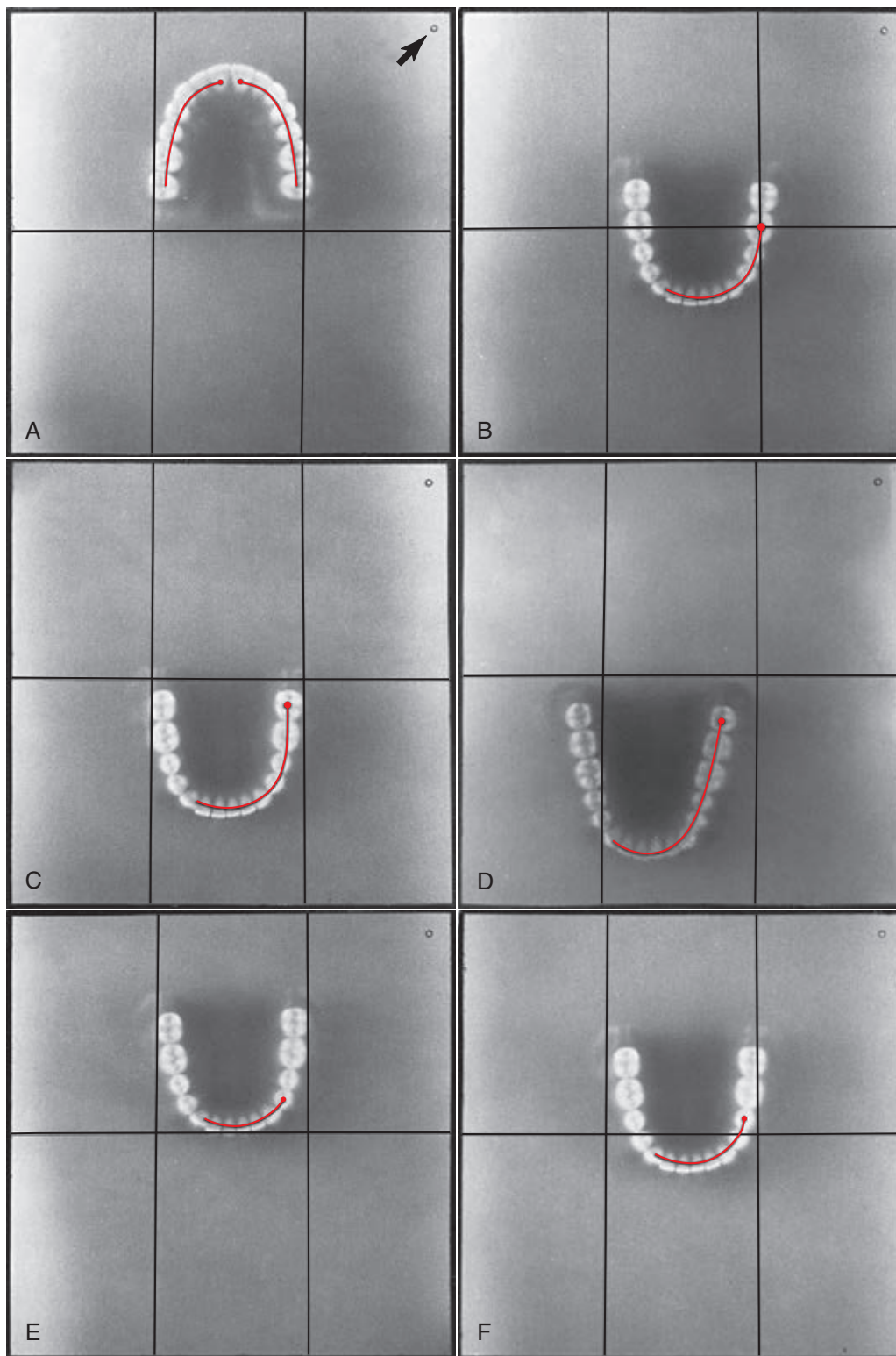


Fig. 7-19 Hole position. **A**, When maxillary teeth are to be isolated, the first holes punched are for central incisors, approximately 1 inch (2.5 cm) from superior border. **B**, Hole position when the anchor tooth is the mandibular first molar. **C**, Hole position when the anchor tooth is the mandibular second molar. **D**, Hole position when the anchor tooth is the mandibular third molar. **E**, Hole position when the anchor tooth is the mandibular first premolar. **F**, Hole position when the anchor tooth is the mandibular second premolar. Note the hole punched in each of these six representative rubber dam sheets for identification of the upper left corner (*arrow in A*).

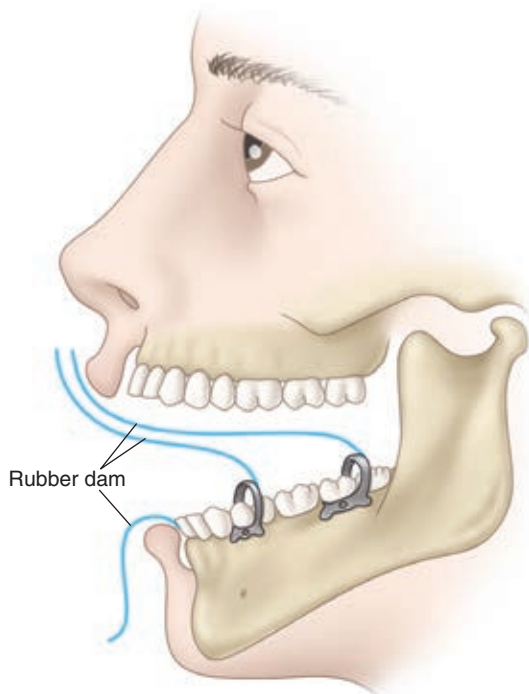


Fig. 7-20 The more posterior the mandibular anchor tooth, the more dam material is required to come from behind retainer over the upper lip.

cover the patient's upper lip. For a patient with a large upper lip or mustache, position the holes more than 1 inch from the edge. Conversely, for a child or an adult with a small upper lip, the holes should be positioned less than 1 inch from the edge. When the holes for the incisors are located, the remaining holes are punched.

- When the rubber dam is applied to mandibular teeth, the first hole punched (after the optional identification hole) is for the posterior anchor tooth that is to receive the retainer. To determine the proper location, mentally divide the rubber dam into three vertical sections: left, middle, and right. If the anchor tooth is the mandibular first molar, punch the hole for this tooth at a point halfway from the superior edge to the inferior edge and at the junction of the right (or left) and middle thirds (see Fig. 7-19, B). If the anchor tooth is the second or third molar, the position for the hole moves toward the inferior border and slightly toward the center of the rubber dam compared with the first molar hole just described (see Fig. 7-19, C and D). If the anchor tooth is the first premolar, the hole is placed toward the superior border compared with the hole for the first molar and toward the center of the dam (see Fig. 7-19, E). The farther posterior the mandibular anchor tooth, the more dam material is required to come from behind the retainer over the upper lip. Figure 7-20 illustrates the difference in the amount of dam required, comparing the first premolar and the second molar as anchor teeth. The distances also may be compared by noting the length of dam between the superior edge of the dam and the position of the hole for the posterior anchor tooth (see Fig. 7-19, B to F).
- When a thinner rubber dam is used, smaller holes must be punched to achieve an adequate seal around the teeth because the thin dam has greater elasticity.

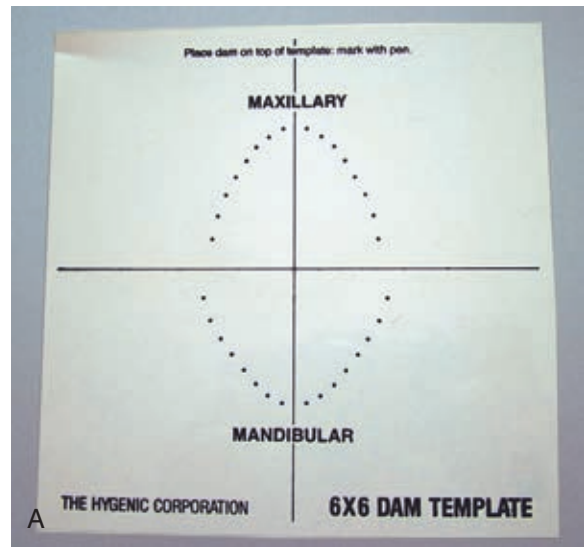


Fig. 7-21 Commercial products to aid in locating hole position. **A**, Dental dam template. **B**, Dental dam stamp. (From Boyd LRB: *Dental instruments: A pocket guide*, ed 4, St. Louis, 2012, Saunders.)

Until these guidelines and suggestions related to hole position are mastered, an inexperienced operator may choose to use commercial products to aid in locating hole position (Fig. 7-21). A rubber stamp that imprints permanent and primary arch forms on the rubber dam is available, and several sheets of dam material can be stamped in advance. A plastic template also can be used to mark hole position. Experienced operators and assistants may not require these aids, and accurate hole location is best achieved by noting the patient's arch form and tooth position.

Placement

Usually, administering the anesthetic precedes application of the rubber dam. This approach allows for the beginning of profound anesthesia and more comfortable retainer placement on the anchor tooth. Occasionally, the posterior anchor tooth in the maxillary arch may need to be anesthetized if it is remote from the anesthetized operating site.

The technique for the application of the rubber dam is presented by numerous authors.^{7,27,28} The step-by-step application and removal of the rubber dam using the maxillary left first molar for the posterior retainer and including the maxillary right lateral incisor as the anterior anchor is described and illustrated here. The procedure is described as if the operator and the assistant are working together.

Compared with the alternative procedures discussed in a later section, [Procedures 7-1 and 7-2](#) allow the retainer and the dam to be placed sequentially. This approach provides for maximal visibility when placing the retainer, which reduces the risk of impinging on gingival tissue. Isolating a greater number of teeth, as illustrated in [Procedure 7-1](#), is indicated for quadrant operative procedures. For limited operative procedures, it is often acceptable to isolate fewer teeth. Appropriate seal of each tooth is accomplished by inversion of the rubber material in a gingival direction. Interproximal inversion is accomplished first by using dental floss. Inversion of the dam on the facial and lingual surfaces is accomplished by air-drying the surfaces and use of a blunt instrument (see [Procedure 7-1](#), step 18).

Alternative and Additional Methods and Factors

The procedure detailed in [Procedure 7-1](#) describes the method of sequentially placing the retainer and rubber dam on the anchor tooth.

APPLYING THE DAM AND RETAINER SIMULTANEOUSLY

The retainer and dam may be placed simultaneously to reduce the risk of the retainer being swallowed or aspirated before the dam is placed. This approach also solves the occasional difficulty of trying to pass the dam over a previously placed retainer, the bow of which is pressing against oral soft tissues.

In this method, the posterior retainer is applied first to verify a stable fit. The operator removes the retainer and, still holding the retainer with forceps, passes the bow through the proper hole from the underside of the dam (the lubricated rubber dam is held by the assistant) ([Fig. 7-22, A](#)). The free end of the floss tie should be threaded through the anchor hole before the retainer bow is inserted. When using a retainer with lateral wings, place the retainer in the hole punched for the anchor tooth by stretching the dam to engage these wings ([Fig. 7-23](#)).

The operator grasps the handle of the forceps in the right hand and gathers the dam with the left hand to clearly visualize the jaws of the retainer and facilitate its placement (see [Fig. 7-22, B](#)). The operator conveys the retainer (with the dam) into the mouth and positions it on the anchor tooth. Care is needed when applying the retainer to prevent the jaws of the retainer from sliding gingivally and impinging on the soft tissue (see [Fig. 7-22, C](#)).

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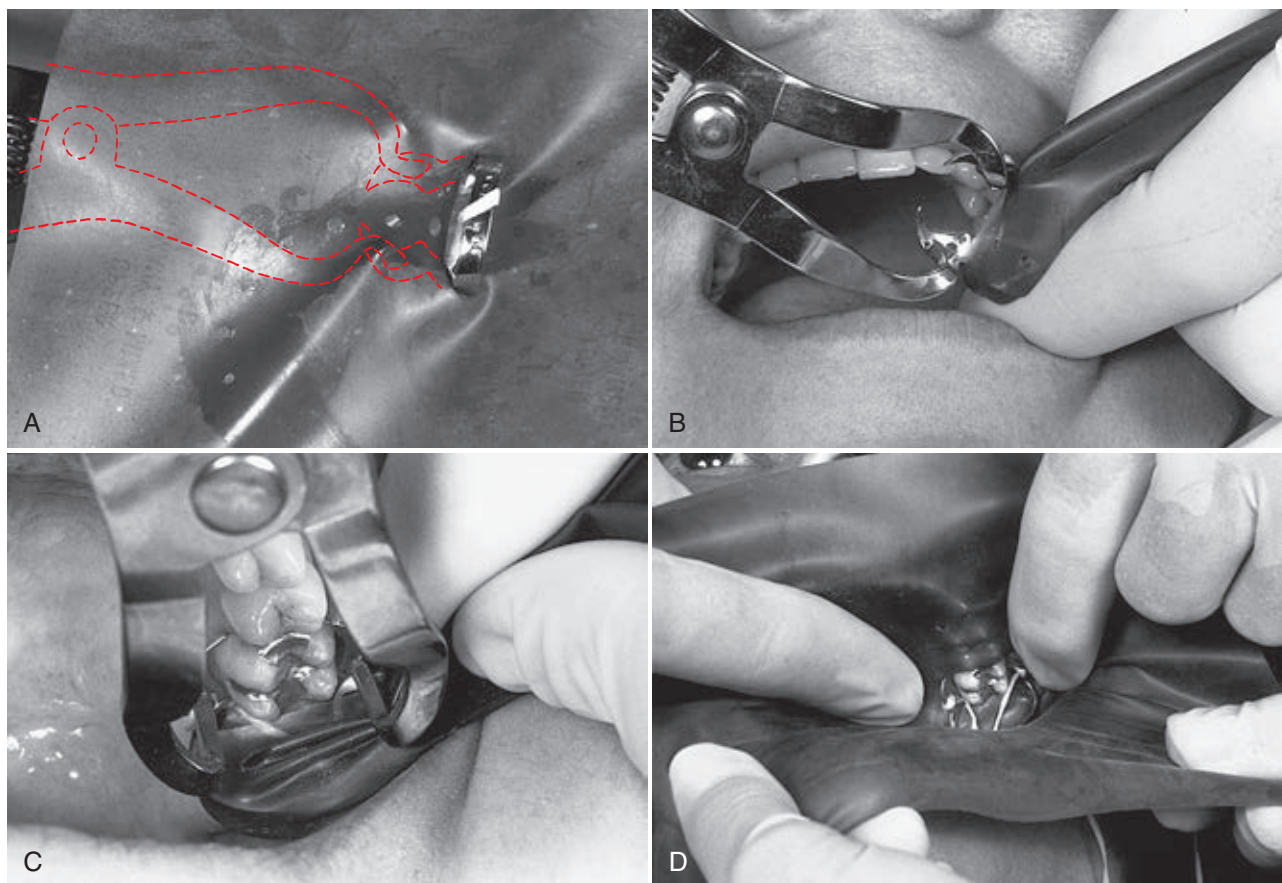


Fig. 7-22 **A**, Bow being passed through the posterior anchor hole from the underside of the dam. **B**, Gathering the dam to facilitate placement of the retainer. **C**, Positioning the retainer on the anchor tooth. **D**, Stretching the anchor hole borders over and under the jaws of the retainer.

Procedure 7-1 Application of Rubber Dam Isolation

The application procedure is described for right-handed operators. Left-handed users should change right to left. Each step number has a corresponding illustration.

Step 1: Testing and Lubricating the Proximal Contacts

The operator receives the dental floss from the assistant to test the interproximal contacts and remove debris from the teeth to be isolated. Passing (or attempting to pass) the floss through the contacts identifies any sharp edges of restorations or enamel that must be smoothed or removed to prevent tearing the dam. Using waxed dental tape may lubricate tight contacts to facilitate dam placement. Tight contacts that are difficult to floss but do not cut or fray the floss may be wedged apart slightly to permit placement of the rubber dam. A blunt hand instrument may be used for separation. For some clinical situations, the proximal portion of the tooth to be restored may need to be partially prepared to eliminate a sharp or difficult contact before the dam is placed.



Step 1: Testing and lubricating the proximal contacts.

Step 2: Punching Holes

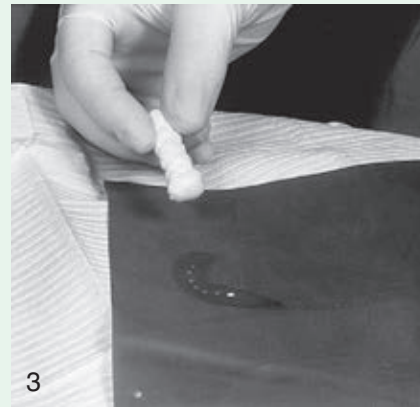
It is recommended that the assistant punch the holes after assessing the arch form and tooth alignment. Some operators prefer to have the assistant pre-punch the dam, however, using holes marked by a template or a rubber dam stamp.



Step 2: Punching the holes.

Step 3: Lubricating the Dam

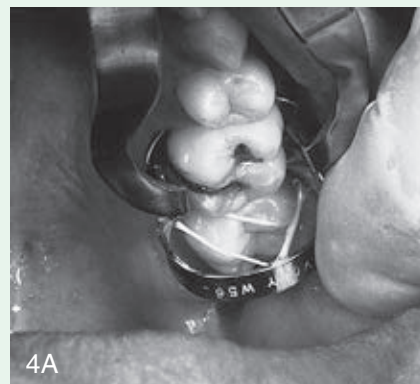
The assistant lubricates both sides of the rubber dam in the area of the punched holes using a cotton roll or gloved fingertip to apply the lubricant. This facilitates passing the rubber dam through the contacts. The lips and especially the corners of the mouth may be lubricated with petroleum jelly or cocoa butter to prevent irritation.



Step 3: Lubricating the dam.

Step 4: Selecting the Retainer

The operator receives (from the assistant) the rubber dam retainer forceps with the selected retainer and floss tie in position (A). The free end of the tie should exit from the cheek side of the retainer. Try the retainer on the tooth to verify retainer stability. If the retainer fits poorly, it is removed either for adjustment or for selection of a different size.²⁴ (Retainer adjustment, if needed to provide stability, is discussed in the previous section on rubber dam retainer.) Whenever the forceps is holding the retainer, care should be taken not to open the retainer more than necessary to secure it in the forceps. Stretching the retainer open for extended periods causes it to lose its elastic recovery. Retainers that have been deformed ("sprung"), such as the one shown in B, should be discarded.



Procedure 7-1 Application of Rubber Dam Isolation—cont'd



Step 4: Selecting the retainer. (From Peterson JE, Nation WA, Matsson L: *Effect of a rubber dam clamp (retainer) on cementum and junctional epithelium, Oper Dent 11:42-45, 1986.*)

Step 5: Testing the Retainer's Stability and Retention

If during trial placement the retainer seems acceptable, remove the forceps. Test the retainer's stability and retention by lifting gently in an occlusal direction with a fingertip under the bow of the retainer. An improperly fitting retainer rocks or is easily dislodged.



Step 5: Testing the retainer's stability and retention.

Step 6: Positioning the Dam over the Retainer

Before applying the dam, the floss tie may be threaded through the anchor hole, or it may be left on the underside of the dam. With the forefingers, stretch the anchor hole of the dam over the retainer (bow first) and then under the retainer jaws. The lip of the hole must pass completely under the retainer jaws. The forefingers may thin out, to a single thickness, the septal dam for the mesial contact of the retainer tooth and attempt to pass it through the contact, lip of the hole first. The septal dam always must pass through its respective contact in single thickness. If it does not pass through readily, it should be passed through with dental tape later in the procedure.



Step 6: Positioning the dam over the retainer.

Step 7: Applying the Napkin

The operator now gathers the rubber dam in the left hand, while the assistant inserts the fingers and thumb of the right (or left) hand through the napkin's opening and grasps the bunched dam held by the operator.



Step 7: Applying the napkin.

Step 8: Positioning the Napkin

The assistant pulls the bunched dam through the napkin and positions it on the patient's face. The operator helps by positioning the napkin on the patient's right side. The napkin reduces skin contact with the dam.



Step 8: Positioning the napkin.

Continued

Procedure 7-1 Application of Rubber Dam Isolation—cont'd

Step 9: Attaching the Frame

The operator unfolds the dam. (If an identification hole was punched, it is used to identify the upper left corner.) The assistant aids in unfolding the dam and, while holding the frame in place, attaches the dam to the metal projections on the left side of the frame. Simultaneously, the operator stretches and attaches the dam on the right side. The frame is positioned outside the dam. The curvature of the frame should be concentric with the patient's face. The dam lies between the frame and napkin. Either the operator or the assistant attaches the dam along the inferior border of the frame. Attaching the dam to the frame at this time controls the dam to provide access and visibility. The free ends of the floss tie are secured to the frame.



Step 9: Attaching the frame.

Step 10 (Optional): Attaching the Neck Strap

The assistant attaches the neck strap to the left side of the frame and passes it behind the patient's neck. The operator attaches it to the right side of the frame. Neck strap tension is adjusted to stabilize the frame and hold the frame (and periphery of the dam) gently against the face and away from the operating field. If desired, using soft tissue paper between the neck and strap may prevent contact of the patient's neck against the strap.



Step 10 (optional): Attaching the neck strap.

Step 11: Passing the Dam through the Posterior Contact

If a tooth is present distal to the retainer, the distal edge of the posterior anchor hole should be passed through the contact (single thickness, with no folds) to ensure a seal around the anchor tooth.

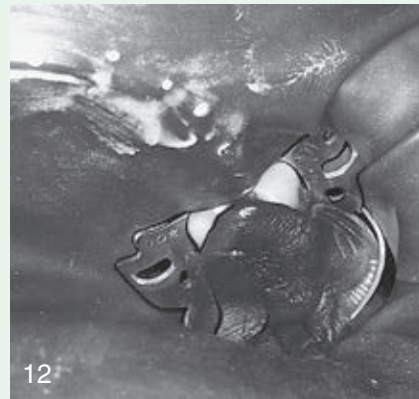
If necessary, use waxed dental tape to assist in this procedure (see step 15 for the use of dental tape). If the retainer comes off unintentionally as this is done or during subsequent procedures, passage of the dam through the distal contact anchors the dam sufficiently to allow easier reapplication of the retainer or placement of an adjusted or different retainer.



Step 11: Passing the dam through the posterior contact.

Step 12 (Optional): Applying a Rigid Supporting Material

If the stability of the retainer is questionable, a rigid supporting material such as low-fusing modeling compound may be applied.



Step 12 (optional): Applying the rigid material.

Step 13: Applying the Anterior Anchor (If Needed)

The operator passes the dam over the anterior anchor tooth, anchoring the anterior portion of the rubber dam. Usually, the dam passes easily through the mesial and distal contacts of the anchor tooth if it is passed in single thickness starting with the lip of the hole. Stretching the lip of the hole and sliding it back and forth aids in positioning the septum. When the contact farthest from the retainer is minimal ("light"), an anchor may be required in the form of a double thickness of dental tape or a narrow strip of dam material or Wedjet that is stretched, inserted, and released. If the contact is open, a rolled piece of dam material may be used.

Procedure 7-1 Application of Rubber Dam Isolation—cont'd



Step 13: Applying the anterior anchor (if needed).

Step 14: Passing the Septa through the Contacts without Dental Tape

The operator passes the septa through as many contacts as possible without the use of dental tape by stretching the septal dam facio-lingually and linguo-lingually with the forefingers. Each septum must not be allowed to bunch or fold. Rather, its passage through the contact should be started with a single thickness. Passing the dam through as many contacts as possible without using dental tape is urged because the use of dental tape always increases the risk of tearing holes in the septa. Slight separation (wedging) of the teeth is sometimes an aid when the contacts are extremely tight. Pressure from a blunt hand instrument (e.g., beaver-tail burnisher) applied in the facial embrasure gingival to the contact usually is sufficient to obtain enough separation to permit the septum to pass through the contact.

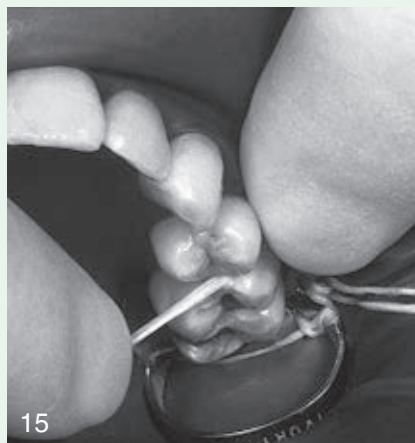


Step 14: Passing the septa through the contacts without dental tape.

Step 15: Passing the Septa through the Contacts with Tape

Use waxed dental tape to pass the dam through the remaining contacts. Dental tape is preferred over floss because its wider dimension more effectively carries the rubber septa through the contacts. Also, dental tape is not as likely to cut the septa. The waxed variety makes passage easier and decreases the chances for cutting holes in the septa or tearing the edges of the holes. The leading edge of the septum should be over the contact, ready to be drawn into and through the contact with dental tape. As before, the septal rubber should be kept in single thickness with no folds. Dental tape should be placed at the contact on a slight angle. With a good finger rest on the tooth, dental tape should be controlled

so that it slides (not snaps) through the proximal contact, preventing damage to the interdental tissues. When the leading edge of the septum has passed the contact, the remaining interseptal dam can be carried through more easily.



Step 15: Passing the septa through the contacts with dental tape.

Step 16 (Optional): Technique for Using Dental Tape

Often, several passes with dental tape are required to carry a reluctant septum through a tight contact. When this happens, previously passed tape should be left in the gingival embrasure until the entire septum has been placed successfully with subsequent passage of dental tape. This prevents a partially passed septum from being removed or torn. The double strand of the tape is removed from the facial embrasure.



Step 16 (optional): Technique for using dental tape.

Step 17: Inverting the Dam Interproximally

Invert the dam into the gingival sulcus to complete the seal around the tooth and prevent leakage. Often, the dam inverts itself as the septa are passed through the contacts as a result of the dam being stretched gingivally. The operator should verify that the dam is inverted interproximally. Inversion in this region is best accomplished with dental tape.

Continued

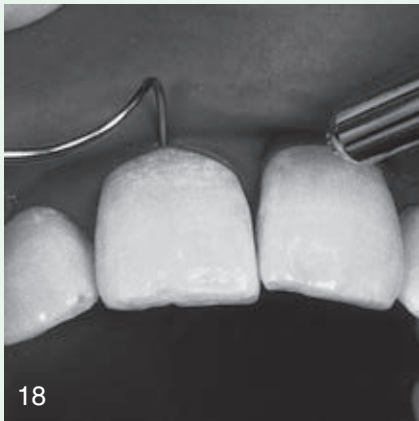
Procedure 7-1 Application of Rubber Dam Isolation—cont'd



Step 17: Inverting the dam interproximally.

Step 18: Inverting the Dam Faciolingually

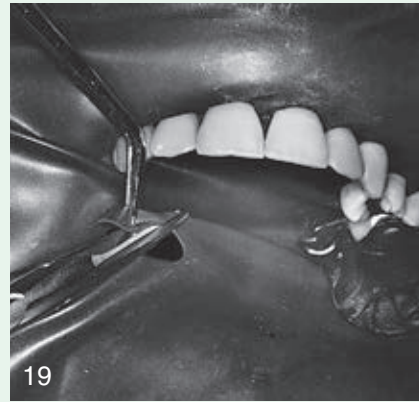
With the edges of the dam inverted interproximally, complete the inversion facially and lingually using an explorer or a beaver-tail burnisher while the assistant directs a stream of air onto the tooth. Move the explorer around the neck of the tooth facially and lingually with the tip perpendicular to the tooth surface or directed slightly gingivally. A dry surface prevents the dam from sliding out of the crevice. Alternatively, the dam can be inverted facially and lingually by drying the tooth while stretching the dam gingivally and releasing it slowly.



Step 18: Inverting the dam faciolingually.

Step 19 (Optional): Using a Saliva Ejector

The use of a saliva ejector is optional because most patients are able, and usually prefer, to swallow excess saliva. Salivation is greatly reduced when profound anesthesia is obtained. If salivation is a problem, the operator or assistant uses cotton pliers to pick up the dam lingual to mandibular incisors and cuts a small hole through which the saliva ejector is inserted. The hole should be positioned so that the rubber dam helps support the weight of the ejector, preventing pressure on the delicate tissues in the floor of the mouth.



Step 19 (optional): Using a saliva ejector.

Step 20: Confirming Proper Application of the Rubber Dam

The properly applied rubber dam is securely positioned and comfortable to the patient. The patient should be assured that the rubber dam does not prevent swallowing or mouth closing (about halfway) during a pause in the procedure.



Step 20: Confirming proper application of the rubber dam.

Step 21: Checking for Access and Visibility

Check to see that the completed rubber dam provides maximal access and visibility for the operative procedure.



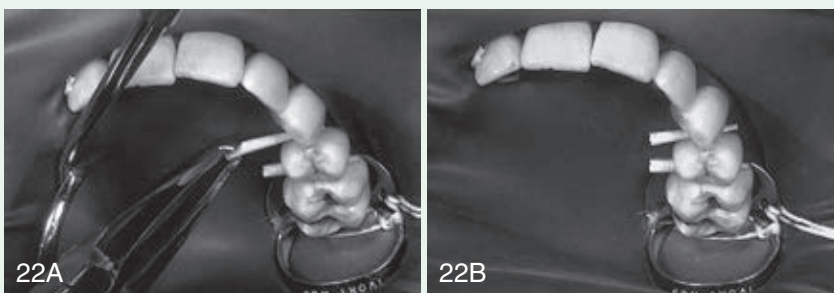
Step 21: Checking for access and visibility.

Procedure 7-1 Application of Rubber Dam Isolation—cont'd

Step 22: Inserting the Wedges

For proximal surface preparations (Classes II, III, and IV), many operators consider the insertion of interproximal wedges as the final step in rubber dam application. Wedges are generally round toothpick ends about $\frac{1}{2}$ inch (12 mm) in length that are snugly inserted into the gingival embrasures from the facial or lingual aspect, whichever is greater, using No. 110 pliers.

To facilitate wedge insertion, first stretch the dam slightly by fingertip pressure in the direction opposite wedge insertion (A), then insert the wedge while slowly releasing the dam. This results in a passive dam under the wedge (i.e., the dam does not rebound the wedge) and prevents bunching or tearing of the septal dam during wedge insertion. The inserted wedges appear in B.



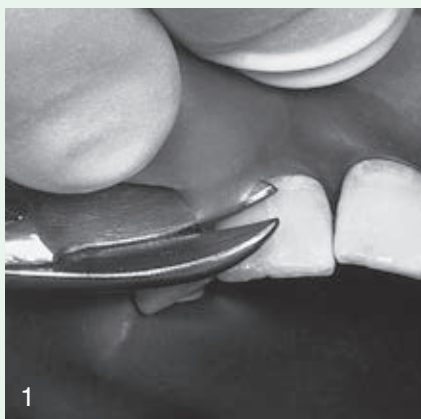
Step 22: Inserting the wedges.

Procedure 7-2 Removal of Rubber Dam Isolation

Before the removal of the rubber dam, rinse and suction away any debris that may have collected to prevent it from falling into the floor of the mouth during the removal procedure. If a saliva ejector was used, remove it at this time. Each numbered step has a corresponding illustration.

Step 1: Cutting the Septa

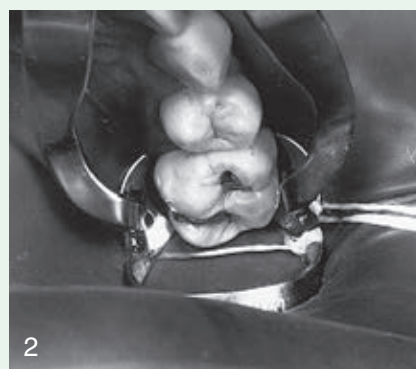
Stretch the dam facially, pulling the septal rubber away from gingival tissue and the tooth. Protect the underlying soft tissue by placing a fingertip beneath the septum. Clip each septum with blunt-tipped scissors, freeing the dam from the interproximal spaces, but leave the dam over the anterior and posterior anchor teeth. To prevent inadvertent soft tissue damage, curved nose scissors are preferred.



Step 1: Cutting the septa.

Step 2: Removing the Retainer

Engage the retainer with retainer forceps. It is unnecessary to remove any compound, if used, because it will break free as the retainer is spread and lifted from the tooth. While the operator removes the retainer, the assistant releases the neck strap, if used, from the left side of the frame.



Step 2: Removing the retainer.

Step 3: Removing the Dam

After the retainer is removed, release the dam from the anterior anchor tooth, and remove the dam and frame simultaneously. While doing this, caution the patient not to bite on newly inserted amalgam restorations until the occlusion can be evaluated.

Continued

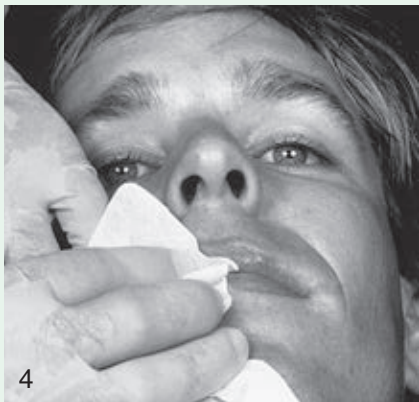
Procedure 7-2 Removal of Rubber Dam Isolation—cont'd



Step 3: Removing the dam.

Step 4: Wiping the Lips

Wipe the patient's lips with the napkin immediately after the dam and frame are removed. This helps prevent saliva from getting on the patient's face and is comforting to the patient.



Step 4: Wiping the lips.

Step 5: Rinsing the Mouth and Massaging the Tissue

Rinse teeth and the mouth using the air-water spray and the high-volume evacuator. To enhance circulation, particularly

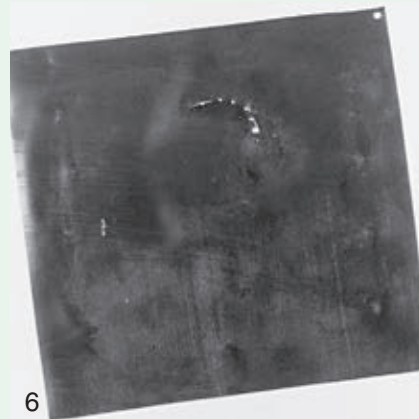
around anchor teeth, massage the tissue around the teeth that were isolated.



Step 5: Rinsing the mouth and massaging the tissue.

Step 6: Examining the Dam

Lay the sheet of rubber dam over a light-colored flat surface, or hold it up to the operating light to determine that no portion of the rubber dam has remained between or around the teeth. Such a remnant would cause gingival inflammation.



Step 6: Examining the dam.

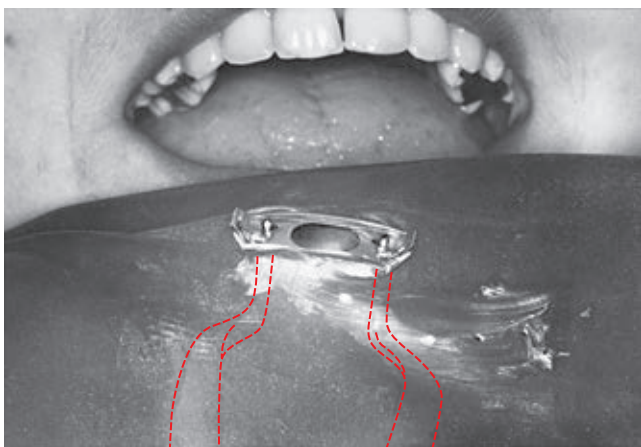


Fig. 7-23 The lip of hole for the anchor tooth is stretched to engage the lateral wings of the retainer.

The assistant gently pulls the inferior border of the dam toward the patient's chin, while the operator positions the superior border over the upper lip. As the assistant holds the borders of the dam, the operator uses the second or middle finger of both hands, one finger facial and the other finger lingual to the bow, to pass the anchor hole borders over and under the jaws of the retainer (see Fig. 7-22, D). At this point, the application procedure continues as was previously described, beginning with step 7 in Procedure 7-1.

APPLYING THE DAM BEFORE THE RETAINER

The dam may be stretched over the anchor tooth before the retainer is placed. The advantage of this method is that it is not necessary to manipulate the dam over the retainer. The operator places the retainer, while the dental assistant stretches and holds the dam over the anchor tooth (Fig. 7-24). The



Fig. 7-24 The retainer is applied after the dam is stretched over the posterior anchor tooth.

disadvantage is the reduced visibility of underlying gingival tissue, which may become impinged on by the retainer.

CERVICAL RETAINER PLACEMENT

The use of a No. 212 cervical retainer for restoration of Class V tooth preparations was recommended by Markley.²⁹ When punching holes in the rubber dam, the hole for the tooth to receive this retainer for a facial cervical restoration should be positioned slightly facial to the arch form to compensate for the extension of the dam to the cervical area (Fig. 7-25, A). The farther gingivally the lesion extends, the farther the hole must be positioned from the arch form. In addition, the hole should be slightly larger, and the distance between it and the adjacent holes should be slightly increased (Fig. 7-26). If the cervical retainer is to be placed on an incisor, isolation should be extended to include the first premolars, and metal retainers usually are not needed to anchor the dam (see Fig. 7-25, B). If the cervical retainer is to be placed on a canine or a posterior

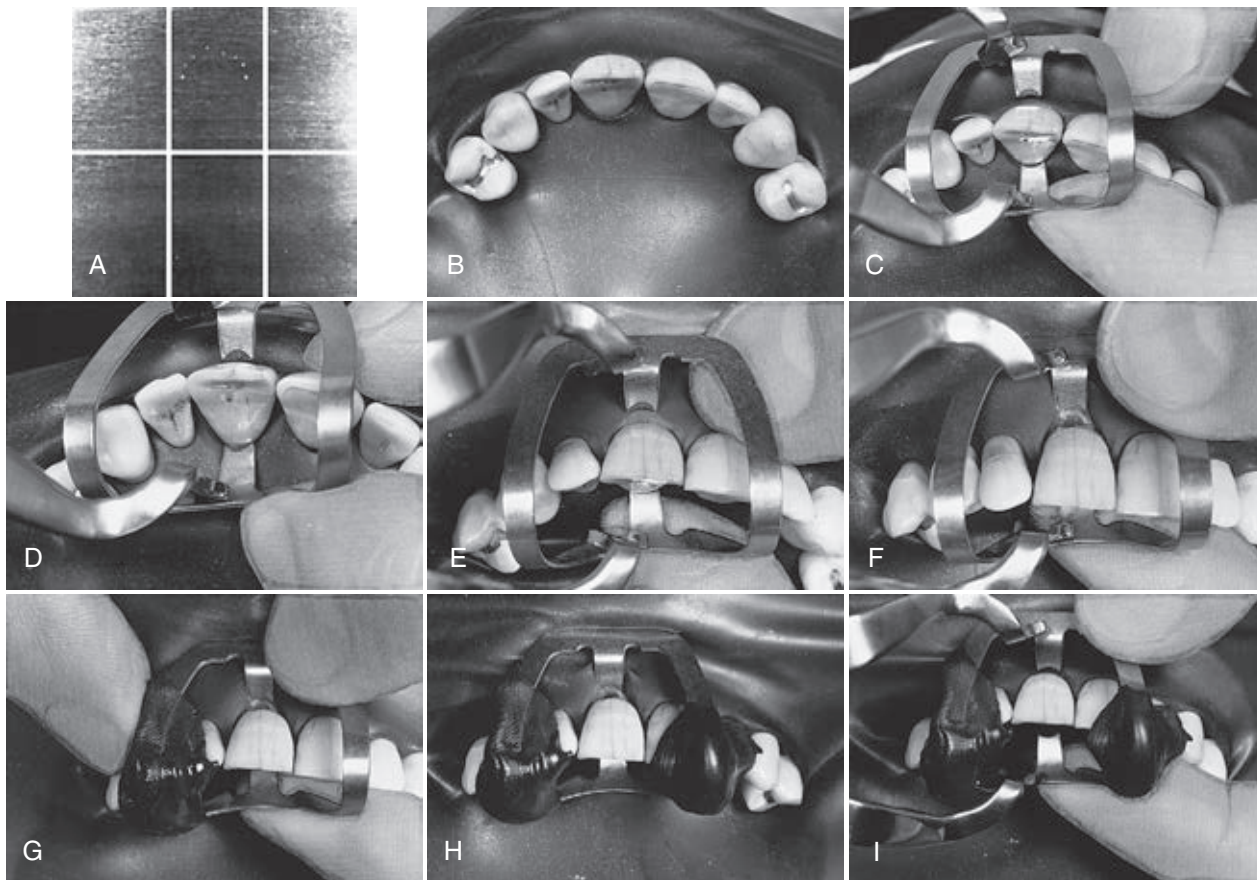


Fig. 7-25 Applying a cervical retainer. **A**, The hole for maxillary right central incisor is punched facial to the arch form. **B**, Isolation is extended to include the first premolars; metal posterior retainers are unnecessary. **C**, First, position the lingual jaw touching the height of contour, while keeping the facial jaw from touching the tooth; steady the retainer with the fingers of the left hand using the index finger under the lingual bow and the thumb under the facial bow. **D**, Note the final position of the lingual jaw after gently moving it apical of height of contour, with fingers continually supporting and guiding the retainer and with the facial jaw away from the tooth. **E**, Stretch the facial rubber apically by the thumb to expose the lesion and soft tissue, with the forefinger maintaining the position of the lingual jaw and with the facial jaw not touching. **F**, Note the facial jaw having apically retracted the tissue and the dam and in position against the tooth 0.5 to 1 mm apical of lesion. The thumb has now moved from under the facial bow to apply holding pressure, while the index finger continues to maintain the lingual jaw position. **G**, Apply stabilizing material over and under the bow and into the gingival embrasures, while the fingers of left hand hold the retainer's position. **H**, Application of the retainer is completed by the addition of a stabilizing material to the other bow and into the gingival embrasures. The retainer holes are accessible to the forceps for removal. **I**, Note the removal of the retainer by ample spreading of the retainer jaws before lifting the retainer from the site of the operation.

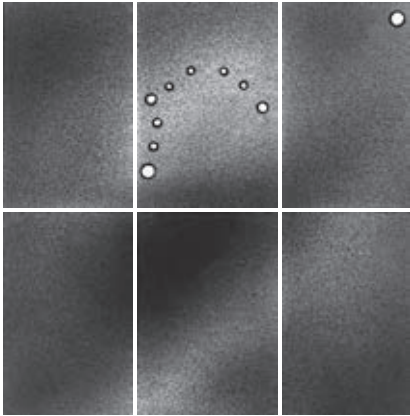


Fig. 7-26 The hole position for the tooth (maxillary right canine) to receive the cervical retainer is positioned facially to the arch form.

tooth, the anchor tooth retainer is positioned sufficiently posterior so as to not interfere with placement of the cervical retainer. If this is not possible, the anchor tooth retainer should be removed before positioning the cervical retainer. A heavier rubber dam usually is recommended for better tissue retraction in such restorations.

The operator engages the jaws of the cervical retainer with the forceps, spreads the retainer sufficiently, and positions its lingual jaw against the tooth at the height of contour (see Fig. 7-25, C). The operator gently moves the retainer jaw gingivally, depressing the dam and soft tissue, until the jaw of the retainer is positioned slightly apical of the height of contour (see Fig. 7-25, D). Care should be exercised in not allowing the lingual jaw to pinch the lingual gingiva or injure the gingival attachment. While positioning the lingual jaw, the index finger of the left hand should help in supporting and guiding the retainer jaw gingivally to the proper location.

While stabilizing the lingual jaw with the index finger, the operator uses the thumb of the left hand to pull the dam apically to expose the facial lesion and gingival crest (see Fig. 7-25, E). The operator positions the facial jaw gingival to the lesion and releases the dam held by the thumb. Next, the operator moves the thumb onto the facial jaw to secure it (see Fig. 7-25, F). Care should be exercised while positioning the facial jaw so as to not scar enamel or cementum. The tip of each retainer jaw should not be sharp and should conform to the contour of the engaged tooth surface. The retainer jaw should not be positioned too close to the lesion because of the danger of collapsing carious or weak tooth structure. Such proximity also would limit access and visibility to the operating site. As a rule, the facial jaw should be at least 0.5 mm gingival to the anticipated location of the gingival margin of the completed tooth preparation. While maintaining the retainer's position with the fingers of the left hand, the operator removes the forceps.

At times, the No. 212 retainer needs to be stabilized on the tooth with a fast-setting rigid material (e.g., polyvinyl siloxane bite registration material or stick compound) (see Figure 7-25). To remove the cervical retainer, the operator engages it with the forceps, spreads the retainer jaws to free the compound support, and lifts the retainer incisally (occlusally), being careful to spread the retainer sufficiently to prevent its jaws from scraping the tooth or damaging the newly inserted

restoration (see Fig. 7-25, I). The embrasures are freed of any remaining compound before removing the rubber dam.

A modified No. 212 retainer is recommended, especially for treatment of cervical lesions with greatly extended gingival margins. The modified No. 212 retainer can be ordered, if specified, or the operator can modify an existing No. 212 retainer. The modification technique involves heating each jaw of the retainer in an open flame, then bending it with No. 110 pliers from its oblique orientation to a more horizontal one. Allowing the modified retainer to bench-cool returns it to its original hardened state.

FIXED BRIDGE ISOLATION

It is sometimes necessary to isolate one or more abutment teeth of a fixed bridge. Indications for fixed bridge isolation include restoration of an adjacent proximal surface and cervical restoration of an abutment tooth.

The technique suggested for this procedure is as follows.³⁰ The rubber dam is punched as usual, except for providing one large hole for each unit in the bridge. Fixed bridge isolation is accomplished after the remainder of the dam is applied (Fig. 7-27, A). A blunted, curved suture needle with dental floss attached is threaded from the facial aspect through the hole for the anterior abutment and then under the anterior connector and back through the same hole on the lingual side (see Fig. 7-27, B). The needle's direction is reversed as it is passed from the lingual side through the hole for the second bridge unit, then under the same anterior connector, and through the hole of the second bridge unit on the facial side (see Fig. 7-27, C). A square knot is tied with the two ends of the floss, pulling the dam material snugly around the connector and into the gingival embrasure. The free ends of the floss should be cut closely so that they neither interfere with access and visibility nor become entangled in a rotating instrument. Each terminal abutment of the bridge is isolated by this method (see Fig. 7-27, D). If the floss knot on the facial aspect interferes with cervical restoration of an abutment tooth, the operator can tie the septum from the lingual aspect. Removal of the rubber dam isolating a fixed bridge is accomplished by cutting the interseptal rubber over the connectors with scissors and removing the floss ties (see Fig. 7-27, E). As always, after dam removal, the operator needs to verify that no dam segments are missing and massage the adjacent gingival tissue.

SUBSTITUTION OF A RETAINER WITH A MATRIX

When a matrix band must be applied to the posterior anchor tooth, the jaws of the retainer often prevent proper positioning and wedging of the matrix (Fig. 7-28, A). Successful application of the matrix can be accomplished by substituting the retainer with the matrix. Figure 7-28, B through D, illustrates this exchange on a mandibular right molar, as the index finger of the operator depresses gingivally and distally the rubber dam adjacent to the facial jaw, while the assistant similarly depresses the dam on the lingual side. After the matrix band is placed, the tension is released on the dam, allowing it to invert around the band. The matrix, in contrast to the retainer, has neither jaws nor a bow, so the dam tends to slip occlusally and over the matrix unless dryness is maintained.

The operator obtains access and visibility for insertion of the restorative material by reflecting the dam distally and occlusally with the mirror. Care must be exercised, however, not to stretch the dam so much that it is pulled away from the

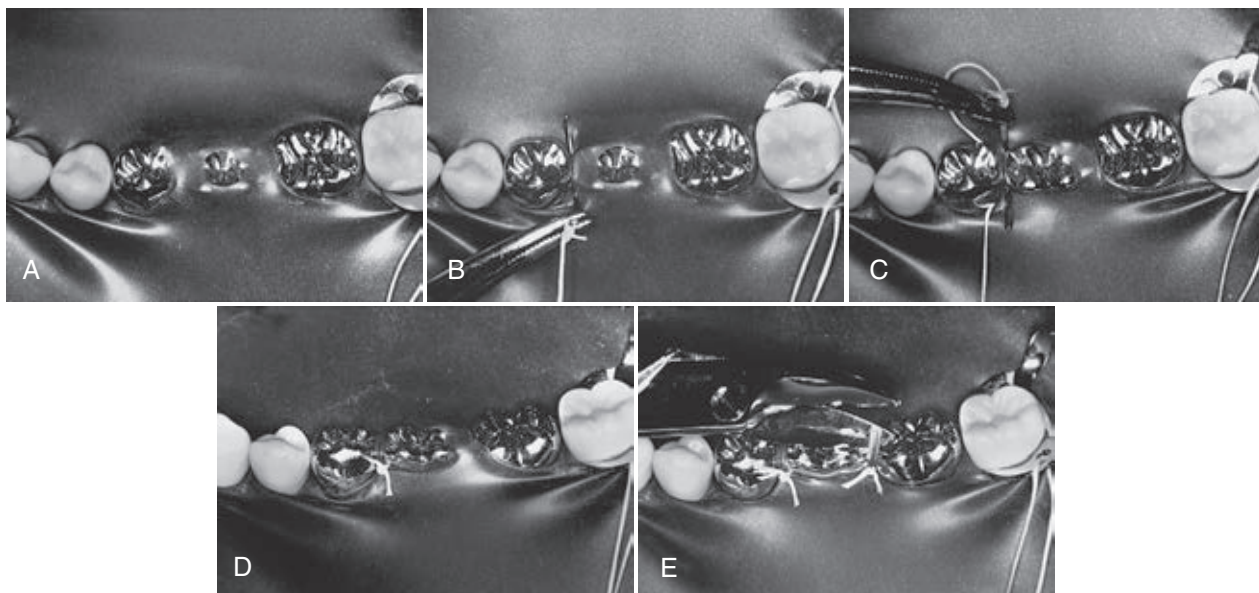


Fig. 7-27 Procedure for isolating a fixed bridge. **A**, Apply the dam except in the area of the fixed bridge. **B**, Thread the blunted suture needle from the facial to the lingual aspect through the anterior abutment hole, then under the anterior connector and back through the same hole on the lingual surface. **C**, Pass the needle facially through the hole for the second bridge unit, then under the same connector and through the hole for the second unit. **D**, Tie off the first septum. **E**, Cut the posterior septum to initiate removal of the dam.

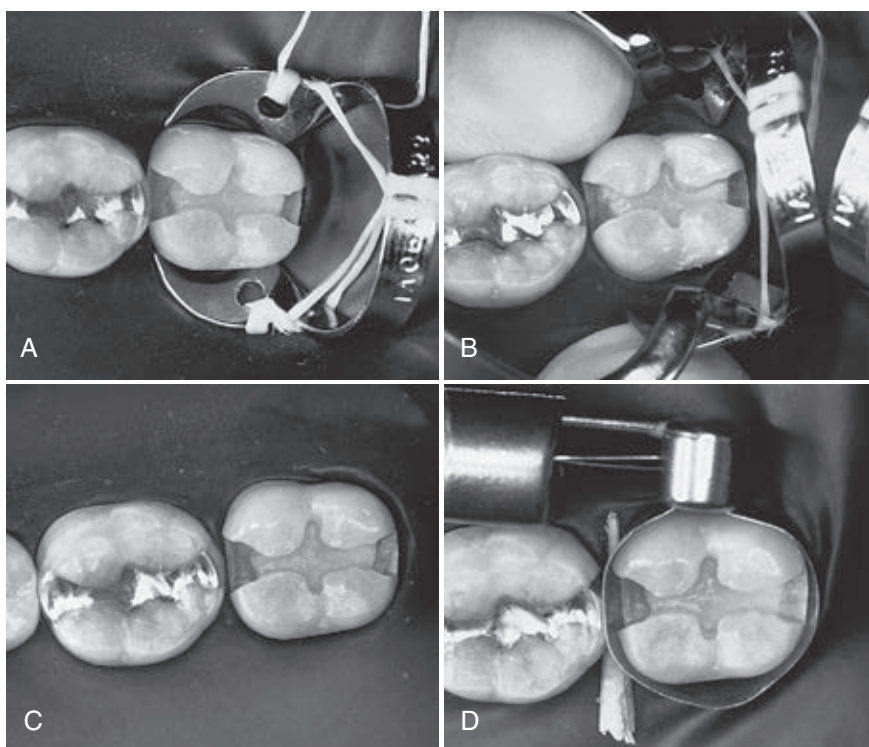


Fig. 7-28 Substituting the retainer with matrix on the terminal tooth. **A**, Completed preparation of the terminal tooth with the retainer in place. **B**, The dentist and the assistant stretch the dam distally and gingivally as the retainer is being removed. **C**, The retainer is removed before placement of the matrix. **D**, Completed matrix is in place. To maximize access and visibility during insertion, the mouth mirror is used to reflect the dam distally and occlusally.

matrix, permitting leakage around the tooth or slippage over the matrix. After insertion, the occlusal portion is contoured before removing the matrix. To complete the procedure, the operator has the choice of removing the matrix, replacing the retainer, and completing the contouring or removing the matrix and rubber dam and completing the contouring.

VARIATIONS WITH PATIENT AGE

The age of a patient often dictates changes in the procedures of rubber dam application. A few variations are described here. Because young patients have smaller dental arches compared with adult patients, holes should be punched in the dam

accordingly. For primary teeth, isolation is usually from the most posterior tooth to the canine on the same side. The sheet of rubber dam may be smaller for young patients so that the rubber material does not cover the nose. The unpunched rubber dam is attached to the frame, the holes are punched, the dam with the frame is applied over the anchor tooth, and the retainer applied (Fig. 7-29). Because the dam is generally



Fig. 7-29 On a child, the rubber dam often is attached to a frame before holes are punched. The dam is positioned over the anchor tooth before a retainer is applied (as in Fig. 7-24).

in place for shorter intervals than in an adult patient, the napkin might not be used.

The jaws of the retainers used on primary and young permanent teeth need to be directed more gingivally because of short clinical crowns or because the anchor tooth's height of contour is below the crest of the gingival tissue. The S.S. White No. 27 retainer is recommended for primary teeth. The Ivory No. W14 retainer is recommended for young permanent teeth.

Isolated teeth with short clinical crowns (other than the anchor tooth) may require ligation to hold the dam in position. Generally, ligation is unnecessary if enough teeth are isolated by the rubber dam. When ligatures are indicated, however, a surgeon's knot is used to secure the ligature (Fig. 7-30). The knot is tightened as the ligature is moved gingivally and then secured. Ligatures may be removed by teasing them occlusally with an explorer or by cutting them with a hand instrument or scissors. Ligatures should be removed first during rubber dam removal.

ERRORS IN APPLICATION AND REMOVAL

Certain errors in application and removal can prevent adequate moisture control, reduce access and visibility, or cause injury to the patient.

Off-Center Arch Form

A rubber dam punched off-center (off-center arch form) may not shield the patient's oral cavity adequately, allowing foreign matter to escape down the patient's throat. An off-center dam can result in an excess of dam material superiorly that may

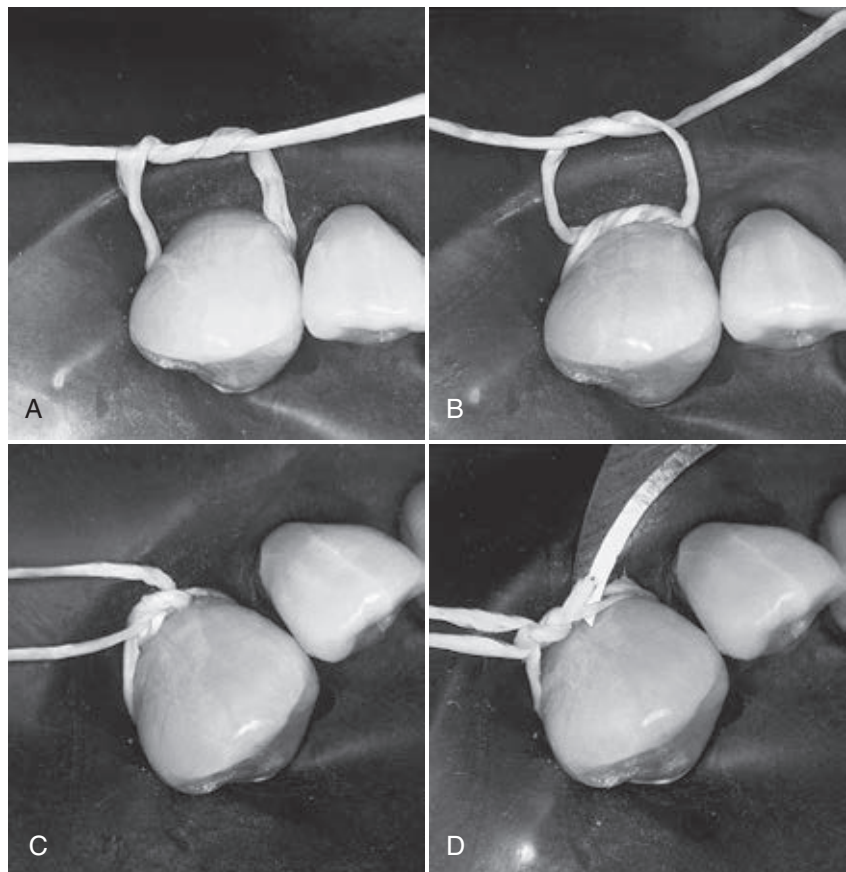


Fig. 7-30 Surgeon's knot. **A** and **B**, Dental tape is placed around the tooth gingival to the height of contour (**A**), and a knot is tied by first making two loops with the free ends, followed by a single loop (**B**). **C**, The free ends are not cut but tied to frame to serve as a reminder that ligature is in place. **D**, To remove the ligature, simply cut the tape with a scalpel blade, amalgam knife, or scissors.

occlude the patient's nasal airway (Fig. 7-31, *A*). If this happens, the superior border of the dam can be folded under or cut from around the patient's nose (see Fig. 7-31, *B* and *C*). It is important to verify that the rubber dam frame has been applied properly so that its ends are not dangerously close to the patient's eyes.

Inappropriate Distance between the Holes

Too little distance between holes precludes adequate isolation because the hole margins in the rubber dam are stretched and do not fit snugly around the necks of the teeth. Conversely, too much distance results in excess septal width, causing the

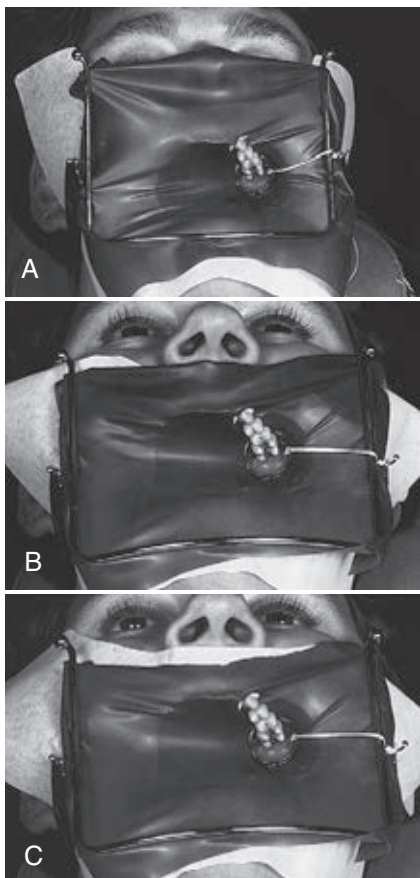


Fig. 7-31 *A*, An inappropriately punched dam may occlude the patient's nasal airway. *B*, Excess dam material along the superior border is folded under to the proper position. *C*, Excess dam material is cut from around the patient's nose.

dam to wrinkle between the teeth, interfere with proximal access, and provide inadequate tissue retraction.

Incorrect Arch Form of Holes

If the punched arch form is too small (incorrect arch form), the holes are stretched open around the teeth, permitting leakage. If the punched arch form is too large, the dam wrinkles around the teeth and may interfere with access.

Inappropriate Retainer

An inappropriate retainer may (1) be too small, resulting in occasional breakage when the retainer jaws are overspread; (2) be unstable on the anchor tooth; (3) impinge on soft tissue; or (4) impede wedge placement. An appropriate retainer should maintain a stable four-point contact with the anchor tooth and not interfere with wedge placement.

Retainer-Pinched Tissue

The jaws and prongs of the rubber dam retainer usually slightly depress the tissue, but they should not pinch or impinge on it.

Shredded or Torn Dam

Care should be exercised to prevent shredding or tearing the dam, especially during hole punching or passing the septa through the contacts.

Sharp Tips on No. 212 Retainer

Sharp tips on a No. 212 retainer should be sufficiently dulled to prevent damaging cementum.

Incorrect Technique for Cutting Septa

During removal of the rubber dam, an incorrect technique for cutting the septa may result in cut tissue or torn septa. Stretching the septa away from the gingiva, protecting the lip and cheek with an index finger, and using curve-beaked scissors decreases the risk of cutting soft tissue or tearing the septa with the scissors as the septa are cut.

Cotton Roll Isolation and Cellulose Wafers

Absorbents, such as cotton rolls (Fig. 7-32), also can provide isolation. Absorbents are isolation alternatives when rubber dam application is impractical or impossible. In selected situations, cotton roll isolation can be as effective as rubber dam isolation.^{2,31} In conjunction with profound anesthesia, absorbents provide acceptable moisture control for most clinical procedures. Using a saliva ejector in conjunction with



Fig. 7-32 Absorbents such as cotton rolls (*A* and *B*), reflective shields (*C*), and gauze sponges (*D*) provide satisfactory dryness for short periods. (Courtesy Richmond Dental, Charlotte, NC.)



Fig. 7-33 A cotton roll holder in position. (Courtesy R. Scott Eidson, DDS.)



Fig. 7-34 Isolate maxillary posterior teeth by placing the cotton roll in the vestibule adjacent to teeth. (Courtesy R. Scott Eidson, DDS.)

absorbents may abate salivary flow further. Cotton rolls should be replaced, as needed. It is sometimes permissible to suction the free moisture from a saturated cotton roll in place in the mouth; this is done by placing the evacuator tip next to the end of the cotton roll while the operator secures the roll.

Several commercial devices for holding cotton rolls in position are available (Fig. 7-33). It is generally necessary to remove the holding appliance from the mouth to change the cotton rolls. An advantage of cotton roll holders is that they may slightly retract the cheeks and tongue from teeth, which enhances access and visibility.

Placing a cotton roll in the facial vestibule (Fig. 7-34) isolates maxillary teeth. Placing a cotton roll in the vestibule and another between teeth and the tongue (Fig. 7-35) isolates mandibular teeth. Although placement of a cotton roll in the facial vestibule is simple, placement on the lingual of mandibular teeth is more difficult. Lingual placement is facilitated by holding the mesial end of the cotton roll with operative pliers and positioning the cotton roll over the desired location. The index finger of the other hand is used to push the cotton roll gingivally while twisting the cotton roll with the operative pliers toward the lingual aspect of teeth. Cellulose wafers may be used to retract the cheek and provide additional

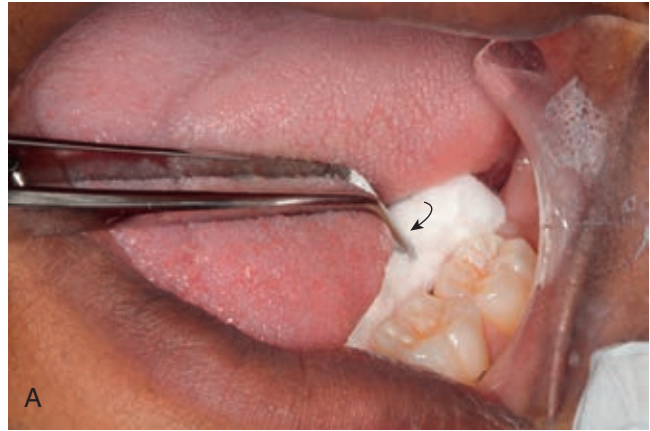


Fig. 7-35 **A**, Position a large cotton roll between the tongue and teeth by “rolling” the cotton to place it in the direction of the arrow. **B**, Properly positioned facial and lingual cotton rolls improve access and visibility. (Courtesy R. Scott Eidson, DDS.)

absorbency. After the cotton rolls, cellulose wafers, or both are in place, the saliva ejector may be positioned. When removing cotton rolls or cellulose wafers, it may be necessary to moisten them using the air-water syringe to prevent inadvertent removal of the epithelium from the cheeks, floor of the mouth, or lips.

Other Isolation Techniques

Throat shields

When the rubber dam is not being used, throat shields are indicated when the risk of aspirating or swallowing small objects is present. Throat shields are particularly important when treating teeth in the maxillary arch. A gauze sponge (2 × 2 inch [5 × 5cm]), unfolded and spread over the tongue and the posterior part of the mouth, is helpful in recovering a small object, for example, an indirect restoration, should it be dropped (Fig. 7-36). Without a throat shield, it is possible for a small object to be aspirated or swallowed (Fig. 7-37).³²

High-Volume Evacuators and Saliva Ejectors

Air-water spray is supplied through the head of the high-speed handpiece to wash the operating site and act as a coolant for the bur and the tooth. High-volume evacuators are preferred for suctioning water and debris from the mouth (Fig. 7-38)



Fig. 7-36 A throat screen is used during try-in and removal of indirect restorations. (Courtesy R. Scott Eidson, DDS.)

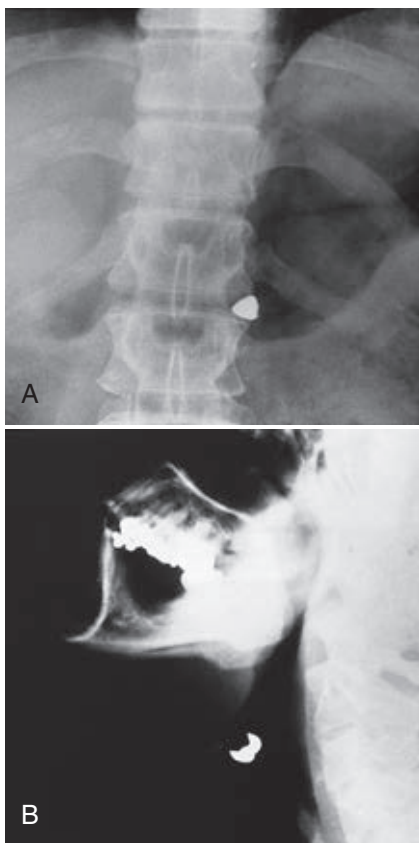


Fig. 7-37 **A**, Radiograph of swallowed casting in the patient's stomach. **B**, Radiograph of casting lodged in the patient's throat.

because saliva ejectors remove water slowly and have little capacity for picking up solids. A practical test for the adequacy of a high-volume evacuator is to submerge the evacuator tip in a 5-oz (150-mL) cup of water. The water should disappear in approximately 1 second. The combined use of water spray or air-water spray and a high-volume evacuator during cutting procedures has the following advantages:

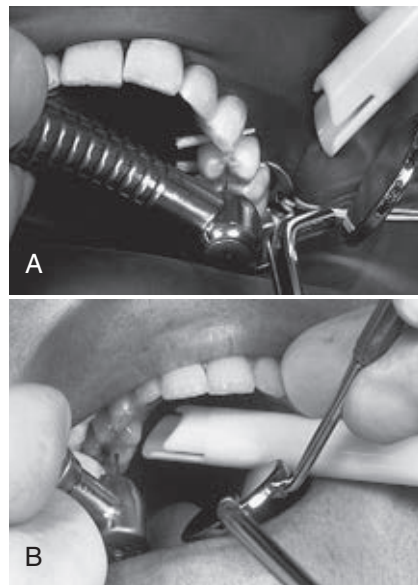


Fig. 7-38 Position of evacuator tip for maximal removal of water and debris in operating area. **A**, With rubber dam applied. **B**, With cotton roll isolation.

1. Cuttings of tooth and restorative material and other debris are removed from the operating site.
2. A clean operating field improves access and visibility.
3. Dehydration of oral tissues does not occur.
4. Precious metals can be more readily salvaged if desired.

The assistant places the evacuator tip as close as possible to the tooth being prepared. It should not, however, obstruct the operator's access or vision. Also, the evacuator tip should not be so close to the handpiece head that the air-water spray is diverted from the rotary instrument (i.e., bur or diamond). The assistant should place the evacuator tip in the mouth before the operator positions the handpiece and the mirror. The assistant usually places the tip of the evacuator just distal to the tooth to be prepared. For maximal efficiency, the orifice of the evacuator tip should be positioned such that it is parallel to the facial (lingual) surface of the tooth being prepared. The assistant's right hand holds the evacuator tip; the left hand manipulates the air-water syringe. (Hand positions are reversed if the operator is left-handed.) When the operator needs to examine the progress of tooth preparation, the assistant rinses and dries the tooth using air from the syringe in conjunction with the evacuator.

In most patients, the use of saliva ejectors is not required for removal of saliva because salivary flow is greatly reduced when the operating site is profoundly anesthetized. The dentist or assistant positions the saliva ejector if needed. The saliva ejector removes saliva that collects on the floor of the mouth. It may be used in conjunction with sponges, cotton rolls, and the rubber dam. It should be placed in an area least likely to interfere with the operator's movements.

The tip of the ejector must be smooth and made of a non-irritating material. Disposable plastic ejectors that may be shaped by bending with the fingers are preferable because of improved infection control (Fig. 7-39). The ejector should be placed to prevent occluding its tip with tissue from the floor of the mouth. Some ejectors are designed to prevent

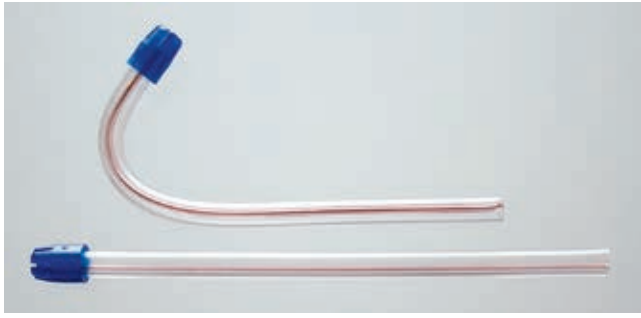


Fig. 7-39 Saliva ejectors. (From Boyd LRB: *Dental instruments: A pocket guide*, ed 4, St. Louis, 2012, Saunders.)

suctioning of tissue. It also may be necessary to adjust the suction for each patient to prevent this occurrence. Svedopter (saliva ejector with tongue retractor) moisture control systems, which aid in providing suction, retraction, illumination, and jaw opening support, are available (Isolite Systems, Santa Barbara, CA). When using the Isolite, a reduction in operating time when placing sealants has been reported. The same study reported that the majority of patients were indifferent with regard to isolation with Isolite and cotton rolls, considering both techniques comfortable.³³

Retraction Cord

When properly applied, retraction cord often can be used for isolation and retraction in direct procedures involving accessible subgingival areas and in indirect procedures involving gingival margins. When the rubber dam is not used, is impractical, or is inappropriate, retraction cord, usually moistened with a noncaustic hemostatic agent, may be placed in the gingival sulcus to control sulcular seepage, hemorrhage, or both. To achieve adequate moisture control, retraction cord isolation should be used in conjunction with salivation control. A properly applied retraction cord improves access and visibility and helps prevent abrasion of gingival tissue during tooth preparation. Retraction cord may help restrict excess restorative material from entering the gingival sulcus and provide better access for contouring and finishing the restorative material. When the proper cord is correctly inserted, its mild physical and chemical (hemostatic) effects achieve isolation from fluids (along with cotton roll use), it provides access and visibility, and it does not cause harm. Anesthesia of the operating site may or may not be needed for patient comfort.

The operator chooses a diameter of cord that can be inserted gently into the gingival sulcus and that produces lateral displacement of the free gingiva (“opening” the sulcus) without blanching it (caused by ischemia secondary to pressure). The length of the cord should be sufficient to extend approximately 1 mm beyond the gingival width of the tooth preparation. A thin, blunt-edged instrument blade or the side of an explorer is used to insert the cord progressively. To prevent displacement of a previously inserted cord, the placement instrument should be moved slightly backward at each step as it is stepped along the cord (Fig. 7-40). Cord placement should not harm gingival tissue or damage the epithelial attachment. If ischemia of gingival tissue is observed, the cord may need to be replaced with a smaller-diameter cord. The objective is

to obtain minimal, yet sufficient, lateral displacement of the free gingiva and not to force it apically. Cord insertion results in adequate apical retraction of the gingival crest in a short time. Occasionally, it may be helpful to insert a second, usually larger, cord over the initially inserted cord.

In procedures for an indirect restoration, inserting the cord before removal of infected dentin and placement of any necessary liner assists in providing maximum moisture control. It also opens the sulcus in readiness for any beveling of the gingival margins, when indicated. The cord may be removed before beveling, or it may be left in place during beveling. Inserting the cord as early as possible in tooth preparation helps prevent abrasion of the gingival tissue, thus reducing the potential for bleeding and allowing only minimal absorption of any medicament from the cord into the circulatory system.

Mirror and Evacuator Tip Retraction

A secondary function of the mirror and the evacuator tip is to retract the cheek, lip, and tongue (Fig. 7-41). This retraction is particularly important when a rubber dam is not used.

Mouth Props

A potential aid to restorative procedures on posterior teeth (for a lengthy appointment) is a mouth prop (Fig. 7-42, A). A prop should establish and maintain suitable mouth opening, relieving the patient’s muscles of this task, which often produces fatigue and sometimes pain. The ideal characteristics of a mouth prop are as follows:

1. It should be adaptable to all mouths.
2. It should be easily positionable, without causing discomfort to the patient.
3. It should be easily adjusted, if necessary, to provide the proper mouth opening or improve its position in the mouth.
4. It should be stable once applied.
5. It should be easily and readily removable by the operator or patient in case of emergency.
6. It should be either sterilizable or disposable.

Mouth props are generally available as either a block type or a ratchet type (see Fig. 7-42, B and C). Although the ratchet type is adjustable, its size and cost are disadvantages.

The use of a mouth prop may be beneficial to the operator and the patient. The most outstanding benefits to the patient are relief of responsibility of maintaining adequate mouth opening and relief of muscle fatigue and muscle pain. For the dentist, the prop ensures constant and adequate mouth opening and permits extended or multiple operations, if desired.

Drugs

The use of drugs to control salivation is rarely indicated in restorative dentistry and is generally limited to atropine. As with any drug, the operator should be familiar with its indications, contraindications, and adverse effects. Atropine is contraindicated for nursing mothers and patients with glaucoma.³⁴



Fig. 7-40 Retraction cord placed in the gingival crevice. **A**, Cord placement initiated. **B**, A thin, flat-bladed instrument is used for cord placement. **C**, Cord placed.



Fig. 7-41 Chairside assistant uses air syringe to dry teeth and to keep the mirror free of debris.



Fig. 7-42 Mouth props. **A**, Block-type prop maintaining mouth opening. **B**, Ratchet-type prop maintaining mouth opening. **C**, Block-type prop. **D**, Ratchet-type prop. (**A** and **B**, From Malamed SF: *Sedation: A guide to patient management*, ed 5, St. Louis, 2010, Mosby. **C** and **D**, From Hupp JR, Ellis E, Tucker MR: *Contemporary oral and maxillofacial surgery*, ed 5, St. Louis, 2008, Mosby.)

Summary

A thorough knowledge of the preliminary procedures addressed in this chapter reduces the physical strain on the dental team associated with daily dental practice. Maintaining optimal moisture control is a necessary component in the delivery of high-quality operative dentistry.

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Introduction to Composite Restorations

Harald O. Heymann, André V. Ritter, Theodore M. Roberson

The search for an ideal esthetic material for restoring teeth has resulted in significant improvements in esthetic materials and in the techniques for using these materials. Composites and the acid-etch technique represent two major advances in restorative dentistry.¹⁻⁴ Adhesive materials that have strong bonds to enamel and dentin further simplify restorative techniques.⁵⁻¹⁰ The possibilities for innovative uses of esthetic materials are exciting and almost unlimited. Many of the specific applications of these materials are presented in Chapters 9 through 12; this chapter provides a general introduction to composites, the predominant direct esthetic restorative materials (Fig. 8-1).

Although these materials are referred to as *resin-based composites*, *composite resins*, and by other terms, this book refers to most direct esthetic restorations as *composites*. Some information also is presented about various types of composites, including macrofill, microfill, hybrid, nanofill, nanohybrid, flowable, and packable types, as well as other direct tooth-colored restorative materials such as glass ionomers and resin-modified glass ionomers. A brief historical perspective of other tooth-colored materials that may still be encountered clinically is also provided.

The choice of a material to restore caries lesions and other defects in teeth is not always simple. Tooth-colored materials such as composites are used in almost all types and sizes of restorations. Such restorations are accomplished with minimal loss of tooth structure, little or no discomfort, relatively short operating time, and modest expense to the patient compared with indirect restorations. When a tooth is significantly weakened by extensive defects (especially in areas of heavy occlusal function), however, and esthetics is of primary concern, the best treatment usually is a ceramic onlay or crown or a porcelain-fused-to-metal crown.

It is the dentist's responsibility to present all logical restorative alternatives to a patient, but the patient should be given the opportunity to make the final decision regarding which alternative will be selected. Explaining the procedure and showing the patient color photographs and models of teeth that have been restored by various methods are helpful. Simulation of possible treatment outcomes, using computer imaging technology, also is helpful.

The lifespan of an esthetic restoration depends on many factors, including the nature and extent of the initial caries lesion or defect; the treatment procedure; the restorative material and technique used; the operator's skill; and patient factors such as oral hygiene, occlusion, caries risk, and adverse habits. Because all direct esthetic restorations are bonded to tooth structure, the effectiveness of generating the bond is paramount for the success and longevity of such restorations. Failures can result from numerous causes, including trauma, improper tooth preparation, inferior materials, and misuse of dental materials. The dentist is responsible for performing or accomplishing each operative procedure with meticulous care and attention to detail. Patient cooperation is crucial, however, in maintaining the clinical appearance and influencing the longevity of any restoration. Long-term clinical success requires that a patient be knowledgeable about the causes of dental disease and be motivated to practice preventive measures, including a proper diet, good oral hygiene, and maintenance recall visits to the dentist.

This chapter primarily presents the properties and clinical uses of composite materials. Composites can be used in almost any tooth surface for any kind of restorative procedure. Naturally, certain factors must be considered for each specific application. The reasons for such expanded usage of these materials relate to the improvements in their ability to bond to tooth structure (enamel and dentin) and in their physical properties. The ability to bond a relatively strong material (composite) to tooth structure (enamel and dentin) results in a restored tooth that is well sealed and possibly regains a portion of its strength.^{11,12}

Types of Esthetic Restorative Materials

Many esthetic restorative materials are available. To gain a full historical appreciation of the types of conservative esthetic materials that might be encountered, a representative list of tooth-colored materials is briefly reviewed. These materials are presented in greater detail in online [Chapter 18, Biomaterials](#).

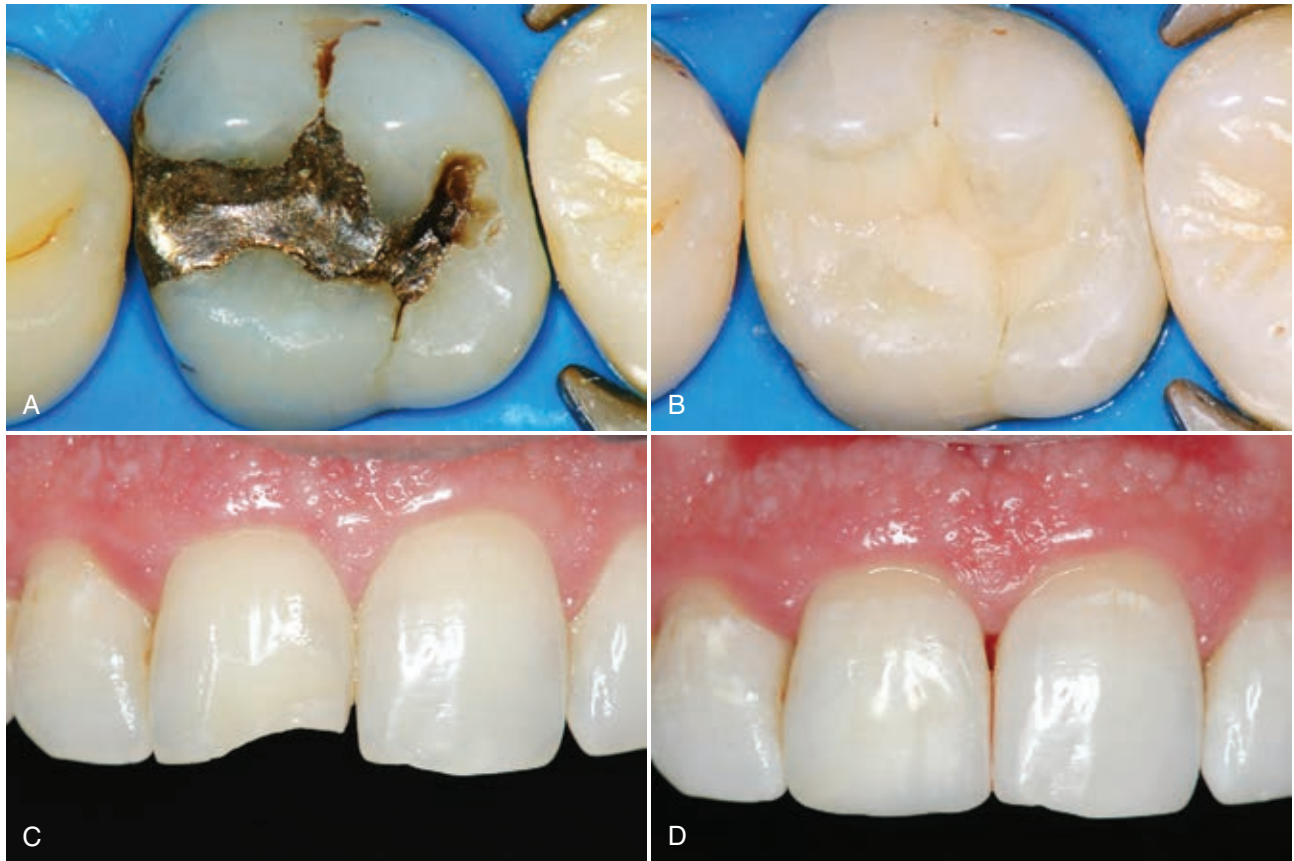


Fig. 8-1 Composite restorations. **A** and **B**, Class II composite restoration, before and after. **C** and **D**, Class IV composite restoration, before and after.

Ceramic Inlays and Onlays

The fused (baked) feldspathic porcelain inlay, an indirect ceramic restoration, dates from 1908, when Byram described several designs of tooth preparations for its use.^{13,14} Since the development of adhesive resin cements, interest in using feldspathic porcelain for inlays and onlays in posterior teeth (see examples in [Chapter 11](#)) and veneers in anterior teeth (see examples in [Chapter 12](#)) has been renewed.¹⁵⁻¹⁹ Many of these restorations are fabricated in a dental laboratory with materials and equipment similar to those used for other types of fused porcelain. Newer versions of ceramics, from which indirect restorations are either pressed or cast, also are available whose physical properties and ease of fabrication are much improved from classic feldspathic porcelain materials (see online [Chapter 18](#)). Sophisticated computer-aided design/computer-assisted machining (CAD/CAM) systems enable fabrication of ceramic restorations chairside, thus eliminating the need for impressions, temporary restorations, laboratory procedures and costs, and additional appointments (see [Chapter 11](#) and online [Chapter 18](#)).²⁰⁻²²

Silicate Cement

Silicate cement, the first translucent restorative material, was introduced in 1878 in England by Fletcher.¹⁴ For more than 60 years, silicate cement was used extensively to restore caries lesions in anterior teeth. Silicate cement powder is composed of acid-soluble glasses, and the liquid contains phosphoric

acid, water, and buffering agents. Although silicate cement is not used as a restorative material today, a practitioner still might encounter silicate restorations in older patients. Of particular interest is that glass ionomer materials are basically contemporary versions of silicate cements. The primary difference relates to the use of polyacrylic acid as opposed to phosphoric acid, rendering glass ionomers less soluble.

Silicate cement was recommended for small restorations in the anterior teeth of patients with high caries activity.²³ By virtue of the high fluoride content and solubility of this restorative material, the adjacent enamel was thought to be rendered more resistant to recurrent caries. Although the average life of a silicate cement restoration was approximately four years, some of these restorations were reported to last for 10 years and longer in some patients.^{24,25}

The failures of silicate cement are easy to detect because of the discoloration and loss of contour of the restoration. When examined with an explorer tip, silicate cement is rough and has the feel of ground glass. Old composite restorations may exhibit a similar surface texture and discoloration, but they are less subject to extensive ditching or loss of contour.

Acrylic Resin

Self-curing (chemically activated) acrylic resin for anterior restorations was developed in Germany in the 1930s.²⁶ Early acrylic materials were disappointing because of their inherent weaknesses such as poor activator systems, high polymerization shrinkage, high coefficient of thermal expansion, and lack

of wear resistance, all of which resulted in marginal leakage, pulp injury, recurrent caries, color changes, and excessive wear.^{26,27} It was not indicated for high-stress areas because the material had low strength and would flow under load. Its high polymerization shrinkage and linear coefficient of thermal expansion (LCTEs) caused microleakage and eventual discoloration at the margins as a result of percolation.²⁶ Acrylic resin restorations are rarely used today but, as with silicate cement restorations, may be seen in older patients.

As a restoration, acrylic resin was most successful in the protected areas of teeth where temperature change, abrasion, and stress were minimal.²⁸ It also was used as an esthetic veneer on the facial surface of Class II and IV metal restorations and for facings in crowns and bridges. A current, although limited, use of acrylic resin is for making temporary restorations in operative and fixed prosthodontic indirect restoration procedures requiring two or more appointments.

Composite

In an effort to improve the physical characteristics of unfilled acrylic resins, Bowen, of the National Bureau of Standards (now called the National Institute of Standards and Technology), developed a polymeric dental restorative material reinforced with inorganic particles.^{1,29} The introduction in 1962 of this filled resin material became the basis for the restorations that are generically termed *composites*. Basically, composite restorative materials consist of a continuous polymeric or resin matrix in which an inorganic filler is dispersed. This inorganic filler phase significantly enhances the physical properties of the composite (compared with previous tooth-colored materials) by increasing the strength of the restorative material and reducing thermal expansion.³⁰ Composites possess LCTEs that are one-half to one-third the value typically found for unfilled acrylic resins and nearer to that of tooth structure. (See online [Chapter 18](#) for details on composite components and properties.)

For a composite to have good mechanical properties, a strong bond must exist between the organic resin matrix and the inorganic filler. This bond is achieved by coating the filler particles with a silane coupling agent, which not only increases the strength of the composite but also reduces its solubility and water absorption.^{30,31}

Composites are usually classified primarily on the basis of the size, amount, and composition of the inorganic filler. Different types of composite used since its introduction include macrofill composites (also called *conventional composites*), microfill composites, hybrid composites (including traditional hybrid, microhybrid, and nanohybrid composites), and nanofill composites. Composites also have been classified on the basis of their handling characteristics, for example, as flowable and packable composites.

Macrofill (or Conventional) Composites

Macrofill composites were the first type of composites introduced in the early 1960s. Although these types of composite restorations are sometimes found in some older patients, they are no longer used in clinical practice. Macrofill composites generally contained approximately 75% to 80% inorganic filler by weight. The average particle size of conventional

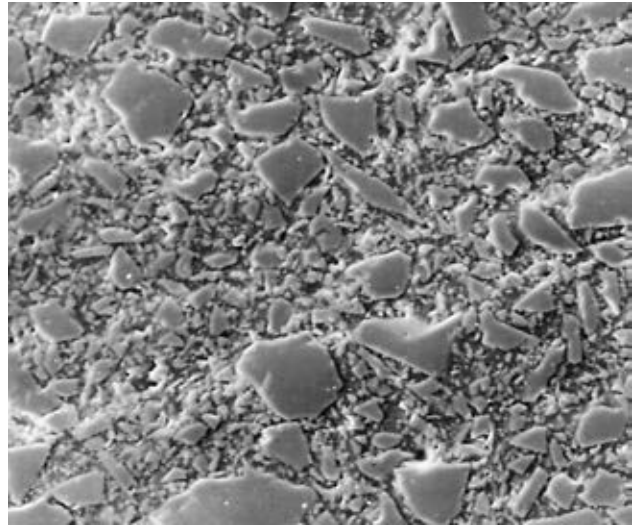


Fig. 8-2 Scanning electron micrograph of polished surface of a conventional composite (×300).

composites was approximately 8 μm .²⁹ Because of the relatively large size and extreme hardness of the filler particles, macrofill composites typically exhibit a rough surface texture. (This characteristic can be seen in the scanning electron micrograph in [Fig. 8-2](#).) The resin matrix wears at a faster rate than do the filler particles, further roughening the surface. This type of surface texture causes the restoration to be more susceptible to discoloration from extrinsic staining. Macrofill composites have a higher amount of initial wear at occlusal contact areas than do the microfill or hybrid types.

Most conventional composites currently have been supplanted by hybrid composites (see later) but may still be encountered in older patients.

Microfill Composites

Microfill composites were introduced in the late 1970s. These materials were designed to replace the rough surface characteristic of conventional composites with a smooth, lustrous surface similar to tooth enamel. Instead of containing the large filler particles typical of the conventional composites, microfill composites contain colloidal silica particles whose average diameter is 0.01 to 0.04 μm . As illustrated in the scanning electron micrograph in [Figure 8-3](#), this small particle size results in a smooth, polished surface in the finished restoration that is less receptive to plaque or extrinsic staining. Because of the greater surface area per unit volume of these microfine particles, however, microfill composites cannot be as heavily filled because of the significant surface area per unit of volume.³¹ Typically, microfill composites have an inorganic filler content of approximately 35% to 60% by weight. Because these materials contain considerably less filler than do conventional or hybrid composites, some of their physical and mechanical characteristics are inferior. Nonetheless, microfill composites are clinically highly wear resistant. Also, their low modulus of elasticity may allow microfill composite restorations to flex during tooth flexure, better protecting the bonding interface. This feature may not have any effect on material selection for Class V restorations in general, but it might make microfill composites an appropriate choice for restoring

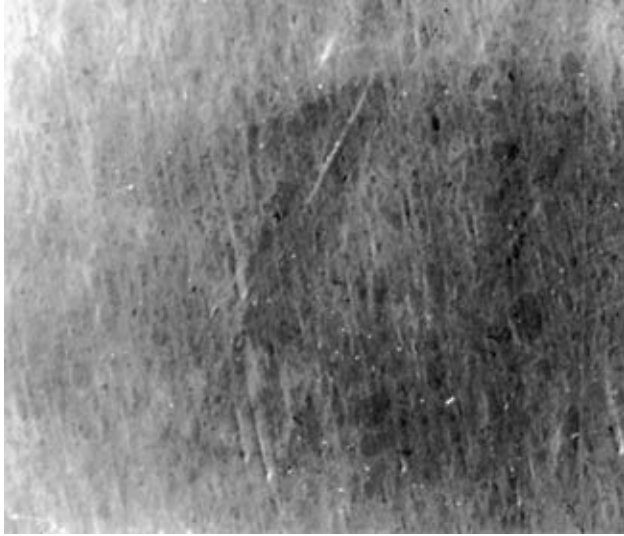


Fig. 8-3 Scanning electron micrograph of polished surface of a microfill composite (×300).

Class V cervical lesions or defects in which cervical flexure can be significant (e.g., bruxism, clenching, stressful occlusion).³²

Hybrid Composites

Hybrid composites were developed in an effort to combine the favorable physical and mechanical properties characteristic of macrofill composites with the smooth surface typical of the microfill composites. These materials generally have an inorganic filler content of approximately 75% to 85% by weight. Classically, the filler has been a mixture of microfiller and small filler particles that results in a considerably smaller average particle size (0.4–1 μm) than that of conventional composites. Because of the relatively high content of inorganic fillers, the physical and mechanical characteristics are generally superior to those of conventional composites. Classic versions of hybrid materials exhibit a smooth “patina-like” surface texture in the finished restoration.

Current versions of hybrid composites also contain ultra-small nanofillers, resulting in superior characteristics. These newer versions of hybrid composites are called *nanohybrid composites*.

Nanofill

Nanofill composites contain filler particles that are extremely small (0.005–0.01 μm). Because these small primary particles can be easily agglomerated, a full range of filler sizes is possible, and optimal particle packing is facilitated. Alternatively, many classic hybrid composites have simply incorporated nanofillers into the existing filler composition, thereby optimizing the material further. Consequently, high filler levels can be generated in the restorative material, which results in good physical properties and improved esthetics. The small primary particle size also makes nanofills highly polishable. Because of these qualities, nanofill and nanohybrid composites are the most popular composite restorative materials in use. These composites have almost universal clinical applicability and are the primary materials referred to as *composites* throughout this book.

Packable Composites

Packable composites are designed to be inherently more viscous to afford a “feel” on insertion, similar to that of amalgam. Because of increased viscosity and resistance to packing, some lateral displacement of the matrix band is possible. Their development is an attempt to accomplish two goals: (1) easier restoration of a proximal contact and (2) similarity to the handling properties of amalgam. Packable composites do not completely accomplish either of these goals. Because of the increased viscosity, it is typically more difficult to attain optimal marginal adaptation, prompting some clinicians to first apply a small amount of flowable composite along proximal marginal areas to enhance adaptation.

Flowable Composites

Flowable composites generally have lower filler content and consequently inferior physical properties such as lower wear resistance and lower strength compared with the more heavily filled composites. They also exhibit much higher polymerization shrinkage. Although manufacturers promote widespread use of these products, they seem to be more appropriate for use in some small Class I restorations, as pit-and-fissure sealants, as marginal repair materials, or, more infrequently, as the first increment placed as a stress-breaking liner under posterior composites. Additionally, flowable composites are being used as first small increments in the proximal box of a Class II restoration in an effort to improve marginal adaptation. This approach is somewhat controversial but may be indicated in conjunction with the use of thicker, packable composites, where optimal marginal adaptation is more difficult to achieve.

Some manufacturers also are currently marketing flowable composites as bulk-fill materials, to be used to restore most, if not all, of a tooth preparation in posterior teeth. The manufacturers claim reduced polymerization shrinkage stress, which may occur because of the low elastic modulus of the flowable materials. However, the physical properties of flowable composites are generally poor, and the long-term performance of such restorations is not yet proven. Whether or not flowable composites are used for bulk-filling, they should never be placed in areas of high proximal or occlusal stress because of their comparatively poor wear resistance. More heavily filled composites are far superior for restorations involving occlusal or proximal contact areas.

Glass Ionomer

Conventional Glass Ionomers

Glass ionomers were developed first by Wilson and Kent in 1972.³³ Similar to silicate cements, their predecessors, the original glass ionomer restorative materials were powder/liquid systems. Glass ionomers have the same favorable characteristics of silicate cements—they release fluoride into the surrounding tooth structure, yielding a potential anti-cariogenic effect, and possess a favorable coefficient of thermal expansion.^{34,35} In contrast to silicate cements, which have phosphoric acid liquid, glass ionomers use polyacrylic acid, which renders the final restorative material less soluble.

Although conventional glass ionomers are relatively technique-sensitive with regard to mixing and insertion

procedures, they may be good materials for restoration of teeth with root-surface caries because of their inherent potential anti-cariogenic quality and adhesion to dentin. Similarly, because of the potential for sustained fluoride release, glass ionomers may be indicated for other restorations in patients exhibiting high caries activity.³⁶ Because of their low resistance to wear and relatively low strength compared with composite or amalgam, glass ionomers are not recommended for the restoration of the occlusal areas of posterior teeth. Glass ionomer cements also have been widely advocated for permanent cementation of crowns.

Today, most glass ionomers also are available in encapsulated forms that are mixed by trituration. The capsule containing the mixed material subsequently is placed in an injection syringe for easy insertion into the tooth preparation.

Resin-Modified Glass Ionomers

In an effort to improve the physical properties and esthetic qualities of conventional glass ionomer cements, resin-modified glass ionomer (RMGI) materials have been developed (Table 8-1). RMGIs are probably best described as glass ionomers to which resin has been added. An acid-base setting reaction, similar to that of conventional glass ionomer cements, is present. This is the primary feature that distinguishes these materials from compomers (see the next section). Additionally, the resin component affords the potential for light-curing, autocuring, or both. RMGIs are easier to use and possess better strength, wear resistance, and esthetics than do conventional glass ionomers. Their physical properties are generally inferior to those of composites, however, and their indications for clinical use are limited. Because they have the potential advantage of sustained fluoride release, they may be best indicated for Class V restorations in adults who are at high risk for caries and for Class I and II restorations in primary teeth that would not require long-term service.³⁷

Compomers (Polyacid-Modified Composites)

Compomers probably are best described as composites to which some glass ionomer components have been added. Primarily light-cured, they are easy to use and gained popularity because of their superb handling properties. Overall, their physical properties are superior to traditional glass ionomers and RMGIs, but inferior to those of composites. Their indications for clinical use are limited. Although compomers are capable of releasing fluoride, the release is not sustained at a constant rate, and anti-cariogenicity is questionable.

Table 8-1 Tooth-Colored Materials

Conventional Glass Ionomer	Resin-Modified Glass Ionomer Compomer	Composite
High fluoride release	←	Low fluoride release
Low strength	→	High strength
Poor esthetics	→	Excellent esthetics
Low wear resistance	→	High wear resistance

Important Properties of Composites

The various properties of composites should be understood for achieving a successful composite restoration. These properties generally require that specific techniques be incorporated into the restorative procedure, either in tooth preparation or in the application of the material. The various property factors are presented here, with additional information provided primarily in online Chapter 18 but also in Chapters 9 through 12.

Linear Coefficient of Thermal Expansion

The *LCTE* is the rate of dimensional change of a material per unit change in temperature. The closer the *LCTE* of the material is to the *LCTE* of enamel, the lower the chance for creating voids or openings at the junction of the material and the tooth when temperature changes occur. The *LCTE* of modern composites is approximately three times that of tooth structure.³⁸ Bonding a composite to etched tooth structure reduces the potential negative effects as a result of the difference between the *LCTE* of the tooth structure and that of the material.

Water Sorption

Water sorption is the amount of water that a material absorbs over time per unit of surface area or volume. When a restorative material absorbs water, its properties change, and its effectiveness is usually diminished. All of the available tooth-colored materials exhibit some water absorption. Materials with higher filler contents exhibit lower water absorption values than materials with lower filler content.

Wear Resistance

Wear resistance refers to a material's ability to resist surface loss as a result of abrasive contact with opposing tooth structure, restorative material, food boli, and such items as toothbrush bristles and toothpicks. The filler particle size, shape, and content affect the potential wear of composites and other tooth-colored restorative materials. The location of the restoration in the dental arch and occlusal contact relationships also affect the potential wear of these materials.

Wear resistance of contemporary composite materials is generally good. Although not yet as resistant as amalgam, the difference is becoming smaller.^{39,40} A composite restoration offers stable occlusal relationship potential in most clinical conditions, particularly if the occlusal contacts are shared with the contacts on natural tooth structure.

Surface Texture

Surface texture is the smoothness of the surface of the restorative material. Restorations in close approximation to gingival tissues require surface smoothness for optimal gingival health. The size and composition of the filler particles primarily determine the smoothness of a restoration, as does the material's ability to be finished and polished. Although microfill composites historically have offered the smoothest restorative surface, nanohybrid and nanofill composites also provide surface textures that are polishable, esthetically satisfying, and compatible with soft tissues.

Radiopacity

Esthetic restorative materials must be sufficiently *radiopaque* so that the radiolucent image of recurrent caries around or under a restoration can be seen more easily in a radiograph. Most composites contain radiopaque fillers such as barium glass to make the material radiopaque.

Modulus of Elasticity

Modulus of elasticity is the stiffness of a material. A material having a higher modulus is more rigid; conversely, a material with a lower modulus is more flexible. A microfill composite material with greater flexibility may perform better in certain Class V restorations than a more rigid hybrid composite.^{32,41} This is particularly true for Class V restorations in teeth experiencing heavy occlusal forces, where stress concentrations exist in the cervical area. Such stress can cause tooth flexure that can disrupt the bonding interface.⁴² Using a more flexible material such as a microfill composite allows the restorations to bend with the tooth, better protecting the bonding interface. The elastic modulus of the material may be less significant, however, with current bonding systems unless significant occlusal stress from bruxism, clenching, or other forms of stressful occlusion are present. Stress-breaking liners that possess a lower elastic modulus also can be used to potentially protect the bonding interface from polymerization shrinkage effects.

Solubility

Solubility is the loss in weight per unit surface area or volume secondary to dissolution or disintegration of a material in oral fluids, over time, at a given temperature. Composite materials do not show any clinically relevant solubility.

Polymerization of Composite

Polymerization Shrinkage

Composite materials shrink while polymerizing. This is referred to as *polymerization shrinkage*. This phenomenon cannot be avoided, and important clinical procedural

techniques must be incorporated to help offset the potential problems associated with a material pulling away from the preparation walls as it polymerizes. Careful control of the amount and insertion point of the material and appropriate use of an adhesive on the prepared tooth structure to improve bonding reduce these problems.

Polymerization shrinkage usually does not cause significant problems with restorations cured in preparations having all-enamel margins. When a tooth preparation has extended onto the root surface, however, polymerization shrinkage can (and usually does) cause a gap formation at the junction of the composite and root surface.^{43,44} This problem can be minimized by using the appropriate technique but probably cannot be eliminated. The clinical significance of the gap is not fully known. The gap occurs because the force of the polymerization of the composite is greater than the initial bond strength of the composite to the dentin of the root. The gap is probably composed of composite on the restoration side and hybridized dentin on the root side. If extending onto the root surface, it may be beneficial to place an RMGI first in the gingival portion of the preparation on the root followed by the composite. This approach may reduce the potential for microleakage and gap formation and render the surrounding tooth structure more resistant to recurrent caries.⁴⁵⁻⁵¹

Another important clinical consideration regarding the effects of polymerization shrinkage is the configuration factor (C-factor). The C-factor is the ratio of bonded surfaces to the unbonded, or free, surfaces in a tooth preparation. The higher the C-factor, the greater is the potential for bond disruption from polymerization effects. A Class IV restoration (one bonded surface and four unbonded surfaces) with a C-factor of 0.25 is at low risk for adverse polymerization shrinkage effects. A Class I restoration with a C-factor of 5 (five bonded surfaces, one unbonded surface) is at much higher risk of bond disruption associated with polymerization shrinkage, particularly along the pulpal floor (Fig. 8-4).⁵² Internal stresses can be reduced in restorations subject to potentially high disruptive contraction forces (e.g., Class I preparations with a high C-factor) by using (1) “soft-start” polymerization instead of high-intensity light-curing; (2) incremental additions to reduce the effects of polymerization shrinkage; and (3) a stress-breaking liner such as a filled dentinal adhesive, flowable composite, or RMGI.

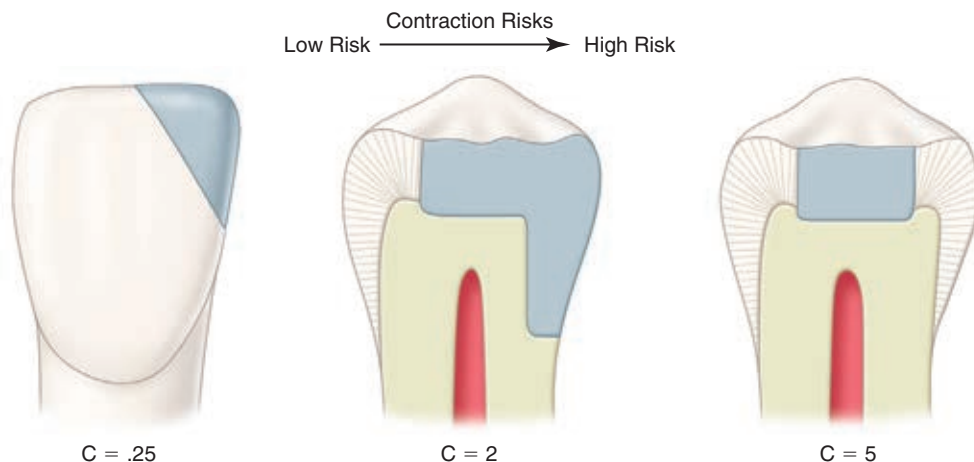


Fig. 8-4 Configuration factor (C-factor) (bonded surfaces/unbonded surfaces).

Another approach to reducing polymerization shrinkage stress with composites is to use a different polymer as the matrix. Typical hybrid composites using BIS-GMA or UDMA as the matrix shrink approximately 2.4% to 2.8%. Microfilled and flowable composites shrink considerably more because they are less highly filled. One product, Filtek LS (3M ESPE, St. Paul, MN) uses a silorane polymer matrix and the linear shrinkage of this composite is approximately 0.7%. These materials have very different chemistry compared with conventional composites and require dedicated bonding systems. The efficacy of such materials will be determined by ongoing clinical trials.

Method of Polymerization

The method of polymerization of a composite may affect the technique of insertion, direction of polymerization shrinkage, finishing procedure, color stability, and amount of internal porosity in the material. The two polymerization methods are (1) the self-cured method and (2) the light-cured method using visible light. Self-cured materials require mixing two components, a catalyst and a base, which then react to cause the material to polymerize. Because the components are mixed, the risk for air inclusion in the mixture and internal porosity is greater. Also, the working time to insert the self-cured material is restricted by the speed of chemical reaction and can result in the need for increased finishing time because limited contouring can be done before setting occurs. The color stability of self-cured materials also is lower because of the eventual breakdown of tertiary amines, the polymerization-initiating chemical ingredients. The direction of polymerization shrinkage for self-cured materials is generally centralized (toward the center of the mass). It is theorized that this may help maintain marginal adaptation to prevent microleakage.

Light-cured materials require the use of light-curing units or generators. The use of light sources may cause retinal damage unless appropriate precautions are taken to avoid direct, prolonged exposure to the light source. Light-cured materials do provide increased working time during insertion of the material, however, and may require less finishing time. They also exhibit greater color stability and less internal porosity. Effects of polymerization shrinkage can be partially compensated for by an incremental insertion (and curing) technique. In some clinical situations, however, positioning the light source close enough to the material is difficult or compromised. Despite these disadvantages, almost all contemporary composites are of the light-cured type.

Interest in improving the light-curing methods continues to grow. In addition to the classic quartz, tungsten, or halogen light-curing systems, plasma arc curing systems have been available for rapid polymerization of light-cured materials. These provide high-intensity and high-speed curing compared with the quartz, tungsten, or halogen systems. However, they also significantly increase the stresses from heat generation and polymerization shrinkage. Light-curing systems using blue light-emitting diodes (LEDs) are predominantly used today. Blue LED light-curing units are more efficient, more portable, and more durable than the systems noted previously. All of these efforts have been made to develop a light-curing system that is consistent and faster and produces a stress-free cured material. These features, along with the development of composites with less volumetric

polymerization shrinkage, are expected to make light-curing more successful and more economical and to possibly result in restorations with better bonding and improved properties.

General Considerations for Composite Restorations

A composite restoration is placed as follows: (1) The defect is removed from the tooth; (2) the prepared tooth structure is treated with an appropriate enamel and dentin adhesive; and (3) a filled restorative material (composite) is inserted, contoured, and polished. A successful composite restoration requires careful attention to technique detail, resulting in gaining the maximum benefit of the material's properties and appropriate bonding of the material to the tooth (the main advantage of composite is its ability to be bonded to the tooth). The fundamental concepts of adhesion of a restorative material to tooth structure are presented in [Chapter 4](#).

This section summarizes general considerations about all composite restorations. Information for specific clinical applications is presented in Chapters 9 through 12. In selecting a direct restorative material, practitioners usually choose between composite and amalgam. Consequently, some of the following information provides comparative analyses between those two materials.

Indications

Directly placed composite can be used for most clinical applications. Limiting factors for a specific clinical use are identified in later chapters. Generally, the indications for use are as follows:

1. Class I, II, III, IV, V, and VI restorations
2. Foundations or core buildups
3. Sealants and preventive resin restorations (conservative composite restorations)
4. Esthetic enhancement procedures:
 - Partial veneers
 - Full veneers
 - Tooth contour modifications
 - Diastema closures
5. Cements (for indirect restorations)
6. Temporary restorations
7. Periodontal splinting

Isolation Factors

For a composite restoration to be successful (i.e., to restore function, to be harmonious with adjacent tissues, and to be retained within the tooth), it must be bonded appropriately to the tooth structure (enamel and dentin). Bonding to the tooth structure requires an environment isolated from contamination by oral fluids or other contaminants; such contamination prohibits bond development. The ability to isolate the operating area (usually by using a rubber dam or cotton rolls) is a major factor in selecting a composite material for a restoration. If the operating area can be isolated, a bonding procedure can be done successfully. This would include the use of a composite or an RMGI restoration and the bonding of an indirect restoration with an appropriate cementing

agent. If the operating area cannot be totally protected from contamination, an amalgam restoration may be the material of choice because the presence of some oral fluids may not cause significant clinical problems with amalgam.

Occlusal Factors

Composite materials exhibit less wear resistance than amalgam; however, studies indicate that with contemporary composites, the wear resistance is not substantially different from that of amalgam.^{39,40} For patients with heavy occlusion, bruxism, or restorations that provide all of a tooth's occlusal contacts, usually the material of choice is amalgam, rather than composite. Nevertheless, for most teeth experiencing normal occlusal loading and having occlusal contacts that are at least shared with the tooth structure, composite restorations perform well.

Operator Factors

Compared with an amalgam restoration, tooth preparation for a composite restoration is relatively easier and less complex, but tooth isolation; placement of adhesive on the tooth structure; and insertion, finishing, and polishing of the composite are more difficult. The operator must pay greater attention to detail to accomplish a composite restoration successfully. Technical ability and knowledge of the material's use and limitations are required.

Contraindications

The primary contraindications for the use of composite as a restorative material relate to the factors presented above— isolation, occlusion, and operator factors. If the operating site cannot be isolated from contamination by oral fluids, composite (or any other bonded material) should not be used. If all of the occlusion is on the restorative material, composite may not be the right choice. The need to strengthen the remaining weakened, unprepared tooth structure with an economical composite restoration procedure (compared with an indirect restoration) and the commitment to recall the patient routinely and in a timely manner may override any concern about excessive wear potential. Also, as discussed previously, composite restoration extensions on the root surface may exhibit gap formation at the junction of the composite and the root. The use of an RMGI liner beneath the composite in the root-surface area may reduce the potential for microleakage, gap formation, and recurrent caries.⁴⁵⁻⁵¹ Any restoration that extends onto the root surface may result in less than ideal marginal integrity. An amalgam exhibits a slight space at the margin until corrosion products seal the area better. Lastly, the operator must be committed to pursuing procedures, such as tooth isolation, that make bonded restorations successful. These additional procedures may make the procedures associated with successful bonded restorations more difficult and time consuming.

Advantages

Some advantages of composite restorations have been stated already, but the following list provides the reasons composite restorations have become so popular, especially

compared with amalgam restorations. Composite restorations are:

1. Esthetic.
2. Conservative in tooth structure removal (less extension, uniform depth not necessary, mechanical retention usually not necessary).
3. Less complex when preparing the tooth.
4. Insulating; having low thermal conductivity.
5. Used almost universally.
6. Bonded to tooth structure, resulting in good retention, relatively low microleakage, minimal interfacial staining, and increased strength of remaining tooth structure.
7. Repairable.

Disadvantages

The primary disadvantages of composite restorations relate to potential gap formation and procedural difficulties. Composite restorations:

1. May have a gap formation, usually occurring on root surfaces as a result of the forces of polymerization shrinkage of the composite material being greater than the initial early bond strength of the material to dentin. A gap also can result from improper insertion of the composite by the clinician.
2. Are more difficult, time-consuming, and costly (compared with amalgam restorations) because bonding usually requires multiple steps; insertion is more difficult; establishing proximal contacts, axial contours, embrasures, and occlusal contacts may be more difficult; and finishing and polishing procedures are more difficult.
3. Are more technique-sensitive because the operating site must be appropriately isolated, and proper technique is mandatory in the placement of etchant, primer, and adhesive on the tooth structure (enamel and dentin).
4. May exhibit greater occlusal wear in areas of high occlusal stress or when all of the tooth's occlusal contacts are on the composite material.
5. Have a higher LCTE, resulting in potential marginal percolation if an inadequate bonding technique is used.

Clinical Technique

Initial Clinical Procedures

A complete examination, diagnosis, and treatment plan should be finalized before the patient is scheduled for operative appointments (emergencies excepted). A brief review of the chart (including medical factors), treatment plan, and radiographs should precede each restorative procedure (see Chapter 3).

Local Anesthesia

Local anesthesia usually is required for many operative procedures. Profound anesthesia contributes to a more comfortable



Fig. 8-5 Cleaning operating site with slurry of flour of pumice.

and uninterrupted procedure and usually results in a marked reduction in salivation. These effects of local anesthesia contribute to better operative dentistry, especially when placing bonded restorations.

Preparation of the Operating Site

Prior to beginning any composite restoration, it may be necessary to clean the operating site with a slurry of pumice to remove plaque, pellicle, and superficial stains (Fig. 8-5). Calculus removal with appropriate instruments also may be needed. These steps create a site more receptive to bonding. Prophy pastes containing flavoring agents, glycerin, or fluorides may act as contaminants and should be avoided to prevent a possible conflict with the acid-etch technique.

Shade Selection

Special attention should be given to matching the color of the natural tooth with the composite material. The shade of the tooth should be determined before teeth are subjected to any prolonged drying because dehydrated teeth become lighter in shade as a result of a decrease in translucency. Normally, teeth are predominantly white, with varying degrees of yellow, gray, or orange tints. The color also varies with the translucency, thickness, and distribution of enamel and dentin and the age of the patient. Other factors such as fluorosis, tetracycline staining, and endodontic treatment also affect tooth color. Because of so many variables, it is necessary to match the individual surface of the tooth to be restored. A cross-section of an anterior tooth (Fig. 8-6) illustrates why color zones exist. The incisal third (*w*) (mostly enamel) is lighter and more translucent than the cervical third (*y*) (mostly dentin), whereas the middle third (*x*) is a blend of the incisal and cervical colors.

Most manufacturers provide shade guides for their specific materials, which usually are not interchangeable with materials from other manufacturers. Different manufacturers vary in the numbers of shades available. Most manufacturers also cross-reference their shades with those of the Vita Classical shade guide (Vident, Brea, CA), a universally adopted shade guide. Also, most composite materials are available in enamel and dentin shades and translucent and opaque shades. The

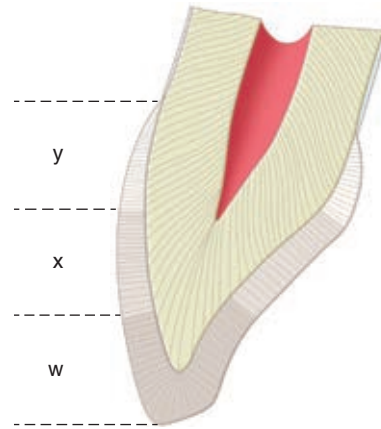


Fig. 8-6 Cross-section of anterior tooth showing three color zones. Incisal third (*w*) is a lighter shade and more translucent than cervical third (*y*), whereas middle third (*x*) represents blending of incisal and cervical thirds.



Fig. 8-7 Shade selection. Shade tab is held near the area to be restored.

translucency of the composite material selected depends on the translucency of the tooth structure in the area of the tooth to be restored. Enamel shades are more translucent and typically are indicated for restoration of translucent areas such as incisal edges. Because of the current popularity of bleaching, many manufacturers also offer composites in very light shades.

Good lighting is necessary for effective color selection. Natural light is preferred for selection of shades. If no windows are present in the operatory to provide natural daylight, color-corrected operating lights or ceiling lights should be available to facilitate accurate shade selection. If the dental operating light is used, it should be moved away to decrease the intensity, allowing the effect of shadows to be seen.

In choosing the appropriate shade, the entire shade guide should be held near the patient's teeth to determine the general color. A specific shade tab is selected and held beside the area of the tooth to be restored (Fig. 8-7). The cervical area of the tooth is usually darker than the incisal area. The selection should be made as rapidly as possible because physiologic limitations of

the color receptors in the eye make it increasingly difficult to distinguish between similar colors after approximately 30 seconds. If more time is needed, the operator should rest the eyes by looking at a blue or violet object for a few seconds.^{53,54} These are the complementary colors of orange and yellow, which are the predominant colors in teeth. By looking at complementary colors, the color receptors in the operator's eye are revitalized and resensitized to perceiving minor variations in yellow and orange. Some dentists request that their assistants make or assist in the shade selection. This practice saves time not only for the dentist but also for the assistant, who, when adequately trained to select shades, may feel a greater sense of responsibility and involvement. Final shade selection can be verified by the patient with the use of a hand mirror.

Most teeth can be matched from manufacturers' basic shades, although some composites from different manufacturers do not match a Vita shade guide the same way. Layering of various shades or opacities also may be required to achieve the desired result.

The shade is recorded in the patient's chart. Because teeth darken with age, a different shade or material may be required if a replacement becomes necessary later. If bleaching (whitening) of teeth is contemplated, it should be done before any restorations are placed (see Chapter 12).

To be more certain of the proper shade selection, a small amount of material of the selected shade can be placed directly on the tooth, close to the area to be restored, and cured. This step may provide a more accurate assessment of the selected shade. If the shade is correct, an explorer is used to remove the cured material from the tooth surface. (A more comprehensive review of factors affecting the esthetic considerations of tooth restoration is presented in Chapter 12.)

Isolation of the Operating Site

Complete instructions for the control of moisture are given in Chapter 7. Isolation for tooth-colored restorations can be accomplished with a rubber dam or cotton rolls, with or without a retraction cord. Regardless of the method, isolation of the area is imperative if the desired bond is to be obtained. Contamination of etched enamel or dentin by saliva results in a significantly decreased bond; likewise, contamination of the composite material during insertion results in degradation of physical properties.

RUBBER DAM

The rubber dam is an excellent means of acquiring access, vision, and moisture control. For proximal surface restorations, the dam should attempt to isolate several teeth mesial and distal to the operating site; this provides adequate access for tooth preparation, application of the matrix, and insertion and finishing of the material. If a lingual approach is indicated for an anterior tooth restoration, it is better to isolate all anterior teeth and include the first premolars to provide more access to the lingual area. For some Class V carious lesions and other facial or lingual defects, it may be necessary to apply a No. 212 retainer (clamp).

If a proximal restoration involves all of the contact area or extends subgingivally, a wedge should be inserted in the gingival embrasure after dam application and before tooth preparation. The wedge (1) depresses interproximal soft tissue, (2) shields the dam and soft tissue from injury during the

operative procedure, and (3) produces separation of teeth to help compensate for the thickness of the matrix that will be used later. Adequate preoperative wedging assists the eventual proximal contact restoration. Wedge insertion should occur whether or not a rubber dam is being used. Usually, the wedge is inserted into the larger facial or lingual embrasure, but this is at the discretion of the operator.

COTTON ROLLS (WITH OR WITHOUT A RETRACTION CORD)

An alternative method of obtaining a dry operating field is the use of cotton roll isolation. When the dentist and the dental assistant are experienced and careful, cotton roll isolation results in an operating site conducive to accomplishing a successful composite (or any other) restoration. A cotton roll is placed in the facial vestibule directly adjacent to the tooth being restored. When restoring a mandibular tooth, a second, preferably larger, cotton roll should be placed adjacent to the tooth in the lingual vestibule.

When the gingival extension of a tooth preparation is to be positioned subgingivally, or near the gingiva, a retraction cord can be used to retract the tissue temporarily and reduce seepage of tissue fluids into the operating site. If hemorrhage control is needed, the cord can be saturated first with a liquid astringent material.

Other Pre-operative Considerations

When restoring posterior proximal surfaces, a wedge should be placed firmly into the gingival embrasure pre-operatively. This wedge causes separation of the operated tooth from the adjacent tooth and creates some space to compensate for the thickness of the matrix used later in the procedure. Pre-operative wedging assists in re-establishing a proximal contact with a composite restoration. A complement for pre-wedging is the use of sectional matrix systems with bitine separating rings (see Chapter 10 for specifics related to sectional matrix systems).

Also, a pre-operative assessment of the occlusion should be made. This assessment should occur before rubber dam placement and should identify not only the occlusal contacts of the tooth or teeth to be restored but also the occlusal contacts on adjacent teeth. Knowing the pre-operative location of occlusal contacts is important in planning the restoration outline form and establishing the proper occlusal contact on the restoration. Remembering where the contacts are located on adjacent teeth provides guidance in knowing when the restoration contacts are correctly adjusted.

Tooth Preparation and Restoration for Composite Restorations

Detailed descriptions of specific composite tooth preparations and restorations are presented in Chapters 5, 9, 10, and 12. The reader is referred to these chapters for specific clinical procedures involved in the preparation for all classes of composite restorations.

Repairing Composite Restorations

If a patient presents with a composite restoration that has a localized defect, a repair usually can be made. Easily accessible

areas may be roughened with a diamond stone; the area is etched; an appropriate enamel/dentin adhesive is applied; and finally the composite is inserted, contoured, and polished. If the defect is not easily accessible, a tooth preparation must be created that exposes the defective area, and a matrix may be necessary; the adhesive and the composite are then placed.

If a void is detected immediately after insertion of a composite restoration, but before contouring is initiated, more composite can be added directly to the void area. These materials bond because the void area has an oxygen-inhibited surface layer that permits composite additions. If any contouring has occurred, however, the oxygen-inhibited layer may have been removed or altered, and the area must be re-etched and the adhesive placed before adding more composite.

Common Problems: Causes and Potential Solutions

This section lists the causes of common problems associated with some composite restorations and potential solutions to those problems. The subsequent chapters on techniques refer back to these because they describe specific composite procedures.

Poor Isolation of the Operating Area

Causes of poor isolation of the operating area include the following:

- No rubber dam or leaking rubber dam
- Inadequate cotton roll isolation
- Careless technique
- Preparation so deep gingivally that the operating area cannot be isolated

Potential solutions for poor isolation of the operating area include the following:

- Use of better technique
- Use of a matrix to help isolation
- Use of a restorative material other than composite that does not require bonding
- Repeating bonding procedures (if the area is contaminated)

White Line or Halo Adjacent to the Enamel Margin

The following factors cause micro-fracture of marginal enamel:

- Traumatic contouring or finishing techniques
- Inadequate etching and bonding of that area
- High-intensity light-curing, resulting in excessive polymerization stresses

Potential solutions are as follows:

- Re-etching, priming, and bonding the area
- Conservatively removing the defect and re-restoring

- Using atraumatic finishing techniques (e.g., light intermittent pressure)
- Using soft-start polymerization techniques
- Leaving as is and monitoring for leakage

Voids

Causes of voids include the following:

- Mixing of self-cured composites (however, self-cured materials are rarely used today)
- Spaces left between increments during insertion
- Tacky composite pulling away from the preparation during insertion

Potential solutions are as follows:

- Using a more careful technique
- Repairing marginal voids by preparing the area and re-restoring

Weak or Missing Proximal Contacts (Class II, III, and IV)

Causes of weak and missing proximal contacts are as follows:

- Inadequately contoured matrix band
- Inadequate wedging, preoperatively and during the composite insertion
- Matrix band movement during composite insertion or matrix band not in direct contact with the adjacent proximal surface
- A circumferential matrix being used when restoring only one contact
- Tacky composite pulling away from matrix contact area during insertion
- Matrix band too thick

Potential solutions include the following:

- Properly contouring the matrix band
- Having the matrix in contact with the adjacent tooth
- Using a firm preoperative and insertion wedging technique
- Using a matrix system that places the matrix only around the proximal surface to be restored
- Using specially designed, triangular light-curing tips to hold the matrix against the adjacent tooth while curing
- Using a hand instrument to hold the matrix against the adjacent tooth while curing the incremental placements of composite
- Being careful with insertion technique

Inaccurate Shade

Causes of an incorrect shade include the following:

- Inappropriate operator lighting while selecting the shade
- Selection of shade after the tooth is dried
- Shade tab not matching the actual composite shade
- Wrong shade selected

Potential solutions are as follows:

- Using natural light when selecting shade, if possible
- Selecting the shade before isolating the tooth
- Pre-operatively placing some of the selected shade on the tooth and curing (then removing)
- Not shining the operating light directly on the area during shade selection
- Understanding the typical zones of different shades for natural teeth

Poor Retention

Causes of poor retention include the following:

- Inadequate preparation form
- Contamination of the operating area
- Poor bonding technique
- Use of incompatible bonding materials

Potential solutions include the following:

- Preparing the tooth with appropriate bevels or flares and secondary retention feature, when necessary
- Keeping the area isolated while bonding
- Following the manufacturer's directions strictly

Contouring and Finishing Problems

Causes of contouring or finishing problems are as follows:

- Injuring adjacent unprepared tooth structure
- Over-contouring the restoration
- Under-contouring the restoration
- Ditching cementum
- Creating inadequate anatomic tooth form
- Dealing with difficult-to-see margins

Potential solutions include the following:

- Being careful with the use of rotary instruments to avoid adversely affecting the structure of the adjacent tooth or teeth
- Having a proper matrix with appropriate axial and line angle contours
- Creating embrasures to match the adjacent tooth embrasure form
- Not using rotary instruments that leave roughened surfaces
- Using a properly shaped contouring instrument for the area being contoured
- Remembering the outline form of the preparation
- Viewing the restoration from all angles as it is contoured

Controversial Issues

Because of the dynamic nature of the practice of operative dentistry, changes are occurring constantly. As new products and techniques are developed, their effectiveness cannot be assessed until they have been tested by appropriately designed

research protocols. Many such developments are taking place at any time, and many of these developments do not have the necessary documentation to prove their effectiveness, even though they receive positive publicity.

Liners and Bases Under Composite Restorations

Various materials have been promoted for routine use as liners or bases under composite restorations. These include RMGIs and flowable composites. Proponents of this approach do not promote these materials for pulp protection in the traditional sense but as materials that provide a better seal for composite restorations when extended onto the root surface. RMGI materials may improve the seal in root-surface areas, which would protect the pulp and render surrounding tooth structure more resistant to recurrent caries and act as stress breakers, which may resist polymerization or flexural stresses placed on the composite restoration.^{45-51,55,56}

Retention in Class V Root-Surface Preparations

This book recommends the use of retention grooves in composite tooth preparations when the operator believes that an additional retention form is necessary. It is likely, however, that with the bonding systems available, retention groove placement is usually not necessary.

Wear Problems

This book recommends that occlusal factors be considered when selecting composite as a restorative material, especially in clinical situations when heavy occlusal forces are anticipated or when all of the occlusal contacts will be on the restoration only. The wear resistance of some composites is similar to that of amalgam, however, and composite restorations should be successful for most occlusal patterns where occlusal contacts are shared with the tooth structure.

Significance of Gap Formation

As discussed previously, the gap formation that usually occurs when the composite restoration is extended onto the root surface may not have any long-term clinical effects. With the two vectors of the defect being primarily resin or composite, recurrent caries may not be a problem. How long the exposed hybridized resin layer on the root stays intact is unknown, however, and if it deteriorates in a short time, the area is exposed to risk for caries. Use of an RMGI liner material may reduce the effect of gap formation by rendering the surrounding tooth structure more resistant to recurrent caries.⁴⁵⁻⁵¹

Summary

The use of composite restorations is increasing because of the benefits accrued from adhesive bonding to tooth structure, esthetic qualities, and almost universal clinical use. When done properly, a composite restoration can provide excellent service for many years. When used in posterior teeth, however, composite restorations are more difficult and sensitive to the

operator's technique and ability than are amalgam restorations. To achieve the bond that provides the desired benefits, the operating site must be free from contamination, and the material and bonding technique must be used properly. Subsequent chapters provide additional information about the specific uses of composite as restorative material.

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Class III, IV, and V Direct Composite and Glass Ionomer Restorations

André V. Ritter, Ricardo Walter, Theodore M. Roberson

Class III, IV, and V Direct Composite Restorations

This chapter presents information about Class III, IV, and V direct composite restorations (Fig. 9-1). It also presents information about any differences in these classes of restorations when a glass ionomer type of material is used for the restoration.

Pertinent Material Qualities and Properties

The specific material qualities and properties that make composite the best material for most Class III, IV, and V restorations relate mainly to esthetics. Other qualities include adequate strength and the benefits of bonding to tooth structure, often resulting in removal of less tooth structure during preparation.

Indications

Class III, IV, and V direct composite restorations are mainly indicated in the restoration of caries lesions (Class III, IV, and V), anterior enamel and/or dentin crown fractures (Class IV), and non-caries cervical defects (Class V). Almost all Class III and IV restorations are appropriately restored with composite. Many Class V restorations that are in esthetically prominent areas also are appropriately restored with composite or other tooth-colored materials. In all of these instances, the operating area must be isolated adequately to attain an effective bond. Also, composites perform best when all margins of the tooth preparation are in enamel.

Contraindications

The main contraindication for use of composite for Class III, IV, and V restorations is an operating area that cannot be adequately isolated.¹⁻³ Class V composite restorations also may

have their durability compromised when the restoration extends onto the root surface (no marginal enamel). Because bonding to dentin is not as predictable or durable as bonding to enamel, in such situations, the dentin gingival margin is more prone to microgap formation and marginal microleakage than the enamel coronal margin.⁴⁻⁷ Any extension onto the root surface requires the most meticulous efforts of the operator to best ensure a successful, long-lasting restoration.

Advantages and Disadvantages

The advantages and disadvantages of using composite for Class III, IV, and V restorations are the same as the advantages and disadvantages presented and discussed in Chapter 8.

Clinical Technique for Class III Direct Composite Restorations

Initial Clinical Procedures

Chapters 7 and 8 presented information about procedures necessary before beginning the restoration: (1) Anesthesia is usually necessary for patient comfort and helps decrease salivary flow during the procedure; (2) occlusal assessments should be made to determine the tooth preparation design and to properly adjust the restoration's function; (3) the composite shade must be selected before the tooth dehydrates and concomitantly lightens; (4) the area must be isolated to permit effective bonding; (5) if the restoration involves the proximal contact, inserting a wedge in the area beforehand may assist in the re-establishment of the proximal contact with composite.

Tooth Preparation

In general, the tooth preparation for a Class III direct composite restoration involves (1) obtaining access to the defect



Fig. 9-1 Direct composite restorations before and after. **A** and **B**, Class III. **C** and **D**, Class IV. **E** and **F**, Class V.

(caries, fracture, non-cariouse defect), (2) removing faulty structures (caries, defective dentin and enamel, defective restoration, base material), and (3) creating the convenience form for the restoration (Fig. 9-2). In most cases, an enamel bevel is used on the facial cavosurface margins to increase the surface area for bonding, and to provide a gradual transition from the restoration to the surrounding tooth structure for esthetics. Obtaining access to the defect may include removal of sound enamel to access carious dentin. The extension of the preparation is, therefore, ultimately dictated by the extension of the fault or defect. It is usually not necessary to reduce sound tooth structure to provide “bulk for strength” or to provide conventional retention and resistance forms.

Because of the adequate bond of composite to enamel and dentin, most Class III composite restorations are retained almost exclusively by bonding, and no additional preparation retention form is necessary. Using diamond rotary instruments for tooth preparation leaves the surfaces rougher than when carbide burs are used, increasing the surface area and the micromechanical retention. Diamonds also leave a thickened smear layer, however.⁸⁻¹⁰ Self-etch bonding systems can be negatively affected by thick smear layers because of their mildly acidic nature and the resultant difficulty in penetrating thick smear layers.¹¹ The selection of the rotary preparation instrument is operator dependent, consistent with appropriate knowledge and technique. In the rare cases where additional retention form is needed, it can be achieved either by

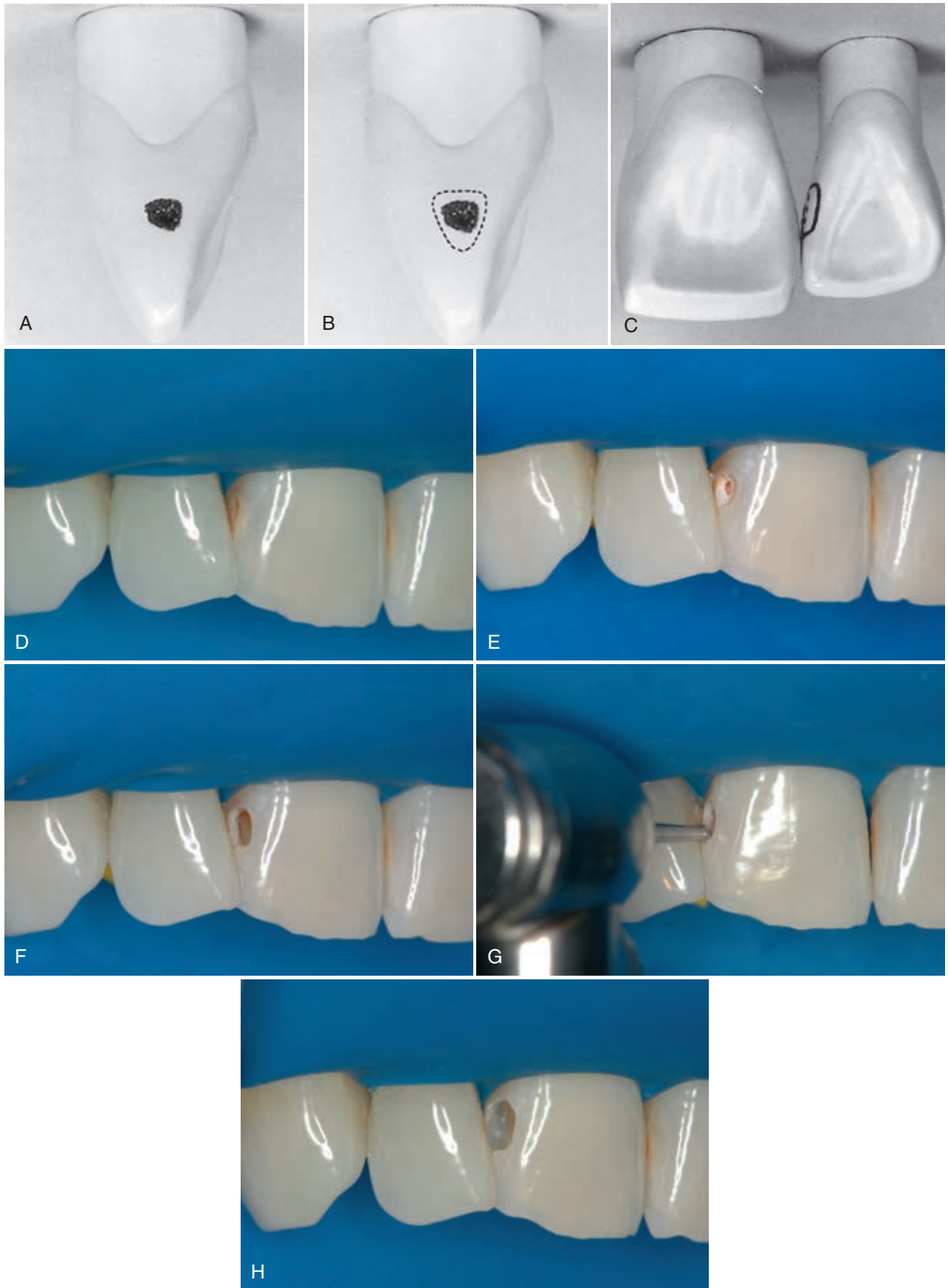


Fig. 9-2 **A**, Small proximal caries lesion on the mesial surface of a maxillary lateral incisor. **B**, Dotted line indicates normal outline form dictated by shape of the caries lesion. **C**, Extension (convenience form) required for preparing and restoring preparation from lingual approach when teeth are in normal alignment. **D–H**, Clinical case showing conservative Class III preparation, facial approach. **D**, Facial view of a caries lesion on the distal surface of the maxillary central incisor. **E–F**, Obtaining access to carious dentin. **G**, Infected dentin is removed with round bur. **H**, Completed caries excavation.

increasing the surface area with a wider enamel bevel or by adding retentive features in the preparation internal walls.

When a proximal surface of an anterior tooth is to be restored, and a choice between facial or lingual entry into the tooth is available, the lingual approach is preferable. A small caries lesion should be treated from the lingual approach unless such an approach would necessitate excessive removal of the tooth structure, such as in instances of irregular alignment of teeth or facial positioning of the lesion. The advantages of restoring the proximal lesion using a *lingual approach* are as follows:

1. The facial enamel is conserved for enhanced esthetics. (Some unsupported, but non-friable, enamel may be left on the facial wall of the preparation.)
2. Shade matching of the composite is less critical.
3. Discoloration or deterioration of the restoration is less visible.

Indications for a *facial approach* include the following:

1. The caries lesion is positioned facially, and facial access would significantly conserve the tooth structure.
2. Teeth are irregularly aligned, and facial access would significantly conserve the tooth structure.

3. An extensive caries lesion extends onto the facial surface.
4. A faulty restoration that originally was placed from the facial approach needs to be replaced.

When the facial and the lingual surfaces are involved, the approach that provides the best access for instrumentation should be used.

The preparation is initiated from a lingual approach (if possible) by using a round carbide bur or diamond instrument of a size compatible with the extent of the lesion. Before contacting the tooth, the bur is positioned for entry and rotated at high speed using air-water spray. The point of entry is located within the incisogingival dimension of the lesion or defect and as close to the adjacent tooth as possible without contacting it (Fig. 9-3, A). The cutting instrument is directed perpendicular to the enamel surface but at an entry angle that places the neck portion of the bur or diamond instrument as far into the embrasure (next to the adjacent tooth) as possible; light pressure and intermittent cutting (brush stroke) are used to gain access into the preparation. Incorrect entry overextends the lingual outline and unnecessarily weakens the tooth (see Fig. 9-3, B and C).

The same instrument may be used to enlarge the initial access opening sufficiently to permit, in subsequent steps,

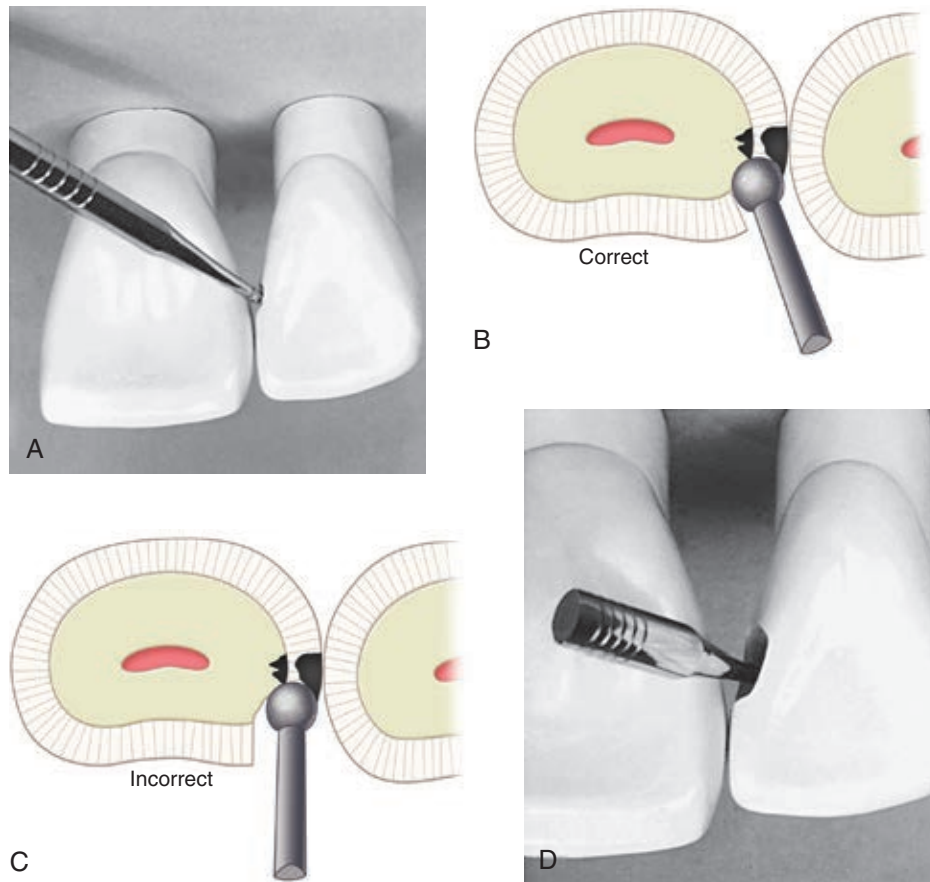


Fig. 9-3 Beginning Class III tooth preparation (lingual approach). **A**, The bur or diamond is held perpendicular to the enamel surface, and an initial opening is made close to the adjacent tooth at the incisogingival level of the caries. **B**, The correct angle of entry is parallel to the enamel rods on the mesiolingual angle of the tooth. **C**, Incorrect entry overextends the lingual outline. **D**, The same bur or diamond is used to enlarge opening for caries removal and convenience form while establishing the initial axial wall depth.



Fig. 9-4 A small, scoop-shaped Class III tooth preparation.

caries removal, completion of the preparation, and insertion of the restorative material (see Fig. 9-3, *D*). No effort is made to prepare the walls that are perpendicular to the enamel surface; for small preparations, the walls may diverge externally from the axial depth in a scooped shape, resulting in a beveled marginal design and conservation of internal tooth structure (Fig. 9-4). For larger preparations, the initial tooth preparation still is as conservative as possible, but the preparation walls may not be as divergent from the axial wall. Subsequent beveling or flaring of accessible enamel areas may be required. Despite the size of the lesion, the objective of the initial tooth preparation is the same: to prepare the tooth as conservatively as possible by extending the outline form just enough to include the peripheral extent of the lesion. Sometimes, the incorporation of an enamel bevel also may be used to extend the final outline form to include the caries lesion (Fig. 9-5). If possible, the outline form should not (1) include the entire proximal contact area, (2) extend onto the facial surface, or (3) be extended subgingivally. Extensions should be minimal, including only the tooth structure that is compromised by the extent of the caries lesion or defect. Some undermined enamel can be left in nonstress areas, but very friable enamel at the margins should be removed.

The extension axially also is dictated by the extent of the fault or caries lesion and usually is not uniform in depth. As noted earlier, most initial composite restorations (primary caries) use a scooped or concave preparation design (Fig. 9-6, *A* and *B*). Because a caries lesion that requires a restoration usually extends into dentin, many Class III preparations are done to an initial axial wall depth of 0.2 mm into dentin (Fig. 9-7). No attempt is made, however, to prepare distinct or uniform axial preparation walls; rather, the objective is to include only the infected carious area as conservatively as possible by “scooping out” the defective tooth structure. Additional caries excavation (deeper than the initial stage of 0.2 mm pulpal to the dentinoenamel junction [DEJ]) or marginal refinement may be necessary later.

The axial wall must provide access for the removal of infected dentin and the application of the adhesive and composite. If the preparation outline extends gingivally onto the root surface, the gingival floor should form a cavosurface margin of 90 degrees, and the depth of the gingivoaxial line angle should be not more than 0.75 mm at this initial stage of

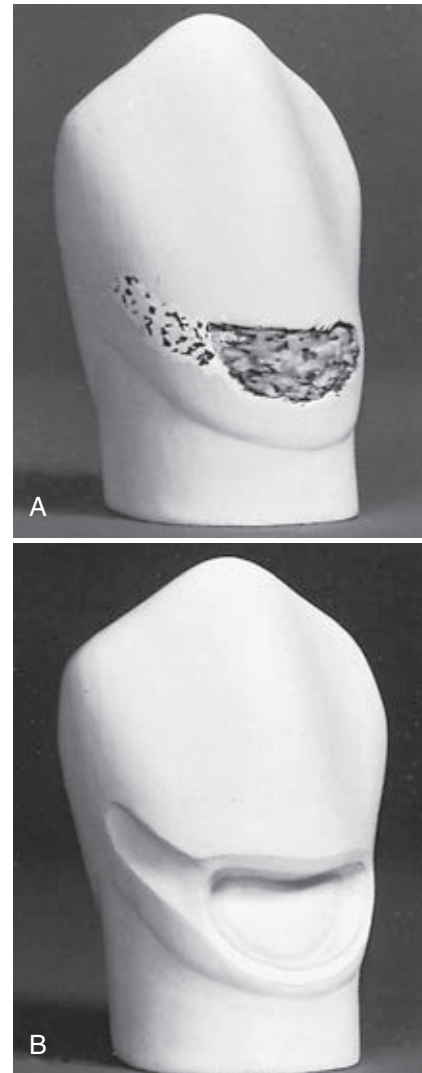


Fig. 9-5 **A**, Decalcified area extending mesially from cavitated Class V lesion. **B**, Completed Class V preparation with conservative mesial extension.

tooth preparation. The external walls are prepared perpendicular to the root surface. In this area of the tooth, apical of the cemento-enamel junction (CEJ), the external walls are composed entirely of dentin and cementum. Another consideration could be the use of a resin-modified glass ionomer (RMGI) liner on the root surface portion before composite placement to help maintain the seal.¹²⁻¹⁵

When completed, the initial tooth preparation extends the outline form to include the entire fault unless it is anticipated that the incorporation of an additional enamel bevel would complete that objective. Small preparations typically have a beveled marginal configuration from the initial tooth preparation.

Little may need to be done in the final tooth preparation stage for these preparations. Final tooth preparation steps for a Class III direct composite restoration are, when indicated, (1) removal of infected dentin; (2) pulp protection; (3) bevel placement on accessible enamel margins; and (4) final procedures of cleaning and inspecting. All remaining infected

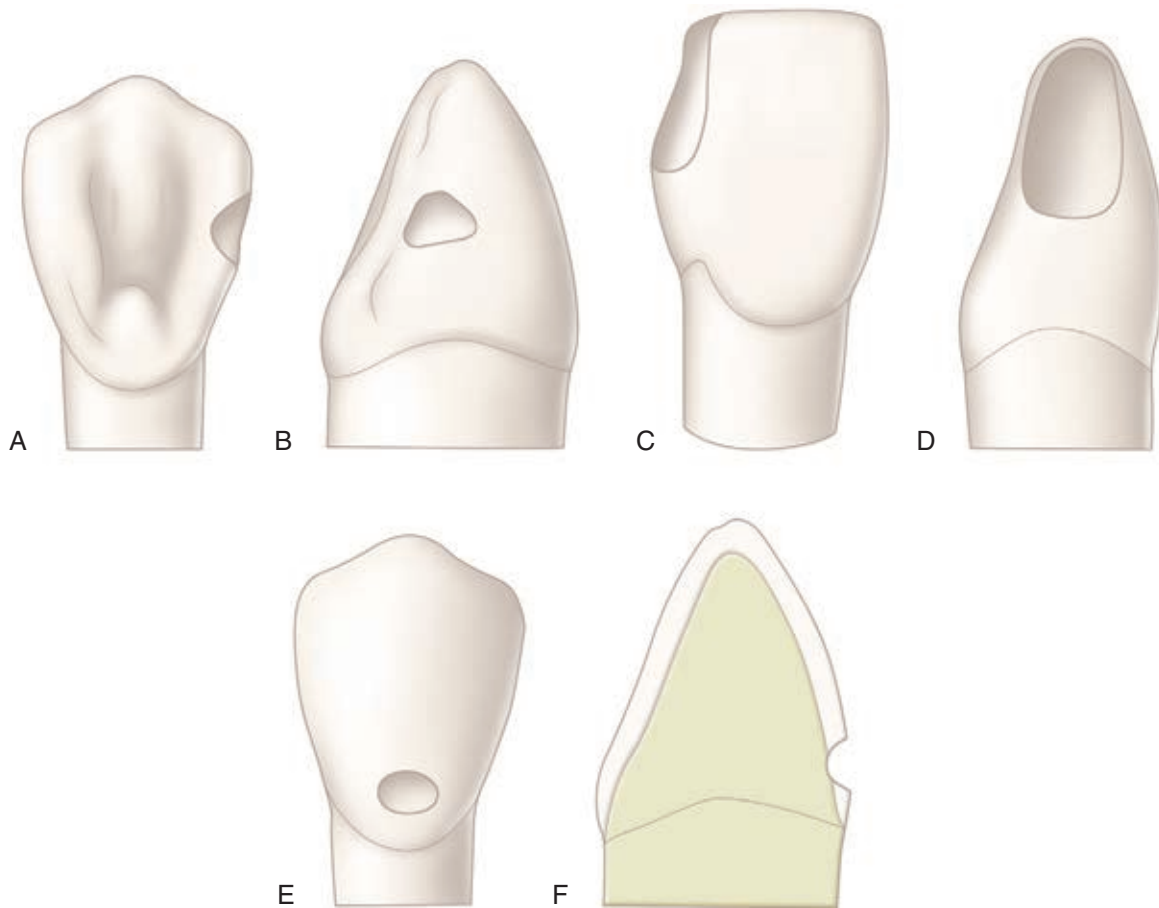


Fig. 9-6 Preparation designs for Class III (A and B), Class IV (C and D), and Class V (E and F) initial composite restorations (primary caries).

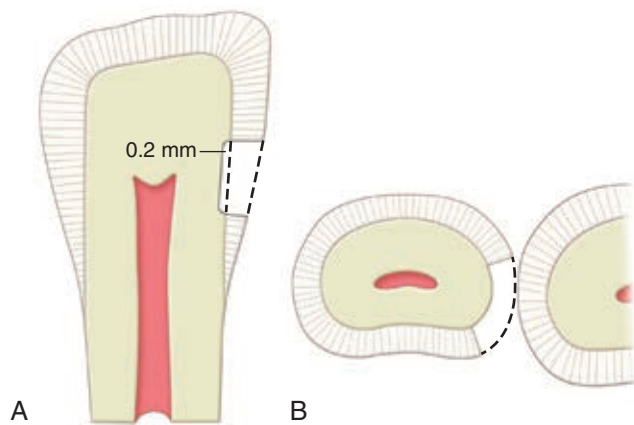


Fig. 9-7 Ideal initial axial wall preparation depth. **A**, Incisogingival section showing axial wall 0.2 mm into dentin. **B**, Faciolingual section showing facial extension and axial wall following the contour of the tooth.

dentin is removed using round burs, small spoon excavators, or both. Particular care must be exercised not to weaken the walls or incisal angles that are subject to masticatory forces.

Larger preparations may require additional beveling of the accessible enamel walls to enhance retention by bonding (Figs. 9-8, A and B, and 9-9). These enamel margins are

beveled with a flame-shaped or round diamond instrument. The bevel is prepared by creating a 45-degree angle to the external surface and to a width of 0.5 to 2.0 mm, depending on the size of the preparation, location of the margin, and esthetic requirements of the restoration (Fig. 9-10; see Fig. 9-9). If the gingival floor has been extended gingivally to a position where the remaining enamel thickness is minimal or nonexistent, the bevel is omitted from this area to preserve the remaining enamel margin or maintain 90-degree cavosurface margin in dentin. Likewise, a bevel on the lingual enamel margin of a maxillary incisor may be precluded because of the presence of occlusal contact.

Remaining old restorative material on the axial wall should be removed if any of the following conditions are present: (1) the old material is amalgam, and its color would negatively affect the color of the new restoration; (2) clinical or radiographic evidence of caries under the old material is present; (3) the tooth pulp was symptomatic preoperatively; (4) the periphery of the remaining restorative material is not intact (i.e., some breach has occurred in the junction of the material with the adjacent tooth structure, which may indicate caries under the material); or (5) the use of the underlying dentin is necessary to effect a stronger bond for retention purposes. If none of these conditions is present, the operator may elect to leave the remaining restorative material, rather than risk unnecessary excavation nearer to the pulp and subsequent irritation or exposure of the pulp. A RMGI base is applied only

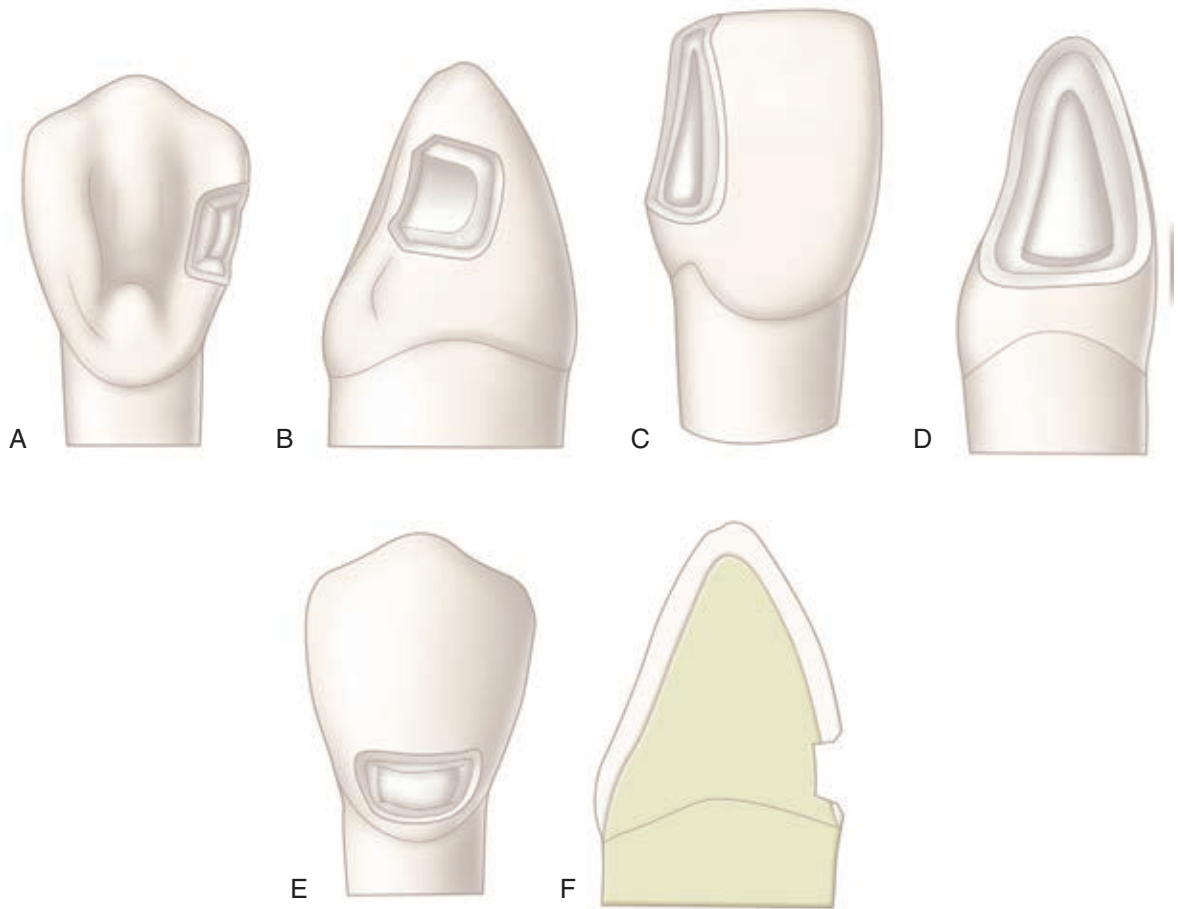


Fig. 9-8 Larger preparation designs for Class III (A and B), Class IV (C and D), and Class V (E and F) restorations.

if the remaining dentin thickness is judged to be less than 1.5 mm and in the deepest portions of the preparation.¹⁶ Calcium hydroxide liners are used only in cases of pulp exposures or near-exposures as a direct pulp-capping material.¹⁶ If used, the calcium hydroxide liner should always be covered with a RMGI base, sealing the area and preventing the etchant (applied later) from dissolving the liner.^{16,17}

When replacing an existing failed Class III restoration, the tooth preparation for the replacement restoration normally will have the same general form of the previous tooth preparation. As discussed previously, usually retention is obtained by bonding to enamel and dentin, and no groove retention is necessary. When replacing a large restoration or restoring a large Class III lesion, however, the operator may decide that retention form should be enhanced by placing groove (at gingival) or cove (at incisal) retention features in addition to bonding.

For Class III direct composite preparations with *facial access*, with a few exceptions, the same stages and steps of tooth preparation are followed as for lingual access. The procedure is simplified because direct vision is used (Fig. 9-11).

It is expeditious to prepare and restore approximating caries lesions or faulty restorations on adjacent teeth at the same appointment. Usually, one of the preparations is larger (more extended outline form) than the other. When the larger outline form is developed first, the second preparation usually can be more conservative because of the improved access

provided by the larger preparation. The reverse order would be followed when the restorative material is inserted.

A large Class III lesion on the distal surface of a maxillary right central incisor is shown in Fig. 9-12, A. The rubber dam is placed after the anesthetic has been administered and the shade has been selected. A wedge is inserted in the gingival embrasure to depress the rubber dam and underlying soft tissue, improving gingival access (see Fig. 9-12, B). Using a carbide bur or diamond instrument rotating at high speed and with air-water spray, the outline form is prepared with appropriate extension and the initial, limited pulpal depth previously described in the lingual approach preparation (see Fig. 9-12, C). Caries removal with a spoon excavator and an explorer is shown (see Fig. 9-11, D and E). Some undermined enamel can be left if it is not in a high-stress area.

When a proximal caries lesion or defective restoration extends onto the facial *and* the lingual surfaces, access may be accomplished from either a facial approach or a lingual approach. An example of an extensive Class III initial tooth preparation that allows such choice is illustrated in Fig. 9-13.

Restorative Technique

Matrix Application

A matrix is a device that is applied to a prepared tooth before the insertion of the restorative material. Its purposes include (1) confining the restorative material excess and (2) assisting

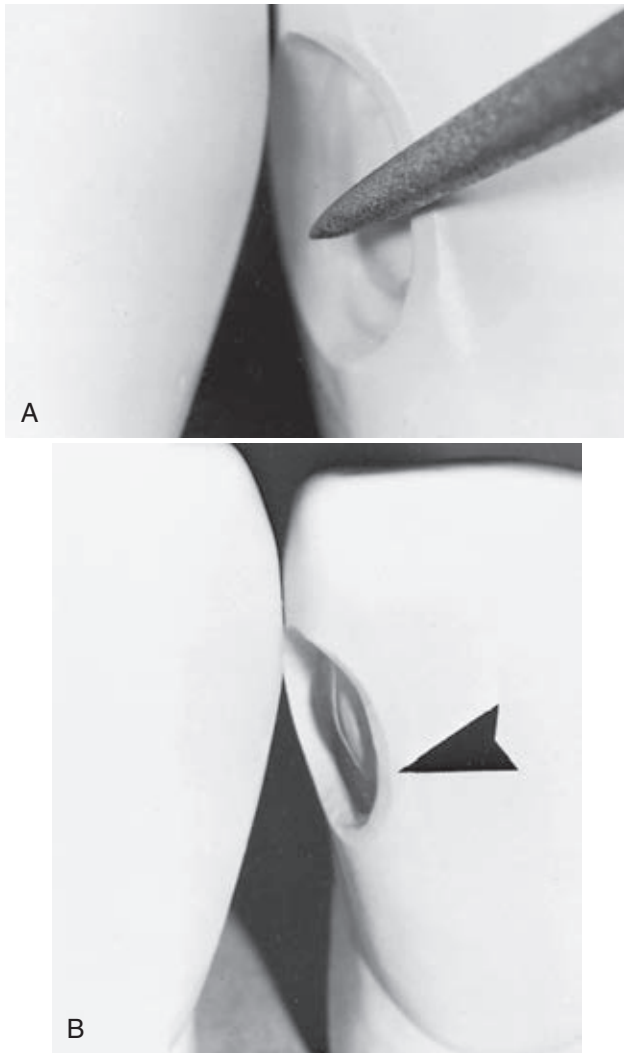


Fig. 9-9 Large Class III tooth preparation. **A**, Beveling. The cavosurface bevel is prepared with a flame-shaped or round diamond, resulting in an angle approximately 45 degrees to the external tooth surface. **B**, Completed cavosurface bevel (*arrowhead*).

in the development of the appropriate axial tooth contours. The matrix usually is applied and stabilized with a wedge before application of the adhesive because it helps contain the adhesive components to the prepared tooth. Care must be taken, however, to avoid pooling of adhesive adjacent to the matrix.

A properly contoured and wedged matrix is a prerequisite for a restoration involving the entire proximal contact area, unless the adjacent tooth is missing in which case the restoration can be completed using a free-hand final approach. When correctly used, not only would a matrix aid in placing and contouring the composite restorative material, but it may also reduce the amount of excess material, thus minimizing the finishing time.

A properly contoured thin Mylar strip matrix is used for most Class III and IV preparations. Because the proximal surface of a tooth is usually convex incisogingivally and the strip may be flat, it is necessary to shape the strip to conform to the desired tooth contour. One way to contour a Mylar strip is by drawing it along a hard, rounded, object (*Fig. 9-14*). The

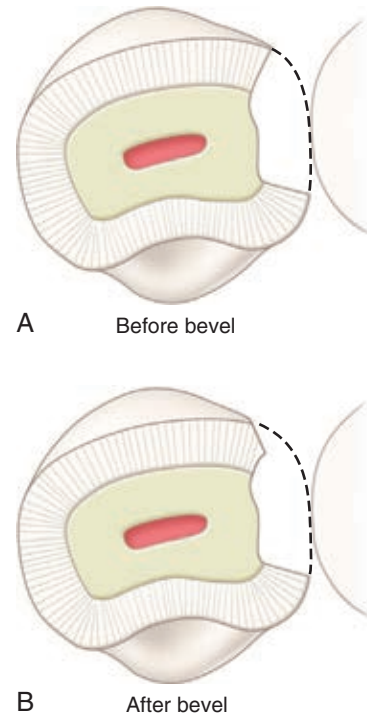


Fig. 9-10 Cross-section of facial approach Class III before (*A*) and after (*B*) 45-degree cavosurface bevel on the facial margin.



Fig. 9-11 Completed Class III tooth preparation (facial approach), with the bevel marked.

amount of convexity placed in the strip depends on the size and contour of the anticipated restoration. Several pulls of the strip with heavy pressure across the rounded end of the operating pliers may be required to obtain enough convexity. The contoured strip is positioned between teeth so that the convex area conforms to the desired tooth contour (*Fig. 9-15, A*). The matrix strip is extended at least 1 mm beyond the prepared gingival and incisal margins. Sometimes, the strip does not slide through or is distorted by a tight contact or preparation margin. In such instances, a wedge is lightly positioned in the gingival embrasure before the strip is inserted. Care must be taken not to injure the interproximal tissues and induce bleeding. When the strip is past the binding area, it may be necessary to loosen the wedge to place the strip past the gingival

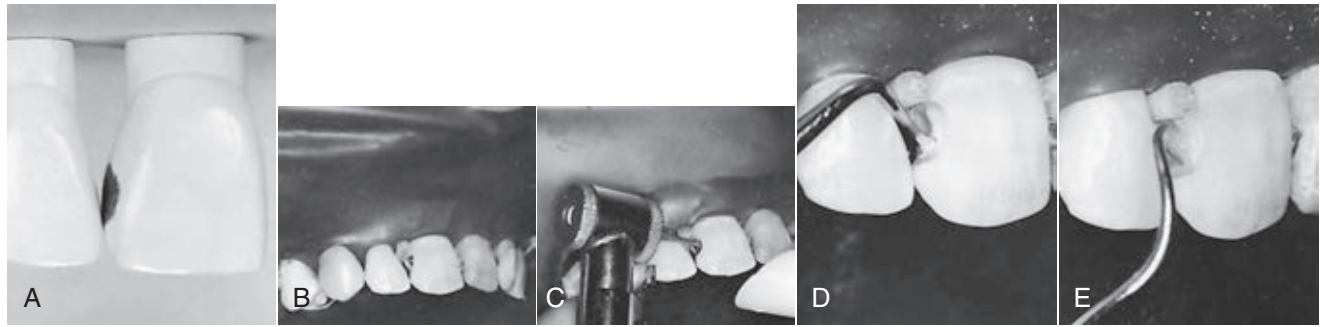


Fig. 9-12 Class III initial preparation (facial approach). **A**, Large proximal caries with facial involvement. **B**, Isolated area of operation. **C**, Entry and extension with No. 2 bur or diamond. **D**, Caries removal with spoon excavator. **E**, Explorer point removes caries at the dentinoenamel junction (DEJ).

margin (between the wedge and margin). Then the wedge is re-inserted tightly (see Fig. 9-15, B).

A wedge is needed at the gingival margin to (1) hold the Mylar strip in position, (2) provide slight separation of the teeth, and (3) prevent a gingival overhang of the composite material. A wedge must be used to separate teeth sufficiently to compensate for the thickness of the matrix if the completed restoration is to contact the adjacent tooth properly.

Several types of commercial wedges are available in assorted sizes. A triangular-shaped wedge (in cross-section) is indicated for preparations with margins that are deep in the gingival sulcus. An end of a round wooden toothpick usually is an excellent wedge for preparations with margins coronal to the gingival sulcus. The wedge is kept as short as possible to avoid conflict with access during insertion of the restorative material.

The wedge is placed using No. 110 pliers from the facial approach for lingual access preparations, and vice versa for facial access, just apical to the gingival margin. When isolation is accomplished with the rubber dam, wedge placement may be aided by a small amount of water-soluble lubricant on the tip of the wedge. The rubber dam is first stretched gingivally (on the side from which the wedge is inserted), then released gradually during wedge insertion (Fig. 9-16). Subsequently, a trial opening and closing of the matrix strip is helpful. It must open enough for access to insert the adhesive and composite and close sufficiently to ensure a proper contour. It may be necessary to shorten the wedge or insert it from the opposite embrasure to optimize access.

Placement of the Adhesive

Adhesive placement steps are accomplished with strict adherence to the manufacturer's directions for the particular adhesive being used.

The usual technique for adhesive placement when using an etch-and-rinse adhesive is as follows: First, the proximal surface of the adjacent unprepared tooth should be protected from inadvertent etching by placing a Mylar strip, if not yet applied, or a Teflon tape. Then, phosphoric acid gel etchant is applied to all of the prepared tooth structure, approximately 0.5 mm beyond the prepared margins onto the adjacent unprepared tooth. The etchant typically is left undisturbed for 15 seconds. The area is rinsed thoroughly to remove the etchant. If dentin is exposed, rather than air-dry the rinsed

area, it may be better to use a damp cotton pellet, a foam pellet, or a disposable brush to remove the excess water. If the area is dried, it can be re-moistened with water, a re-wetting agent, or a desensitizing agent such as glutaraldehyde-containing desensitizers. Glutaraldehyde-containing desensitizers have been shown to have no adverse effects on bond strength and have been shown to reduce postoperative sensitivity by reducing dentin permeability.¹⁸⁻²¹ Ultimately, the dentin surface should appear moist, as evidenced by a glistening appearance. Over-drying or pooling of excess water should be avoided.

If the bonding system combines the primer and the adhesive, as in a one-bottle etch-and-rinse adhesive, the solution is applied next on all of the tooth structure that has been etched. Every effort should be made to prevent the adhesive from pooling in remote areas of the preparation or against the Mylar strip, if used (Fig. 9-17, A). When applied, the adhesive is air-dried to evaporate any solvent (acetone, alcohol, or water), then light-activated, as directed. Because these materials are resin-based, they generally exhibit an oxygen-inhibited layer on the surface after polymerization. The composite material bonds directly to the polymerized adhesive, unless the oxygen-inhibited layer is contaminated. The application of the adhesive and the composite should occur in a timely manner.

Insertion and Light-Activation of the Composite

The composite bonds chemically with the adhesive, forming a strong attachment between the tooth and the restorative material. Although self-cured composites are available, they are very rarely used today for Class III direct composite restorations. The following paragraphs provide the restorative technique for light-activated composites.

The mesial surface of a maxillary left lateral incisor is used to illustrate facial insertion of a light-activated composite (see Fig. 9-17, A through C). The matrix strip is contoured, placed interproximally, and wedged at the gingival margin. The lingual aspect of the strip is secured with the index finger, while the thumb reflects the facial portion out of the way (see Fig. 9-17). Light-activated materials do not have to be mixed and are not dispensed until ready for use.

The composite is inserted by a hand instrument or syringe. Light-activated composites are usually available in two forms: (1) a threaded syringe for manual dispensing and hand instrument insertion or (2) a self-contained compule that is placed

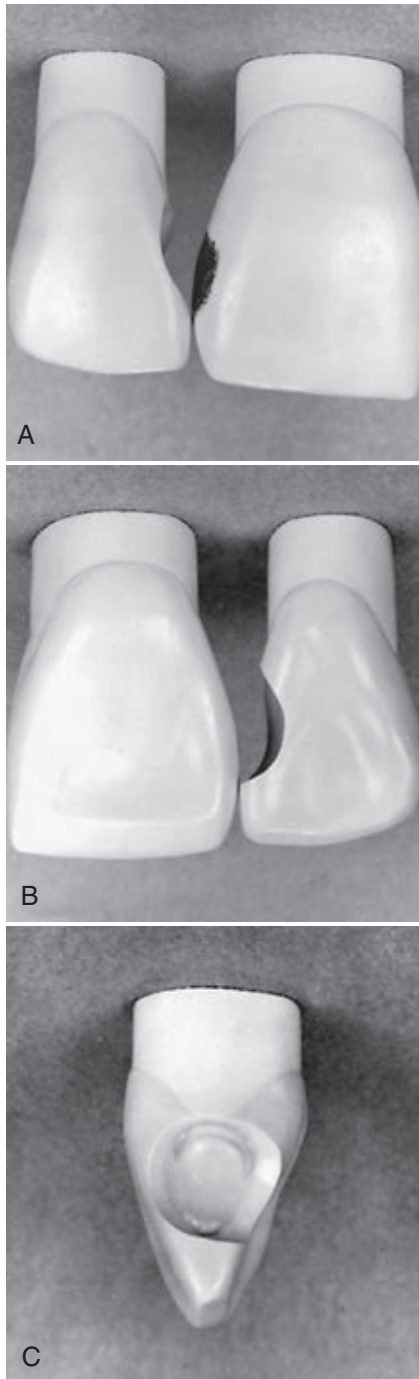


Fig. 9-13 Large Class III tooth preparation extending onto root surface. **A**, Facial view. **B**, Lingual view. **C**, Mesial view showing gingival and incisal retention, which is only used when deemed necessary to increase retention. The tooth preparation is now ready for beveling of the enamel walls.

into an injection syringe for dispensing or insertion. If a threaded syringe is used, a hand instrument is used to cut off an amount of composite that would restore the preparation onto a paper pad or plastic container. The composite also can be dispensed from the compule, if so desired. The composite should be protected from ambient light to prevent premature polymerization. Likewise, the threaded syringe (or compule

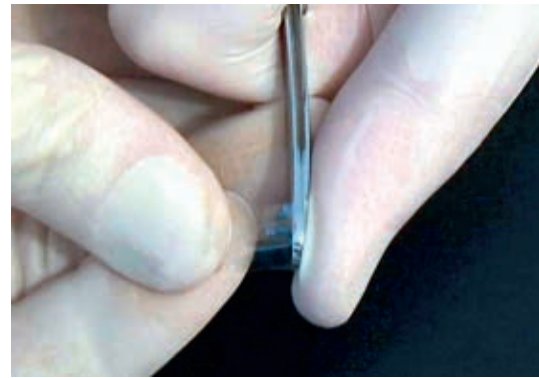


Fig. 9-14 Contouring Mylar strip matrix. (Courtesy Aldridge D. Wilder, DDS.)

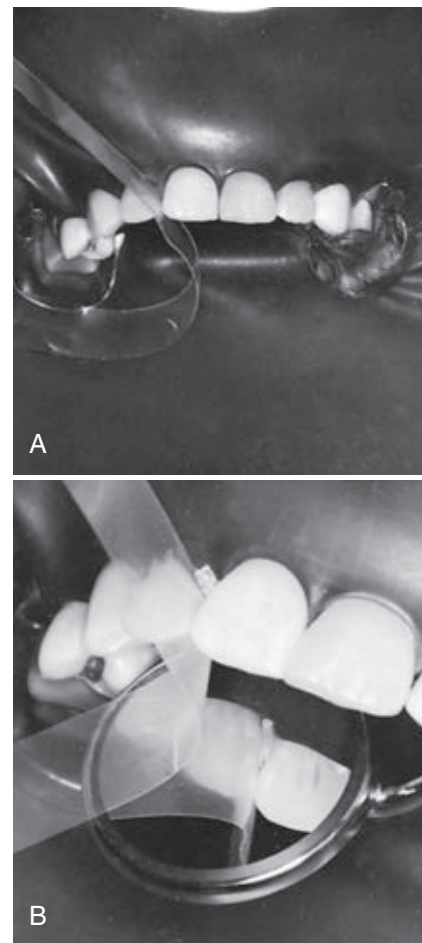


Fig. 9-15 Inserting and wedging Mylar strip matrix. **A**, Strip with concave area next to the preparation is positioned between teeth. **B**, Strip in position and wedge inserted. The length of the Mylar strip can be reduced, as needed.

tip) should be recapped immediately to prevent setting of the composite at the end of the syringe. The composite is picked up with the blade end of the hand instrument and wiped into the tooth preparation. If the composite is to be injected directly into the preparation, the selected compule is placed into the injection syringe, and the composite is injected directly into the preparation. The operator uses the plunger

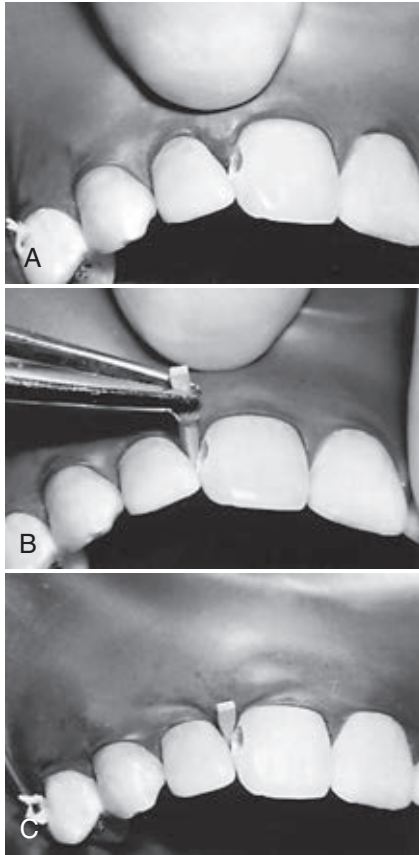


Fig. 9-16 Using a triangular wood wedge to expose gingival margin of large proximal preparation. **A**, The dam is stretched facially and gingivally with the fingertip. **B**, Insertion of wedge (the dam is released during wedge insertion). **C**, Wedge in place.

end of the hand instrument to press the material into the preparation. If the composite has a tendency to stick to the instrument, a sparing amount of bonding resin or a gauze dampened in alcohol can be used to lubricate the instrument. Most modern composites will not stick to a clean instrument. A second increment of composite is applied, if needed, to fill the preparation completely and provide a slight excess so that positive pressure can be applied with the matrix strip when closed. Any gross excess is removed quickly with the blade of the insertion instrument or an explorer tine before closing the matrix.

The operator closes the lingual end of the strip over the composite and holds it with the index finger. Next, the operator pulls the matrix toward the facial direction to cover the facial margin with the composite. This step will provide the best composite–tooth adaptation at that margin. Before light-activating the composite, the operator closes the facial end of the strip over the tooth with the thumb and index finger of the other hand, tightening the gingival aspect of the strip ahead of the incisal portion. The matrix is held in such a way that light can reach the composite. The matrix can be held in this manner until light activation is complete.

When the material has been inserted, it is light-activated through the strip as directed (see Fig. 9-17, C). The strip should not be touched with the tip of the light initially because it could distort the contour of the restoration. The operator

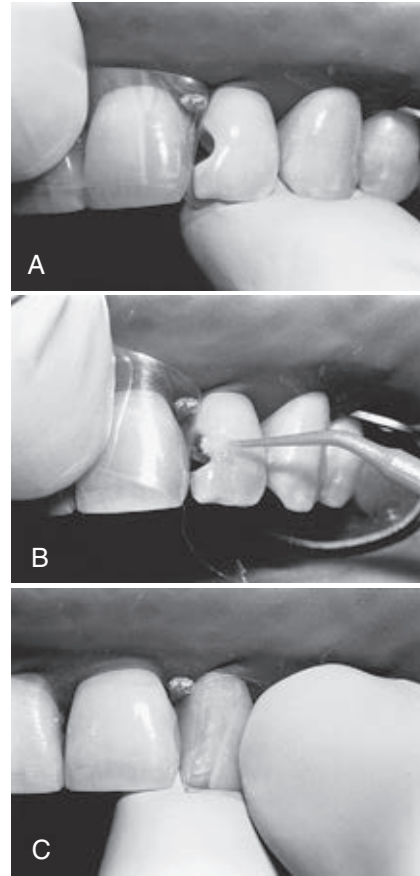


Fig. 9-17 Insertion of light-activated composite. **A**, Bonding adhesive is applied and light-activated. **B**, The lingual aspect of the strip is secured with the index finger, while the facial portion is reflected away for access. **C**, After insertion of the composite, the matrix strip is closed, and the material is activated through the strip.

removes the index finger and light-activates the lingual surface. Longer light exposures usually are required for the polymerization of dark and opaque shades. If the restoration is under-contoured, more composite can be added to the previously placed composite and light-activated. No etching or adhesive is required between layers if the surface has not been contaminated, and the oxygen-inhibited layer remains.

With large restorations, it is better to add and light-activate the composite in several increments to reduce the effects of polymerization shrinkage and to ensure complete light activation in remote regions. Adjacent proximal tooth preparations should be restored one at a time. Techniques have been suggested for inserting two approximating restorations simultaneously, but these procedures may result in matrix movement, poor adaptation, open contact, overhangs, and faulty contours (Fig. 9-18). If two adjacent preparations are present, the preparation with the least access (usually the one prepared second) is restored first. If too much convexity is present on the first proximal restoration, the excess must be removed before the second restoration is inserted. If too little contour is present, more material is added to correct the contour. The proximal surface of the first restoration should be contoured completely before the second restoration is started. Because the second tooth preparation has been contaminated, it must be cleaned before bonding materials and composite are applied and the

composite are inserted. During these procedures, a Mylar strip or Teflon tape should be in place to protect the first restoration and the tooth.

Contouring and Polishing of the Composite

Good technique and experience in inserting composites significantly reduce the amount of finishing required. Usually, a slight excess of material will need to be removed to provide the final contour and smooth finish. Coarse diamond instruments can be used to remove gross excess, but they generally are not recommended for finishing composites because of the high risk of inadvertently damaging the contiguous tooth structure. Compared with finishing burs and disks, they also leave a rough surface on the restoration and the tooth. Special fine diamond finishing instruments, 12-bladed carbide finishing burs, and abrasive finishing disks can be used to obtain excellent results if the manufacturers' instructions are followed. Care must be exercised with all rotary instruments to prevent damage to the tooth structure, especially at the gingival marginal areas.

Similar to tooth preparation rotary instruments, contouring and polishing instruments should be used according to the specific surface being contoured and polished. For example, flexible disks and finishing strips are suitable for convex and flat surfaces; finishing points and oval-shaped finishing burs



Fig. 9-18 Adjacent restorations, restored simultaneously and displaying poor contours and gingival overhangs.

are more suitable for concave surfaces; and finishing cups can be used in both convex and concave surfaces. A flame-shaped carbide finishing bur or diamond is recommended for removing excess composite on facial surfaces (Fig. 9-19, A). Medium speed with light intermittent brush strokes and air coolant are used for contouring.

Abrasive disks (the degree of abrasiveness depends on the amount of excess to be removed) mounted on a mandrel specific to the disk type, in a contra-angle handpiece at low speed, can be used instead of or after the finishing bur or diamond in facial surfaces and some interproximal and incisal embrasures (Fig. 9-20, A). Several brands of abrasive disks are available, and most are effective when used correctly. These disks are flexible and are produced in different diameters, thicknesses, and abrasive textures. Thin disks with small diameters fit into embrasure areas easily and are especially useful in contouring and polishing the gingival areas. Regardless of the type of disk chosen, disks are used sequentially from coarse to very fine grit, generating a smooth surface. The external enamel surface should act as a guide for proper contour. A constant shifting motion aids in contouring and preventing the development of a flat surface. Final polishing is achieved with rubber or silicone polishing instruments, diamond-impregnated polishers, polishing disks, and polishing pastes (see Fig. 9-19, B and D).

Excess lingual composite is removed using a round or oval-shaped 12-bladed carbide finishing bur or finishing diamond. A smoother surface is produced using a finer round or oval carbide finishing bur (with 18–24 or 30–40 blades) or fine diamond at medium speed with air coolant and light intermittent pressure (see Fig. 9-20, B). The appropriate size and shape depend on the amount of excess and shape of the lingual surface. Polishing is achieved with rubber polishing instruments and diamond-impregnated polishers.

Proximal surface contours and margins should be assessed visually and tactilely with an explorer and dental floss. The floss is positioned at the gingival margin and “shoe-shined” as it is pulled occlusally. If the floss catches or frays, additional finishing is required. A No. 12 surgical blade mounted in a Bard-Parker handle (see Fig. 9-20, C) is well suited for

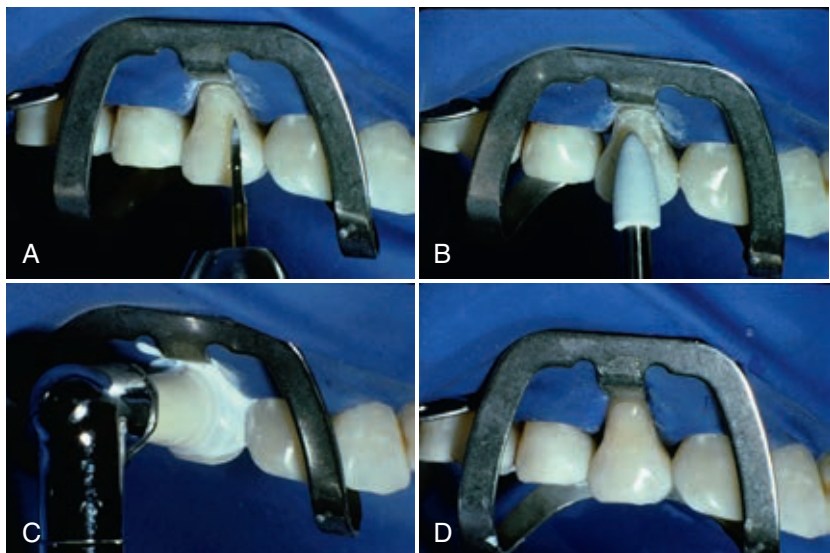


Fig. 9-19 Finishing and polishing. **A**, Flame-shaped finishing bur removing excess and contouring. **B** and **C**, Rubber polishing point (**B**) and aluminum oxide polishing paste (**C**) used for final polishing. **D**, Completed restoration.

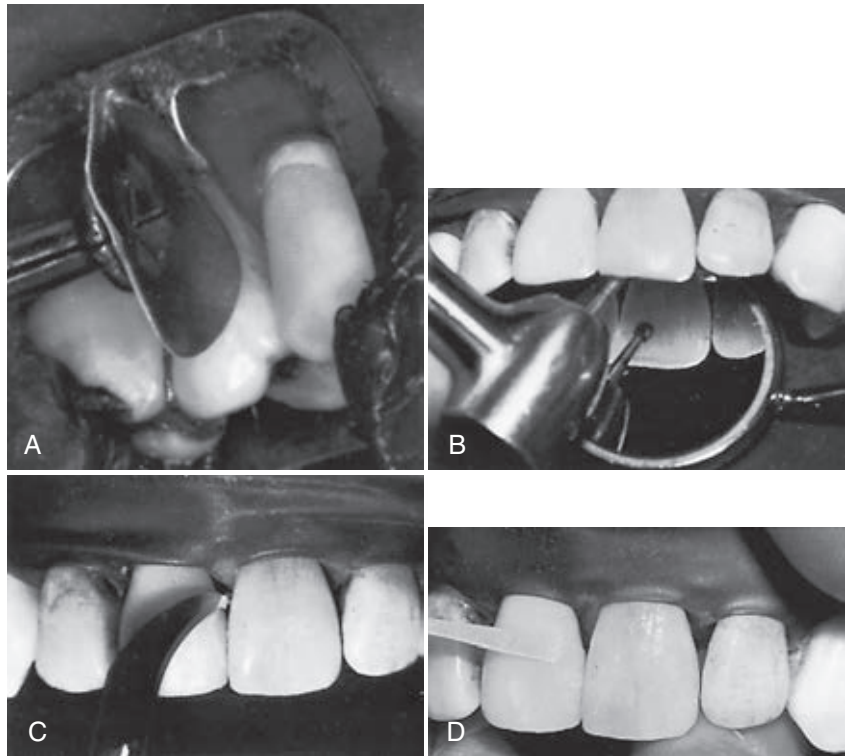


Fig. 9-20 Finishing composites. **A**, Abrasive disk mounted on mandrel can be used for finishing when access permits. **B**, The round carbide finishing bur is well suited for finishing lingual surfaces. **C**, The No. 12 surgical blade in Bard-Parker handle can be used for removing interproximal excess. **D**, The abrasive strip should be curved over the area to be finished.

removing excess material from the gingival proximal area. A No. 12 surgical blade in a Bard-Parker handle is thin and has a curved shape of the blade, making this instrument ideal for removing gingival overhangs. The instrument should be moved from the tooth to the restoration or along the margins, using light shaving strokes, keeping a portion of the cutting edge on the external enamel surface as a guide to prevent over-reduction. If a large amount of composite is removed with one stroke or in the wrong direction, it may fracture inside the tooth preparation and warrant a repair because the irregular void created may collect plaque and debris and cause discoloration or recurrent caries. The excess is gently shaved away to avoid removing a large chunk of material unintentionally. Rotary instruments especially designed for this task are also available and can be used for removing excess and opening embrasure areas. Caution must be taken with all instruments not to remove too much contour or to produce a “ledged” contact (a ledge bordering the contact area). All carbide instruments are made of carbon steel and may leave gray marks on the restoration. This discoloration is superficial and is removed easily during the final finishing by abrasive strips or disks (see Fig. 9-20, D).

Further contouring and finishing of proximal surfaces can be completed with abrasive finishing strips. Some strips have two different types of abrasives (e.g., medium and fine) on opposing ends of the strip, with a small area in-between where no abrasive is present to allow easy and safe insertion of the strip through the contact area. Thin diamond-coated metal strips also are commercially available in various grits. Different widths of strips are available. A narrow width is usually more appropriate for contouring because it allows more versatility for finishing specific areas. Wide strips tend to flatten the proximal contour, remove too much material at the contact

areas, and extend too far gingivally. This results in a poor contour and a weak or absent contact, which must be corrected.

The strip should not be drawn back-and-forth across the restoration in a “sawing” manner. It should be curved over the restoration and tooth surface in a fashion similar to that used with a shoe-shine cloth, concentrating on areas that need attention (see Fig. 9-20, D). To open the lingual embrasure or round the marginal ridge, the lingual part of the strip is held against the composite with the index finger of one hand, while the other end of the strip is pulled facially with the other hand.

Contouring and finishing the proximal surface, including the gingival margin, also develops the general embrasure form around the proximal contact. Further embrasure form development is accomplished with additional use of flame-shaped carbide finishing burs, fine diamonds, or the No. 12 surgical blade.

Finally, occlusion should be carefully checked after the rubber dam is removed, if one was used. The operator evaluates the occlusion in maximum intercuspation and eccentric movements by having the patient close on a piece of articulating paper and slide mandibular teeth over the restored area. If excess composite is present, the operator removes only a small amount at a time and rechecks with articulating paper. Usually, occlusion is adjusted until it does not differ from the original occlusion.

Instead of working sequentially by surface as described above (facial, lingual, proximal, and occlusal), the operator may elect to work by instrument sequence, that is, contour all surfaces of the restoration by using contouring instruments first and then proceed to polish all surfaces by using the polishing instruments described. This approach minimizes

the amount of time necessary to change instruments between surfaces.

Clinical Technique for Class IV Direct Composite Restorations

Initial Clinical Procedures

The same initial procedure considerations presented earlier are appropriate for Class IV direct composite restorations. The preoperative assessment of the occlusion is even more important for Class IV restorations because it might influence the tooth preparation extension (placing margins in noncontact areas) and retention and resistance form features (heavy occlusion requires increased retention and resistance form).

Also, proper shade selection can be more difficult for large Class IV restorations. Use of separate translucent and opaque shades of composite is often necessary. Specific information for esthetic considerations is presented in Chapter 12.

For large Class IV lesions or fractures, a preoperative impression may be taken to be used as a template for developing the restoration contours. This technique is described later.

Tooth Preparation

Similar to the Class III preparation, the tooth preparation for a Class IV direct composite restoration involves (1) creating access to the defective structure (caries, fracture, non-caries defect), (2) removal of faulty structures (caries, defective dentin and enamel, defective restoration and base material), and (3) creating the convenience form for the restoration. The tooth preparation for large incisoproximal areas requires more attention to the retention form than that for a small Class IV defect. If a large amount of tooth structure is missing and the restoration is in a high stress area, groove retention form may be indicated even when the preparation periphery is entirely in enamel. Also, enamel bevels can be increased in width to provide greater surface area for etching, resulting in a stronger bond between the composite and the tooth and potentially better esthetic result.

The treatment of teeth with minor coronal fractures requires minimal preparation. If the fracture is confined to enamel, adequate retention usually can be attained by simply beveling the sharp cavosurface margins in the fractured area with a flame-shaped diamond instrument followed by bonding (Fig. 9-21). Regardless of its size, the extensions of the Class IV direct composite preparation is ultimately dictated by the extension of the caries lesion, fracture, or failed restoration being replaced. The outline form is prepared to include weakened, friable enamel.

A maxillary right central incisor with a large defective Class III restoration and a fractured mesio-incisal corner, which necessitates a Class IV restoration, is illustrated in Figure 9-22, A. Using a round carbide bur or diamond instrument of appropriate size at high speed with air-water coolant, the outline form is prepared. All weakened enamel is removed, and the initial axial wall depth is established. As with the Class III tooth preparation, the final tooth preparation steps for a Class IV tooth preparation are, when indicated, (1) removal of infected dentin, (2) pulp protection, (3) bevel placement on accessible enamel margins, and (4) final procedures of

cleaning and inspecting. The operator bevels the cavosurface margin of all accessible enamel margins of the preparation. The bevel is prepared at a 45-degree angle to the external tooth surface with a flame-shaped or round diamond instrument (see Fig. 9-22, B). The width of the bevel should be 0.5 to 2 mm, depending on the amount of tooth structure missing and the retention perceived necessary. The use of a scalloped, nonlinear bevel sometimes helps in masking the restoration margin.

Although retention for most Class IV direct composite restorations is provided primarily by bonding of the composite to enamel and dentin, when large incisoproximal areas are being restored, additional mechanical retention may be obtained by groove-shaped or other forms of undercuts, dovetail extensions, or a combination of these. If retention undercuts are deemed necessary, a gingival retention groove is prepared using a No. $\frac{1}{4}$ round bur. It is prepared 0.2 mm inside the DEJ at a depth of 0.25 mm (half the diameter of the No. $\frac{1}{4}$ round bur) and at an angle bisecting the junction of the axial wall and gingival wall. This groove should extend the length of the gingival floor and slightly up the facioaxial and linguoaxial line angles (see Fig. 9-22, C). No retentive undercut is usually needed at the incisal area, where mostly enamel exists. An optional dovetail extension onto the lingual surface of the tooth might enhance the restoration's strength and retention, but it is less conservative and not used often. Incisal and gingival retention and dovetail extension are illustrated in Fig. 9-23. Fig. 9-22, D, illustrates the completed large Class IV tooth preparation.

Restorative Technique Matrix Application

Most Class IV composite restorations require a matrix to confine the restorative material excess and to assist in the development of the appropriate axial tooth contours, except for very small incisal edge enamel fractures, which can be restored using a free-hand technique. The Mylar strip matrix, described previously, also can be used for most Class IV preparations, although the strip's flexibility makes control of the matrix difficult. This difficulty may result in an over-contoured or under-contoured restoration, open contact, or both. Also, composite material extrudes incisally, but this excess can be easily removed when contouring and finishing.

Creasing (folding) the matrix at the position of the lingual line angle helps reduce the potential under-contouring (rounding) of that area of the restoration. The matrix is positioned and wedged as described for the Class III composite technique. Gingival overhangs and open contacts are common with any matrix techniques that do not employ gingival wedging. A commercially available preformed plastic or celluloid crown form is usually too thick and is not recommended as a matrix. Alternatively, a custom lingual matrix may be used for large Class IV preparations.²² Figure 9-24, A, illustrates a large defective distofacial Class IV that needs to be replaced. The shade should be selected before isolating the area and removing the restorative material (see Fig. 9-24, B). Before the existing restoration is removed, the lingual matrix is prepared by using either a polyvinyl siloxane impression putty or a fast-set silicone matrix material. The operator records the lingual contours and, if possible, incisal contours of the existing restoration by using a small amount of the



Fig. 9-21 Class IV tooth preparation and restoration. **A**, Extraoral view, minor traumatic fracture. **B**, Intraoral view. **C**, Fractured enamel is roughened with a flame-shaped diamond instrument. **D**, The conservative preparation is etched, while adjacent teeth are protected with Mylar strip. **E-F**, Contouring and polishing the composite. **G**, Intraoral view of the completed restoration. **H**, Extraoral view.

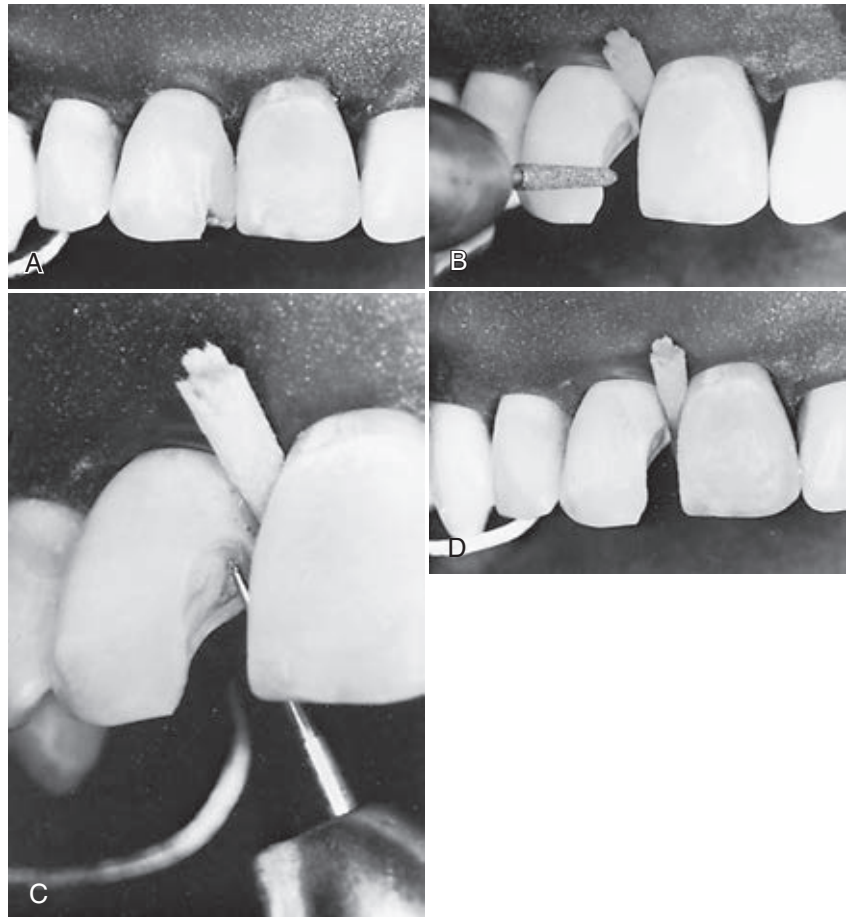


Fig. 9-22 Class IV tooth preparation. **A**, Large defective Class III restoration with resulting fractured incisal angle. **B**, Beveling cavosurface margin. **C**, Gingival retention groove. **D**, Completed Class IV tooth preparation.

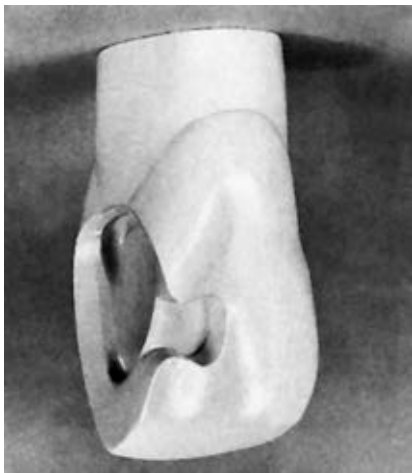


Fig. 9-23 Incisal and gingival retention grooves and dovetail extension in a large Class IV tooth preparation before beveling.

silicone material, thus creating a guide or index with which the new restoration will be formed. The lingual matrix also can be fabricated from a quickly inserted temporary restoration or waxed study model for more complex cases when tooth structure is missing preoperatively. When obtained, the lingual matrix is set aside until it is time to insert the composite.

Placement of the Adhesive

Steps for acid-etching and placing the resin adhesive are the same as previously described for the Class III composite restoration. Also, the same considerations presented previously are appropriate for whether or not the matrix is placed before or after adhesive placement.

Insertion and Light-Activation of Composite

After application of the adhesive, the operator inserts the composite with a hand instrument or a syringe as described earlier for Class III restorations. The composite is inserted in increments less than 2 mm thick. It is usually helpful to develop the lingual surface of the restoration first, then its body, and finally the facial surface. This approach facilitates the development of adequate anatomy with less potential for resultant excess composite material. This anatomic incremental layering also facilitates the development of adequate shade characterization, as dentin and enamel composite shades can be applied according to the structure they are replacing.

When using a properly contoured Mylar strip matrix, care must be taken when closing the strip not to pull with excessive force because the soft material is extruded incisally and results in an under-contoured restoration. When this happens, composite should be added to restore proper contour and contact.

When a custom lingual matrix is the choice, the operator positions the lingual matrix and inserts the initial composite



Fig. 9-24 Custom lingual matrix. **A**, Facial pre-operative view. **B**, Pre-operative shade determination. **C**, Lingual pre-operative view after placement of the rubber dam. **D**, The old composite material is removed, and a conservative enamel bevel is placed. **E**, The lingual matrix obtained before tooth preparation is positioned and guides the application of the first lingual composite layer. **F**, The lingual composite layer determines the future contours of the restoration; note the intrinsic material translucency. Custom lingual matrix. **G**, The dentin buildup can be made directly against the lingual enamel; the clinician can visualize the whole tooth shape and place dentin with appropriate thickness and relation to the incisal edge. **H**, Color modifier or tint blue material is applied between the dentin lobes and slightly below the incisal edge to simulate the blue natural opalescence. **I**, View of the completed restoration (with second enamel layer placed on the buccal surface), after finishing. **J**, Facial post-operative view. (Courtesy of Dr. Didier Dietschi.)

increment against the matrix in the lingual part of the preparation (see Fig. 9-24, E). This initial increment, when polymerized, generally establishes the lingual, proximal, and incisal contours of the final restoration (see Fig. 9-24, F). The operator continues to place and activate additional increments until the desired form is obtained (see Fig. 9-24, G). During these additions, color modifiers or tints may be incorporated

to enhance the natural blue opalescence between tooth lobes or other subtle esthetic effects (see Fig. 9-24, H). Because light-activated composites possess the advantage of an extended working time, the material can be manipulated and shaped to a considerable degree before light-activation. Incremental insertion of light-activated composites also enables the clinician to layer composites with different optical properties

(more opaque, darker in color, or both, to mimic dentin; and more translucent, lighter in color, or both, to mimic enamel), which can result in natural-looking composite restorations. After polymerization, the lingual matrix is removed. To ensure optimal polymerization, the operator light-activates the restoration from facial and lingual directions. The final restoration is illustrated in [Figure 9-24, I and J](#). This technique is particularly useful when the lingual contour of an existing composite restoration is to be duplicated in a new composite restoration, such as the case described. The technique facilitates the development of proper lingual, incisal, and proximal forms, reducing the need for contouring of the restoration.

Contouring and Polishing of the Composite

Contouring and polishing the Class IV composite is similar to the technique described for a Class III composite but usually more difficult. The primary differences are the involvement of the incisal angle and incisal edge of the tooth and an extended facial surface in large Class IV restorations. Contouring and polishing these sections of the restoration require similar procedural steps but close assessment of the incisal edge length and thickness, as well as of the facial macroanatomy and microanatomy of the tooth being restored. Also, the potential occlusal relationship may be greater and require more adjustment and refinement. The facial, lingual, and proximal areas are contoured and finished as described previously.

Clinical Technique for Class V Direct Composite Restorations

Initial Clinical Procedures

The same initial procedure considerations presented for Class III restorations apply for Class V restorations, except for occlusal evaluation, which is not required for Class V restorations. During shade selection, it should be remembered that the tooth is darker and more opaque in the cervical third. Isolation may be achieved by a rubber dam and No. 212 retainer or with a cotton roll and retraction cord as previously described in [Chapter 7](#).

Tooth Preparation

Class V tooth preparations, by definition, are located in the gingival one third of the facial and lingual tooth surfaces. Because of esthetic considerations, composites most frequently are used for the restoration of Class V lesions in anterior and premolar teeth. Numerous factors, including esthetics, caries activity, access to the lesion, moisture control, and patient age, must be taken into consideration in material selection.

Because many Class V restorations involve root surfaces, at least on their cervical margins, careful consideration should be given to the choice of restorative material. Use of materials other than composite is considered when factors that can compromise the performance of composite restorations are present. These factors include decreased salivary function, decreased patient motivation or ability for home care, increased difficulty in adequately isolating the operating area, and increased difficulty in performing the operative procedure because of the patient's physical or medical problems.

Despite these concerns, the use of composite as a restorative material for Class V lesions predominates in areas of esthetic concern.

Similar to the Class III and IV preparations, tooth preparation for a Class V direct composite restoration involves (1) creating access to the defect (caries, non-carious defect), (2) removal of the defect (caries, defective dentin and enamel, defective restoration and base material), and (3) creating the convenience form for the restoration. The tooth preparation for large Class V lesions or defects areas may require more attention to retention form than that of a small Class V defect, especially when little enamel is available for bonding. Areas of hypermineralized (sclerotic) dentin also may require special attention, as these respond differently to bonding than areas with normal dentin.²³⁻²⁵ Enamel bevels are usually used on the occlusal margins of the preparation, while at the cervical margin, enamel bevels are usually not recommended because of the absence of enamel in this area. Class V tooth preparations will vary slightly, depending on the type and extension of the defect being restored.

Class V Tooth Preparation for Small or Moderate Lesions or Defects That Do Not Extend Onto the Root Surface

The objective of the Class V tooth preparation for small or moderate lesions or defects that do not extend onto the root surface is to restore the lesion or defect as conservatively as possible. No effort is made to prepare the walls as butt joints, and usually no groove retention is incorporated. The lesion or defect is “scooped” out, resulting in a preparation form that may have a divergent wall configuration and an axial surface that usually is not uniform in depth (see [Fig. 9-6, E and F](#)). Small or moderate Class V tooth preparations are ideal for small enamel defects or small primary caries lesions ([Fig. 9-25, A](#)). These include decalcified and hypoplastic areas located in the cervical third of the teeth. The typical outline form for a Class V lesion in enamel is shown in [Figure 9-26](#).

After the usual preliminary procedures, the initial tooth preparation is accomplished with a round diamond or carbide bur (see [Fig. 9-25, B](#)), eliminating the entire enamel lesion or defect. The preparation is extended into dentin only when the defect warrants such extension. No effort is made to prepare 90-degree cavosurface margins. If infected dentin remains, it is removed with a round bur or spoon excavator. Usually, this preparation technique will result in a slightly beveled enamel margin. If deemed necessary, the enamel margin can be further beveled. The completed preparation with etched enamel and etched and primed dentin is shown in [Figure 9-25, C](#).

An example of a small Class V tooth preparation is presented in [Figure 9-5, A](#), which illustrates a path of a decalcified enamel lesion (in enamel only) having a broken, rough surface that extends mesially or distally from the cavitated lesion (or failing existing restoration). After preparation of the cavitated lesion (or failing restoration), the margins of the preparation are extended to include these areas of decalcification by using a round diamond or bur to prepare the cavosurface margin in the form of a chamfer, extended in the enamel only to a depth that removes the defect. A completed preparation of this type is illustrated in [Figure 9-5, B](#).



Fig. 9-25 Class V tooth preparation. **A**, Small cavitated Class V lesion. **B**, Surrounding enamel defect is prepared with round diamond instrument. **C**, Completed tooth preparation after acid etching.

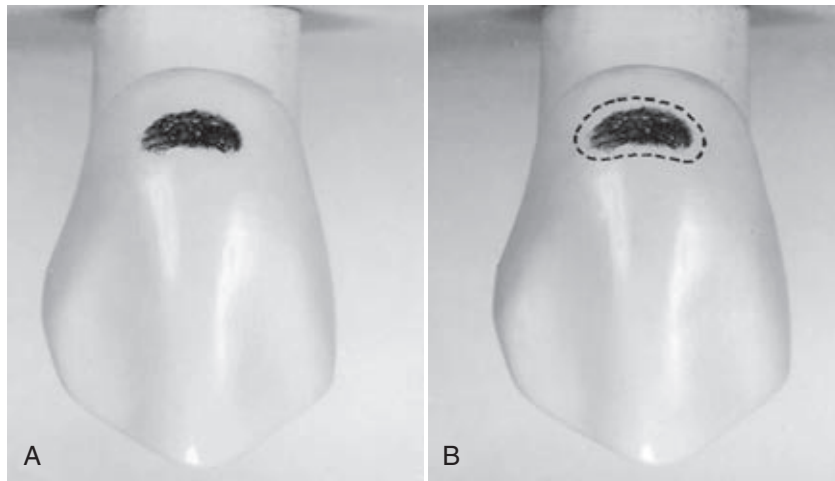


Fig. 9-26 **A**, Class V caries. **B**, Typical outline form.

Small or moderate Class V tooth preparations also are used to restore non-carious cervical lesions. If the causative factor is not eliminated, these lesions are progressive and enlarge with time. When they are detected (Fig. 9-27, A), the operator first must decide, with input from the patient, whether or not the area needs to be restored. This decision is based on certain considerations, which are discussed below.

CARIES

If caries is present, the defect should be restored unless the lesion is incipient and very superficial, or it is chronic and inactive. For the incipient lesion, treatment may consist only of minor recontouring of the area and application of a topical fluoride or adhesive. Chronic, inactive lesions can be monitored and kept unrestored indefinitely, but sometimes these can be esthetically unsatisfactory. (Most erosion and abrasion defects are not carious.)

GINGIVAL HEALTH

If the defect is determined to be causing gingival inflammation (i.e., plaque retention), or further gingival recession is anticipated, the defect should be restored. Usually, gingival health is excellent.

ESTHETICS

If the defect is in an esthetically critical position, the patient may elect to have the area restored with a tooth-colored restoration.

SENSITIVITY

If the defect is very sensitive, application of an adhesive or desensitizing agent may reduce or eliminate the sensitivity, at least temporarily. Continuing sensitivity may require restoration of the area.

PULP PROTECTION

If the defect is very large and deep pulpally, its restoration may be indicated to avoid further defect development that may cause a pulpal exposure.

TOOTH STRENGTH

If the defect is very large or deep, the strength of the tooth at the cervical area may be compromised. Placement of a bonded restoration reduces further progression of the defect and can restore some of the lost strength.

Periodontal therapy with gingival grafts also can be considered as a treatment option for these exposed root surfaces.

Tooth Preparation for A Class V Abrasion or Erosion Area

The tooth preparation for a Class V abrasion or erosion area usually requires only roughening of the internal walls with a diamond instrument and beveling all enamel margins (see Fig. 9-27, B through D). If necessary, the root surface cavosurface margins should be prepared to approximately 90 degrees. Often, because of the inherent form of an abraded or eroded

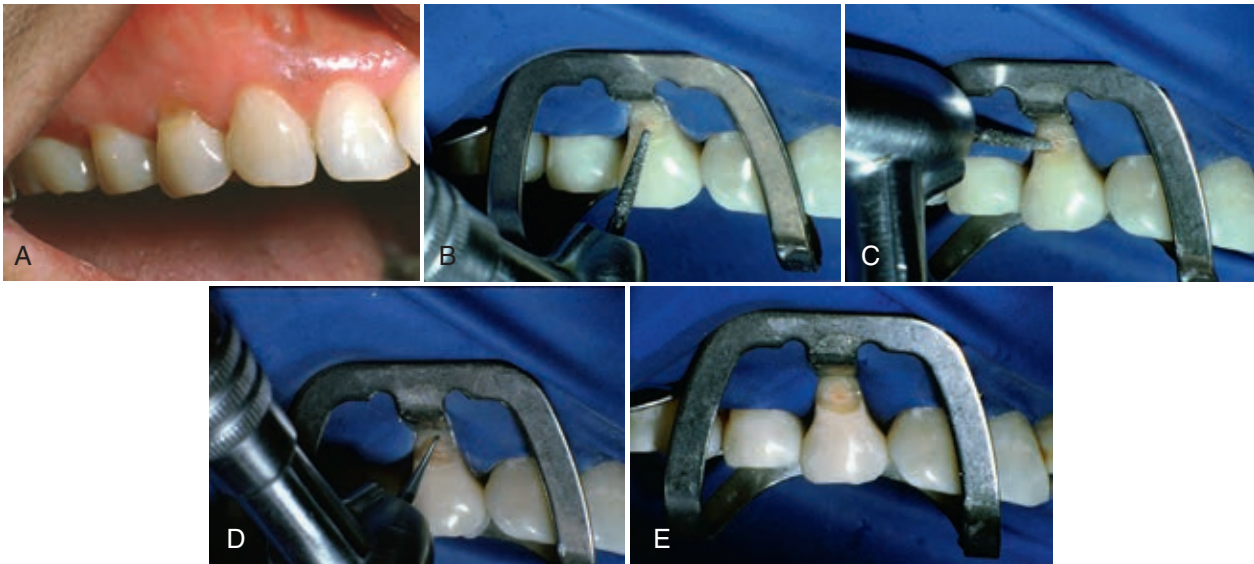


Fig. 9-27 Class V tooth preparation for abrasion and erosion lesions. **A**, Pre-operative notched lesion. **B** to **D**, Beveling the enamel margin and roughening the internal walls. **E**, Completed preparation with etched enamel.

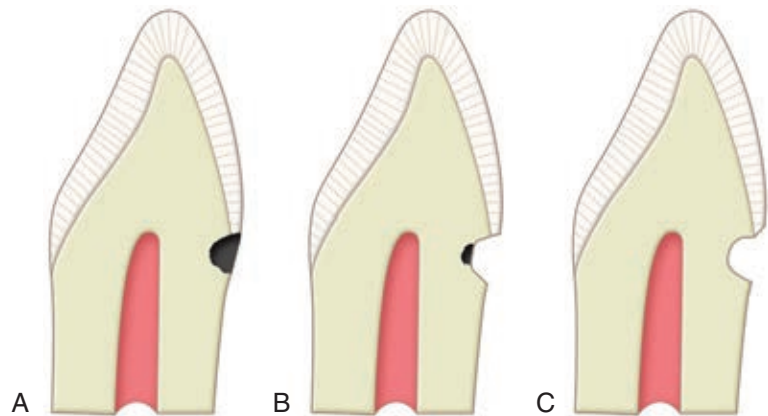


Fig. 9-28 Class V tooth preparation. **A**, Lesion extending onto root surface. **B**, Initial tooth preparation with 90-degree cavosurface margins and axial wall depth of 0.75 mm. **C**, Remaining infected dentin excavated, incisal enamel margin beveled, and gingival retention form prepared.

lesion, further preparation of root surface cavosurface margins is not needed. The completed preparation with etched enamel is shown in [Figure 9-27, E](#).

Class V Tooth Preparation for Large Lesions or Defects that Extend onto the Root Surface

In Class V tooth preparation for large lesions or defects that extend onto the root surface ([Fig. 9-28, A](#)), the gingival aspect of the preparation form is similar to that described in [Chapter 15](#) for a Class V amalgam restoration. The features of the preparation include a 90-degree cavosurface margin with uniform depth of the axial line angles. Groove retention form usually is not necessary but can be used if retention form is a concern. The enamel margins are prepared using the same design described for small or moderate Class V tooth preparations, that is, with a conservative enamel bevel. This preparation design is indicated for the replacement of an existing, defective Class V restoration that initially used a conventional preparation or for a large, new caries. The large Class V

preparation initially exhibits 90-degree cavosurface margins (that subsequently can be beveled when in enamel) and an axial wall that is uniform in depth (see [Fig. 9-8, E and F](#)). The axial depth into dentin is determined by the extent of the defect. Many of these larger preparations are a combination of beveled enamel margins and 90-degree root surface cavosurface margins. As stated above, the root-surface areas may have groove retention form if retention is a concern. A completed large Class V preparation extending onto the root surface is illustrated in [Figure 9-29](#).

To initiate the preparation, a tapered fissure carbide bur (No. 271) or similarly shaped diamond is used at high speed with air-water spray. If interproximal or gingival access is limited, an appropriately-sized round bur or diamond may be used. When a tapered fissure bur or diamond is used, the handpiece is maneuvered to maintain the bur's long axis perpendicular to the external surface of the tooth during preparation of the outline form, which should result in 90-degree cavosurface margins. At this initial tooth preparation stage, the extensions in every direction are to sound tooth structure except that caries or an old restoration may remain in the axial

wall (see Fig. 9-28, B). Any infected dentin remaining on this initial axial wall is removed during the final stage of tooth preparation. Any old restorative material remaining may or may not be removed according to the concepts stated previously. When the desired distal extension is obtained, the instrument is moved mesially, incisally (occlusally), and gingivally for indicated extensions, while maintaining proper depth and the instrument's long axis perpendicular to the external surface. The axial wall should follow the original contour of the facial or lingual surface, which is convex outward mesiodistally and sometimes occlusogingivally. The outline form extension of the mesial, distal, occlusal (incisal), and gingival walls is dictated by the extent of the caries, defect, or old restorative material indicated for replacement (sometimes the new material abuts a still satisfactory old restoration).

All of the external preparation walls of a Class V tooth preparation are visible when viewed from a facial position (outwardly divergent walls). Final tooth preparation consists of the following steps: (1) removing the remaining infected dentin or old restorative material (if indicated) on the axial wall; (2) applying a base, only if necessary, as discussed previously in this chapter; and (3) beveling the enamel margins and adding groove retention, if indicated. The bevel on the enamel margin is accomplished with a flame-shaped or round diamond instrument, resulting in an angle approximately 45 degrees to the external tooth surface, and prepared to a width of at least 0.5 mm depending on the preparation size and esthetic considerations. A completed Class V preparation is shown in Figure 9-30.

Occasionally, a tooth surface that normally is smooth has a pit in the enamel (Fig. 9-31, A). Most unusual pit faults in



Fig. 9-29 Completed Class V tooth preparation extending onto the root; the incisal margin is beveled; the root portion has a retention groove for increased retention. Retention grooves on the incisal aspect are rarely required and are shown here for illustration purposes only.



Fig. 9-30 Completed large Class V preparation. A retention groove on the incisal aspect is rarely required and is shown here for illustration purposes only.

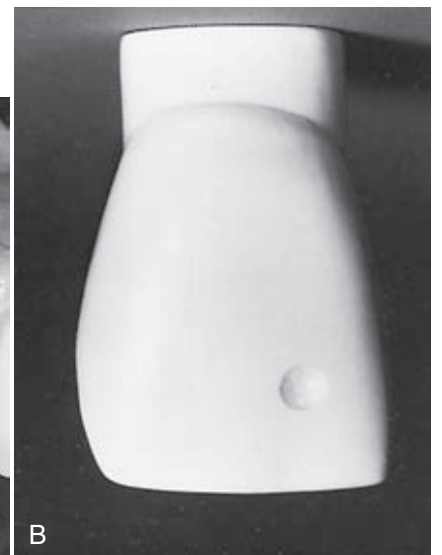


Fig. 9-31 **A**, Faulty pit on the facial surface of the maxillary incisor. **B**, Tooth preparation for an enamel pit defect.

enamel are restored best with the preparation design described for small or moderate Class V defects. For such a preparation for an unusual pit fault, the outline form (extensions and depth) is dictated by the extent of the fault or caries lesion. Faults existing entirely in enamel are prepared with an appropriately-sized round diamond instrument by merely eliminating the defect (see Fig. 9-31, B). Adequate retention is obtained by bonding. When the defect includes carious dentin, the infected portion is removed also, leaving a flared enamel margin.

Restorative Technique

No matrix is needed for Class V restorations because the contour can be controlled as the composite restorative material is being inserted.

Acid Etching and Placement of the Adhesive

The techniques for acid etching of the involved tooth structure and placement of the adhesive are the same as previously described in this chapter.

Insertion and Light-Activation of the Composite

The composite can be inserted with a hand instrument or syringe. Composites and RMGIs are recommended for Class V restorations. A light-activated material is recommended for most Class V preparations because of the extended working time and control of contour before polymerization. Less finishing is usually required. This feature is particularly valuable when restoring large preparations or preparations with margins located on cementum because rotary instrumentation can easily damage the contiguous tooth structure.

The restoration of a non-carious cervical lesion in Figure 9-32, A illustrates the proper insertion technique for a light-activated material. After bonding procedures (according to manufacturer's instructions), the operator inserts the composite incrementally with a hand instrument or syringe (see

Fig. 9-32, C). The number and position of the increments depend on the size and depth of the preparation. For large and deep preparations, an incremental technique is recommended. Deep preparations with retentive undercuts are usually filled with at least two axially-placed increments. The operator should avoid placing increments that connect to both occlusal or incisal walls and gingival walls, or mesial and distal walls, simultaneously, to minimize polymerization shrinkage stresses. Regardless of the technique used, before light-activating the last increment that defines the contour of the restoration, the material is shaped as close to the final contour as possible. An explorer or blade of a composite instrument, or a flat #2 sable brush, are useful in removing excess material from the cervical margin and obtaining the final contour. The light source is applied for polymerization (see Fig. 9-32, D). The restoration should require very little finishing.

Contouring and Polishing of the Composite

When excess composite is present, a flame-shaped carbide finishing bur or diamond is recommended for removing excess composite on the facial surface (see Fig. 9-19, A). Medium speed with light intermittent brush strokes and an air coolant are used for contouring. Final finishing and polishing are achieved with a rubber polishing point (see Fig. 9-19, B) or cup, diamond-impregnated polisher, and sometimes a polishing paste (see Fig. 9-19, C and D).

For some locations, abrasive disks, as stated earlier (degree of abrasiveness depends on the amount of excess to be removed), mounted on an appropriate mandrel in an angled handpiece at low speed can be used (see Fig. 9-20, A). The external enamel surface should act as a guide for a proper contour, preventing the development of a flat surface.

Rotary instruments should be used carefully in gingival locations (especially on the root surface) to prevent inadvertent and undesirable removal of tooth structure (usually cementum and dentin). Finely pointed rotary instruments (finishing burs or diamonds) are difficult to use to remove gingival margin excess. Because of the convexity that typically exists in this area, a more rounded rotary instrument (a fine

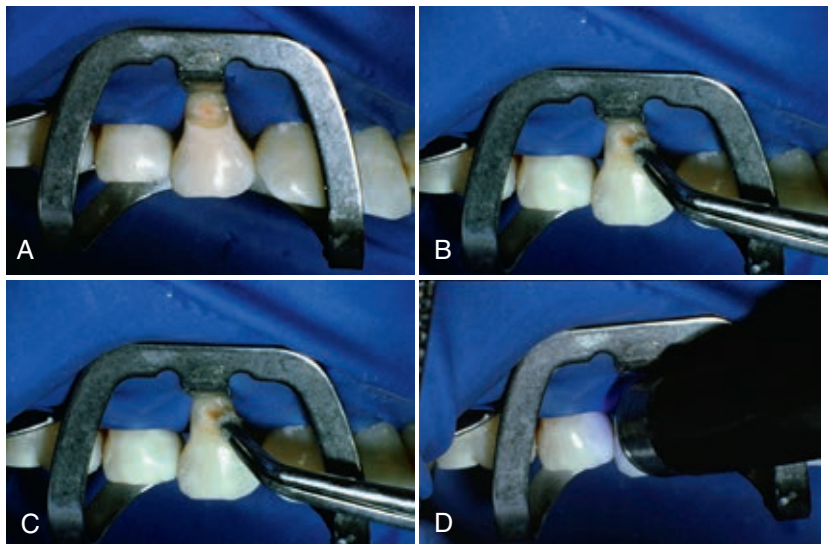


Fig. 9-32 Restoration of a non-carious cervical lesion. **A**, Tooth preparation. **B**, Bonding adhesive applied. **C**, Material inserted incrementally. **D**, Restorative material light-activated.

diamond) may remove the excess with less potential to damage the unprepared root surface. Likewise, abrasive disks used on the root surface can cause ditching of the cementum, if not used correctly.

Clinical Technique for Glass Ionomer Restorations

Glass ionomers possess the favorable quality of releasing fluoride when exposed to the oral environment.^{26,27} These materials also have been shown to “recharge” with fluoride when exposed to fluoride from various sources.²⁸ These properties may render glass ionomer restorations more resistant to recurrent caries, especially in patients with caries activity. Because of this potential anticariogenic quality, glass ionomer may be the material of choice for restoring root-surface caries in patients with high caries activity and in whom esthetics is not as critical. (See Online Chapter 18 for types of glass ionomers.)

Because of their limited strength and wear resistance, glass ionomers are indicated generally for the restoration of

low-stress areas (not for typical Class I, II, or IV restorations), where caries activity potential is of significant concern. In addition to being indicated for root-surface caries in Class V locations, slot-like preparations in Class II or III cervical locations (not involving the proximal contact) may be restored with glass ionomers, if access permits.

The restoration of root caries lesions in older patients or in patients with high caries activity is the primary indication for the use of a glass ionomer as a restorative material. Cervical defects of idiopathic erosion or abrasion origin (or any combination) also may be indications for restoration with glass ionomers, if esthetic demands are not critical. The tooth preparations for either of these clinical indications are the same as previously described for composite restorations (see Figs. 9-27, 9-28, and 9-29), except bevels are rarely used. Older patients and those with high caries activity who have gingival recession also may experience caries lesions on the proximal root surfaces. Gingival recession sometimes provides access to this type of caries lesion from the facial or lingual direction, allowing a slot preparation to be used. The same slot preparation design used for amalgam is used for glass ionomers. (The reader is referred to the sections on slot preparations in

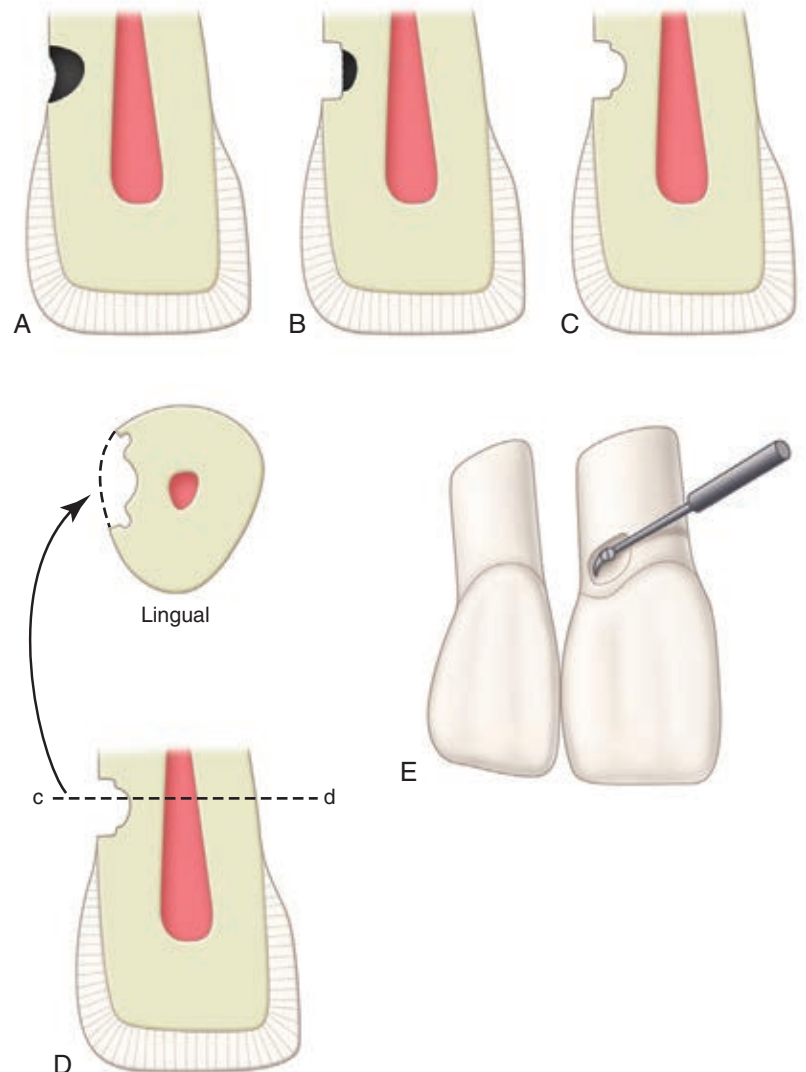


Fig. 9-33 Class III tooth preparation for a lesion entirely on the root surface. **A**, Mesiodistal longitudinal section illustrating a caries lesion. **B**, Initial tooth preparation. **C**, Tooth preparation with infected caries dentin removed. **D**, Retention grooves shown in longitudinal section. Transverse section through plane *cd* illustrates the contour of the axial wall and the direction of the facial and lingual walls. **E**, Preparing the retention form to complete the tooth preparation.

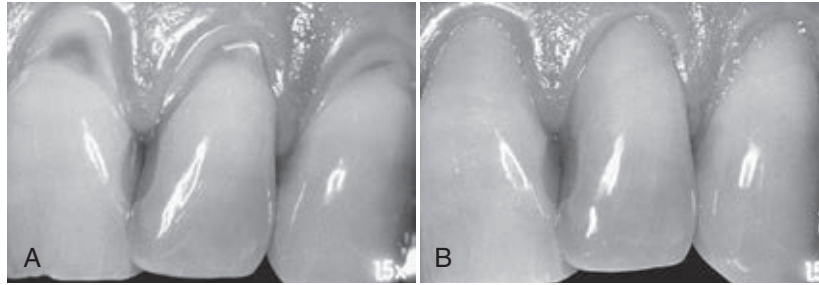


Fig. 9-34 Three typical resin-modified glass ionomer restorations are shown before (A) and after (B) treatment.

Chapters 10 and 14 and to Figure 9-33 for specific details.) With the exception of the matrix used (if needed), slot preparations for Class II and III restorations are restored in a similar manner to a Class V preparation.

Most conventional glass ionomer systems require mild dentin conditioning to remove the smear layer, effecting improved adhesion of the glass ionomer to dentin. To condition dentin, a mild acid, such as 10% polyacrylic acid, is applied to the preparation, according to manufacturer's instructions, followed by rinsing and removal of excess water, leaving dentin slightly moist. Some modified glass ionomer materials may have a substantial resin component and require a special primer to facilitate bonding. Each system should be used strictly according to the manufacturer's specific instructions.

Encapsulated glass ionomers for triturator mixing or paste-paste materials are greatly preferred to the original powder and liquid materials. Such systems optimize and simplify the mixing procedure. Glass ionomer material should be placed into the preparation in slight excess and quickly shaped with a composite instrument. Clear plastic cervical matrices also are available for providing contour to the restoration. If a conventional glass ionomer is used, a thin coat of light-activated, resin-based coating is placed on the surface immediately after placement to prevent dehydration and cracking of the restoration during the initial setting phase. Newer glass ionomers are more resistant to dehydration and do not typically require this step.

Conventional glass ionomers ideally require a polymerization period of 24 hours before final contouring and finishing. Most RMGIs available can, however, be contoured and finished immediately after light activation. (The manufacturer's recommendations should be followed to optimize clinical performance of the material.) When the material has set, the matrix, if used, is removed, and the gross excess is shaved away with a No. 12 surgical blade in a Bard-Parker handle. Contouring and finishing should be accomplished as much as possible with hand instruments, while striving to preserve the smooth surface that occurs on setting. If rotary instrumentation is needed, care must be taken not to dehydrate the surface of the restoration. Micron finishing diamonds used with a petroleum lubricant to prevent desiccation are ideal for contouring and finishing conventional glass ionomers. Also, flexible abrasive disks used with a lubricant can be effective. A fine-grit aluminum oxide polishing paste applied with a prophylax cup is used to impart a smooth surface. Three typical RMGI restorations are shown before and after treatment in Figure 9-34.

Summary

Techniques and rationales for the use of direct composite and glass ionomers for Class III, IV, and V restorations have been presented in this chapter. Composite is the material of choice for most Class III and IV restorations and most esthetically demanding Class V restorations. When accomplished correctly, composite restorations provide excellent dental treatment in these clinical situations. Common problems, potential solutions, and repair techniques for these types of restorations are presented in Chapter 8.

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Class I, II, and VI Direct Composite Restorations and Other Tooth-Colored Restorations

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Class I, II, and VI Direct Composite Restorations

Posterior composite restorations were introduced in the late 1960s and early 1970s.¹⁻⁷ Because of the improved physical properties of composites and bonding systems, studies typically report successful results for their use in posterior teeth.⁸⁻¹⁵ The American Dental Association (ADA) indicates the appropriateness of composites for use as pit-and-fissure sealants, preventive resin restorations, and Class I and II restorations for initial and moderate-sized lesions, using modified conservative tooth preparations.¹⁶ The ADA further states that “when used correctly in the primary and permanent dentition, the expected lifetime of resin-based composites can be comparable to that of amalgam in Class I, Class II, and Class V restorations.”¹⁷ The longevity of posterior composites, however, is directly related to factors such as the size of the restoration, the patient’s caries risk, and operator technique.^{15,18-23}

This chapter presents information about typical Class I, II, and VI direct composite restorations (Fig. 10-1), also known as *posterior composite restorations*. The chapter also presents information and techniques for pit-and-fissure sealants, preventive resin or conservative composite restorations, extensive Class II restorations, and foundations.

Pertinent Material Qualities and Properties

As presented in Chapter 8, composite is a material that has sufficient strength for Class I and II restorations. It is insulative and, in most cases, does not require pulpal protection with bases. Because composite is bonded to enamel and dentin, tooth preparations for composite can be very conservative. A composite restoration not only is retained well in the tooth, but also can strengthen the remaining unprepared tooth

structure.^{24,25} Class I and II composite restorations also have all the other benefits of bonding presented in Chapters 4 and 8.

Indications

Class I, II, and VI direct composite restorations are indicated for the restoration of primary caries lesions in the occlusal (Class I and VI) and proximal (Class II) surfaces of posterior teeth. When used in posterior teeth, direct composite will perform best in small- and moderate-sized restorations, preferably with enamel margins. Because composites are tooth-colored, these restorations are particularly indicated when esthetics is considered to be of primary importance. They also are indicated occasionally as large restorations that may serve as foundations for crowns. Additionally, in selected cases, large composite restorations may be used where an interim restoration is indicated or where economics or other factors preclude a more definitive restoration such as a crown.

Contraindications

The main contraindication for use of composite for Class I, II, and VI restorations is an operating area that cannot be adequately isolated. Class I and II composites also may be contraindicated for large restorations when heavy occlusal stresses are present.²⁶ In restorations in which the proximal box extends onto the root surface, posterior composites should only be used if absolutely required because of the difficulty in predictably bonding to the gingival wall absent an enamel margin. Extended (deep) gingival margins also can be more difficult to light-activate owing to their location. Whenever a defect extends onto the root surface, negative effects for the restoration may occur, no matter what restorative material is being used. Any extension onto the root surface requires the best and most meticulous efforts of the operator to ensure a successful,



Fig. 10-1 Composite restorations. A and B, Class I composite, before and after. C and D, Class II composite, before and after.

long-lasting restoration. This chapter presents information of alternative restorative techniques for such cases.

Advantages

The advantages of composite as a Class I and II direct restorative material relative to other restorative materials are:

1. Esthetics
2. Conservative tooth structure removal
3. Easier, less complex tooth preparation
4. Insulation
5. Decreased microleakage
6. Increased short-term strength of remaining tooth structure^{24,27}

Disadvantages

The disadvantages of Class I and II direct composite restorations are as follows:

1. Polymerization shrinkage effects
2. Lower fracture toughness than most indirect restorations
3. More technique-sensitive than amalgam restorations and some indirect restorations
4. Possible greater localized occlusal wear²⁸⁻³⁰
5. Unknown biocompatibility of some components (bisphenol A [BPA])

This chapter presents techniques for restoring the occlusal surface (including the occlusal thirds of facial and lingual surfaces) and proximal surface of posterior teeth with composite and other directly placed tooth-colored materials. The least invasive treatments are presented first, followed by progressively more involved methods of treatment. Consequently, the rationale and technique for pit-and-fissure sealants, preventive resin or conservative composite restorations, and Class VI composite restorations are presented first. Next, Class I and II composite restorations are presented, followed by composite foundations.

Pit-and-Fissure Sealants

Pits and fissures typically result from an incomplete coalescence of enamel and are particularly prone to caries. These areas can be sealed with a low-viscosity fluid resin after acid-etching. Long-term clinical studies indicate that pit-and-fissure sealants provide a safe and effective method of preventing caries.³¹⁻³³ In children, sealants are most effective when they are applied to the pits and fissures of permanent posterior teeth immediately on eruption of the clinical crowns, provided proper isolation can be achieved. Adults also can benefit from the use of sealants if the individual experiences an increase in caries susceptibility because of a change in diet, lack of adequate saliva, or a particular medical condition. Most currently used sealant materials are light-activated urethane dimethacrylate or BIS-GMA (bisphenol A-glycidyl

methacrylate) resins. Opaquers and tints frequently are added to sealants to produce color contrast to aid in visual assessment.

Indications

Sealants are indicated, regardless of the patient's age, for either preventive or therapeutic uses, depending on the patient's caries risk, tooth morphology, or presence of incipient enamel caries.

In assessing the occlusal surfaces of posterior teeth as potential candidates for a sealant procedure, the primary decision is whether or not a cavitated lesion exists. This decision is based primarily on radiographic and clinical examinations, although other technologies for occlusal caries detection are available. Explorers must be used judiciously in the detection of caries, as a sharp explorer tine may cause a cavitation. The clinical examination should be primarily focused on visual assessments of a clean tooth surface, preferably under adequate light and magnification. If the examination reveals chalkiness or softening of the tooth structure at the base or walls of the pit or groove, brown-gray discoloration radiating peripherally from the pit or groove, or radiolucency beneath the enamel surface on the radiograph, it is likely that an active caries lesion is present and a sealant may not be indicated. The patient's caries risk also should be considered when considering treatment options. See Chapter 3 for a discussion of emerging technologies for occlusal caries detection and monitoring, including laser fluorescence and alternative current (AC) impedance spectroscopy.

When no cavitated caries lesion is diagnosed, the treatment decision is either to pursue no treatment or to place a pit-and-fissure sealant, particularly if the surface is at high risk for future caries. If a small caries lesion is detected, and the adjacent grooves and pits, although sound at the present time, are at risk for caries in the future, a preventive resin restoration or conservative composite restoration (which combines a small Class I composite with a sealant) may be the treatment recommendation. Before any of these treatments are initiated, the operator must be certain that no interproximal (Class II) caries or fault exists.

Although studies show that sealants can be applied over small, cavitated lesions, with no subsequent progression of caries, sealants should be used primarily for the prevention of caries rather than for the treatment of existing caries lesions.^{34,35} A bitewing radiograph should be obtained and evaluated before sealant placement to ensure that no dentinal or proximal caries is evident. Only caries-free pits and fissures or incipient lesions in enamel not extending to the dentino-enamel junction (DEJ) currently are recommended for treatment with pit-and-fissure sealants.³⁶

Clinical Technique

Because materials and techniques vary, it is important to follow the manufacturer's instructions for the sealant material being used. A standard method for applying sealants to posterior teeth is presented here. Each quadrant is treated separately and may involve one or more teeth. The following discussion deals with a fissure present on a mandibular first permanent molar (Fig. 10-2, A). The tooth is isolated by using a rubber dam (or another effective isolation method such as

cotton rolls or Isolite). Isolation of the area is crucial to the success of the sealant. Sealant placement in younger patients is more common, and since molar teeth are often not fully erupted in these patients, isolation can be difficult. If proper isolation cannot be obtained, the bond of the sealant material to the tooth surface can be compromised, resulting in either loss of the sealant or caries under the sealant. The area is cleaned with a slurry of pumice on a bristle brush (see Fig. 10-2, B). Bristles reach into faulty areas better than a rubber prophyl cup can, which tends to burnish debris and pumice into the pits and fissures. The tooth is rinsed thoroughly, while the explorer tip is used carefully to remove residual pumice or additional debris. The tooth surface is dried, and etched with 35% to 40% phosphoric acid for 15 to 30 seconds. Liquid acid etchants were used in the past, but gel etchants are more popular now because they are easier to apply and to control. However, only gels that are sufficiently fluid to penetrate the grooves and fissures should be used. Airborne particle abrasion techniques have been advocated for preparing pits and grooves before sealant placement, but their effectiveness has not been fully investigated yet.³⁷

One technique that is used by many clinicians, especially in cases where occlusal caries could be present in deep grooves, is to lightly prepare the suspicious grooves with a thin flame-shaped diamond to lightly roughen the enamel, remove the fluoride-rich enamel that is more impervious to acid-etching, and open the grooves and fissures for better resin penetration. If caries is noted to extend toward the DEJ, the preparation is then approached as a preventive resin restoration (see the next section in this Chapter).

Properly acid-etched enamel surface has a lightly frosted appearance (see Fig. 10-2, C). Fluoride-rich, acid-resistant enamel may need to be etched for a longer time. Any brown stains that originally may have been in the pits and fissures still may be present and should be allowed to remain. The sealant material is then applied with an applicator or small hand instrument. The sealant is gently teased into place, to avoid entrapping air, and it should overfill slightly all pits and fissures, but it should not extend onto unetched surfaces. If too much sealant is applied, excess can be removed with a microbrush prior to light-activation. After light-activation and removal of the rubber dam, if used, the occlusion is evaluated by using articulating paper. If necessary, a round carbide finishing bur or white stone is used to remove any excess sealant. The surface usually does not require further polishing.

Preventive Resin and Conservative Composite Restorations

When restoring minimally carious pits and fissures on an unrestored tooth, an ultraconservative preparation design is recommended. This design allows for restoration of the lesion or defect with minimal removal of the tooth structure and often may be combined with the use of flowable composite or sealant to seal radiating non-carious fissures or pits that are at high risk for subsequent caries activity (Fig. 10-3). Originally referred to as a preventive resin restoration, this type of ultraconservative restoration is now termed *conservative composite restoration* at the University of North Carolina.^{38,39} An accurate diagnosis is essential before restoring the occlusal surface of a posterior tooth. The crucial factor in this clinical assessment

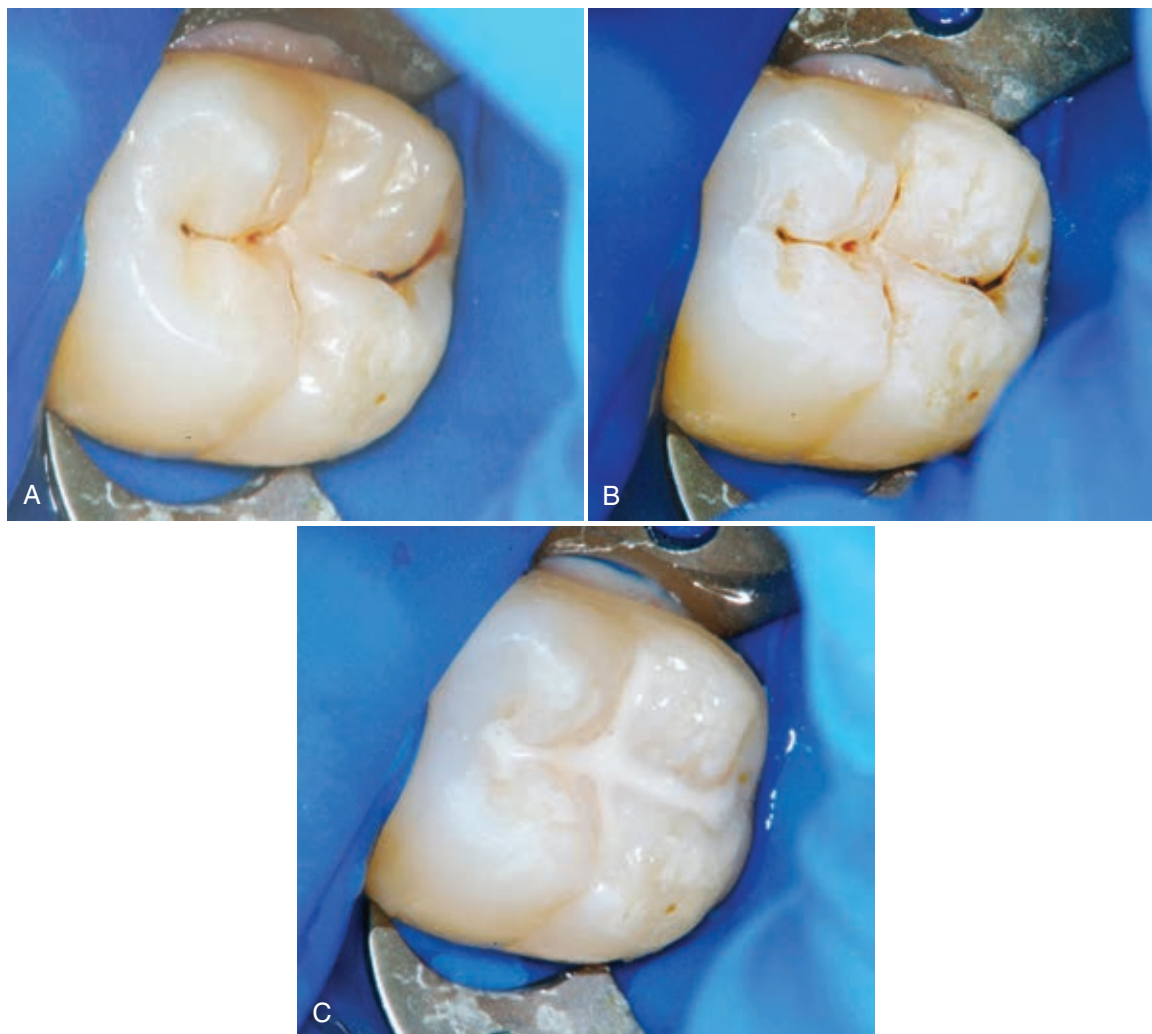


Fig. 10-2 Steps in application of pit-and-fissure sealant. **A**, After isolation and thorough cleaning of the occlusal surface to be sealed. **B**, After acid-etching, rinsing, and drying. **C**, With sealant applied.

is whether or not the suspicious pit or fissure has active caries that requires restorative intervention. Usually, a conservative composite restoration is the treatment of choice for the primary occlusal caries lesion as the tooth preparation can be minimally invasive.

Sometimes, if a definitive diagnosis of caries cannot be made, an exploratory preparation of the suspicious area is performed with a small bur or diamond (Fig. 10-4). This approach is particularly indicated in patients at high risk for caries. The objective of this procedure is to explore suspicious pits or grooves with a very small bur or diamond to determine the extent of the suspected fault. As the tooth preparation is deepened, an assessment is made in the suspicious areas to determine whether or not to continue the preparation toward the DEJ (see Fig. 10-4, C). If the suspicious fault is removed or found to be sound at a shallow preparation depth (minimal dentin caries), the conservative exploratory preparation and adjacent pits and fissures are etched with 35% to 40% phosphoric acid for 15 to 30 seconds, rinsed thoroughly, and lightly dried. The etched surfaces then are treated with an adhesive, which is placed and light-activated, according to manufacturer's instructions. The conservatively prepared area can then be

restored with a flowable composite, which is placed and light-activated, according to manufacturer's instructions. The adjacent etched pits and fissures, if judged to be at risk, can then be sealed using a pit-and-fissure sealant or the same flowable composite following the technique described previously. If the suspicious area is found to be carious, the preparation depth is extended until all of the caries is removed, and the prepared area is then restored with composite as described later in this chapter (Class I direct composite restoration), and unprepared pits and fissures are sealed. In the example presented in Fig. 10-4, the preparation was restored with composite.

An example of a conservative composite restoration is illustrated in Figure 10-5, A. All initial examinations are inconclusive relative to a definitive diagnosis of active caries in this site. Figure 10-5, B through D, shows the initial, exploratory tooth preparation of the fissure. The initial depth is kept just into dentin where caries is present. Where caries is not present, the preparation stops on enamel. The occlusal extension is complete when a caries-free DEJ is reached. If dentin at the pulpal floor is judged to be infected as evidenced by a soft feel or "stick" of the explorer, a larger round bur, No. 330 bur or diamond, or No. 245 bur or diamond is used to extend the

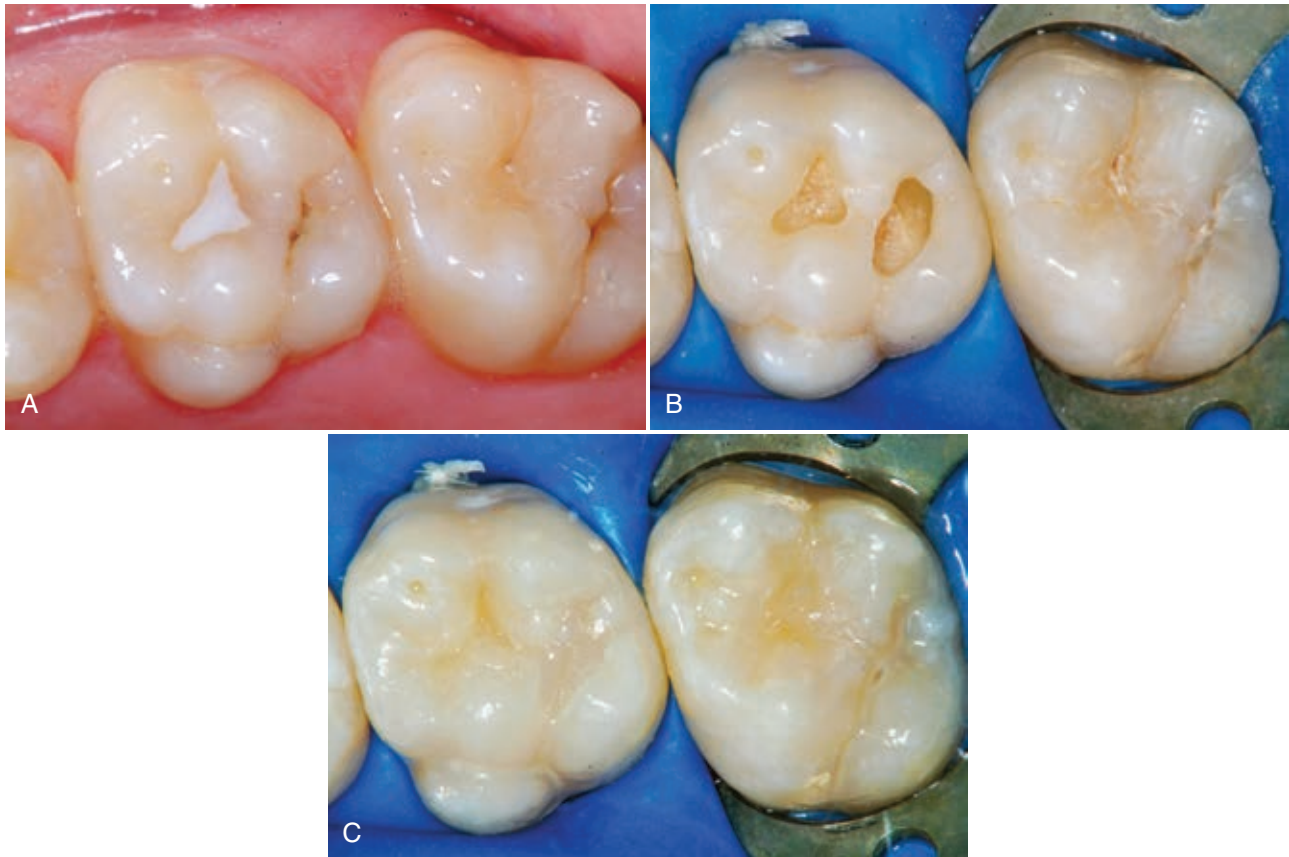


Fig. 10-3 Conservative composite restoration. **A**, Occlusal view of the maxillary first and second molars. The first molar has caries on the distal occlusal pit, and the second molar has suspicious pit on the disto-occlusal aspect. **B**, Caries was excavated from the first molar, and the second molar was minimally prepared. **C**, The first molar was restored with composite, and the second molar received a conservative composite restoration with flowable composite.

preparation pulpally into these areas. It is not necessary to extend the preparation in a pulpal direction if only a hard, dark line remains that cannot be penetrated by a sharp explorer, and the radiograph is negative for dentinal caries. If necessary, the preparation is completed by using a flame-shaped diamond instrument to flare the cavosurface margin (see Fig. 10-5, *E*). This flare may be widened to include any terminal ends of fissures, as illustrated in Figure 10-6. If no radiating fissures exist, the flaring is not necessary because of the enamel rod direction in this area, especially if steep cuspal inclines are present.

Clinical Technique for Class VI Direct Composite Restorations

One of the most conservative indications for a directly placed posterior composite is a small faulty developmental pit located on a cuspal tip. Figure 10-7, *A*, is an example of a Class VI defect on the facial cuspal tip of a maxillary premolar. The typical Class VI tooth preparation should be as small in diameter and as shallow in depth as possible. The faulty pit is entered with an appropriate round bur or diamond oriented perpendicular to the surface and extended pulpally to eliminate the lesion (see Fig. 10-7, *B*). Visual examination and probing with an explorer often reveal that the fault is limited to enamel because

the enamel in this area is quite thick. If a faulty restoration or extensive caries is present on the cuspal tip, a round bur of appropriate size is used for removing the faulty restoration or excavating remaining infected dentin. Stains that appear through the translucent enamel should be removed; otherwise, they may be seen after the composite restoration is completed. Some undermined, but not friable, enamel may be left and bonded to the composite.

Clinical Technique for Class I Direct Composite Restorations

Initial Clinical Procedures

The same general procedures described previously in Chapters 7 and 8 regarding anesthesia, shade selection, occlusal relationship, and isolation of the operating field are necessary before beginning a Class I composite restoration.

Tooth Preparation

As a general rule, similar to the tooth preparation for direct anterior restorations, the tooth preparation for direct posterior composites involves (1) creating access to the faulty structure, (2) removal of faulty structures (caries, defective restoration and base material, if present), and (3) creating



Fig. 10-4 Class I direct composite restoration and conservative composite restoration. **A**, Mandibular second molar with suspicious occlusal pits; mandibular first molar with questionable sealant. **B**, After rubber dam isolation. **C**, Initial exploratory preparation reveals caries extending toward the dentinoenamel junction (DEJ). **D**, Conservative preparation on the second molar; the first molar was minimally prepared. **E**, Complete Class I direct composite restoration on the second molar; the first molar received a conservative composite restoration with flowable composite. **F**, Final restorations after the rubber dam was removed and the occlusion was checked.

convenience form for the restoration. Retention is obtained by bonding. When placing most posterior composites, it is not necessary to incorporate mechanical retention features in the tooth preparation.

Small to Moderate Class I Direct Composite Restorations

Small to moderate Class I direct composite restorations may use minimally invasive tooth preparations and do not require typical resistance and retention form features. Instead, these

conservative preparations typically use more flared cavosurface forms without uniform or flat pulpal or axial walls. These preparations are less specific in form, having a scooped-out appearance. They are prepared with a small round or elongated pear diamond or bur with round features. The initial pulpal depth is approximately 0.2 mm inside the DEJ but may not be uniform (i.e., the pulpal floor is not flat throughout its length). Usually, a more rounded, and perhaps smaller, cutting instrument is used for this preparation, in an attempt to be as conservative as possible in the removal of the tooth structure. If a round instrument is used, the resulting cavosurface margin

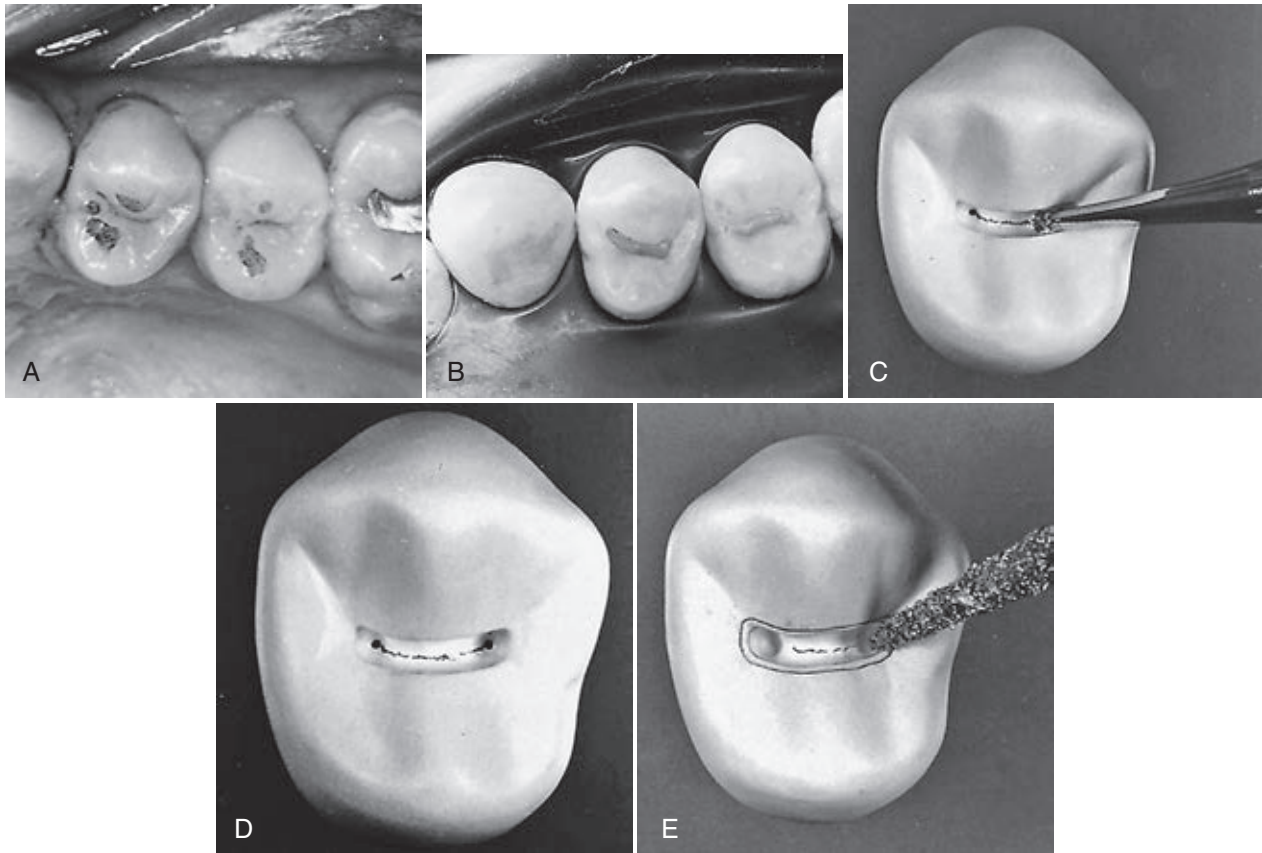


Fig. 10-5 Conservative composite restoration preparation. **A** and **B**, Clinical examples of fissures and final exploratory tooth preparations. **C**, Preparation is made with a No. 1 or No. 2 bur or similar diamond. **D**, Initial extensions. Pit remnants remain. **E**, Carious pits excavated and preparation roughened (*margins highlighted*).

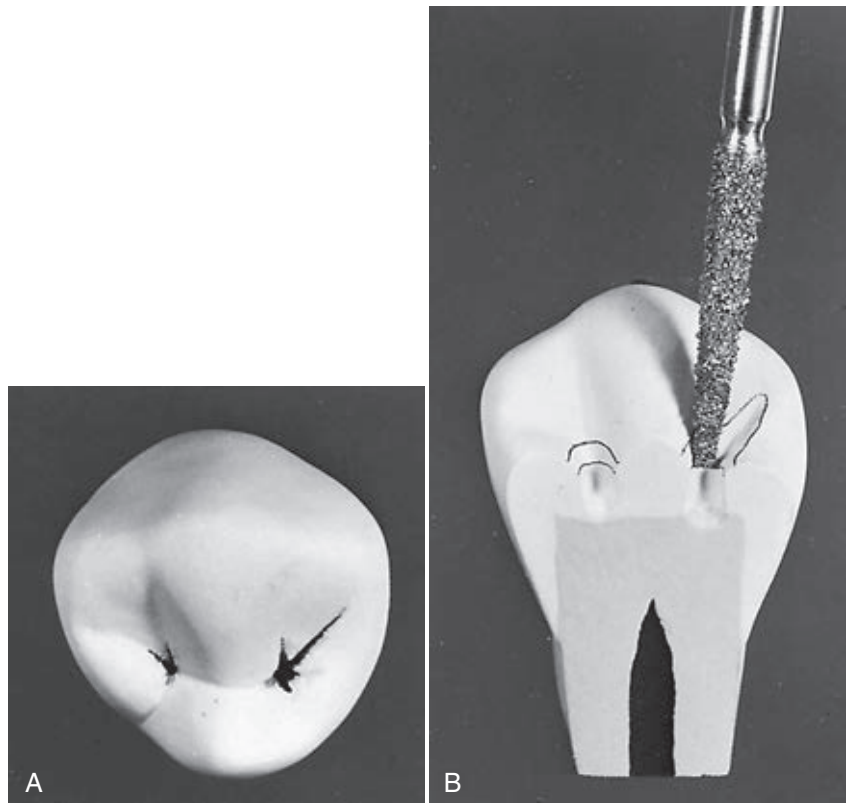


Fig. 10-6 Conservative composite restoration preparation. **A**, Two small, faulty pits are often present on a mandibular first premolar. **B**, Preparations are accomplished with coarse diamond.

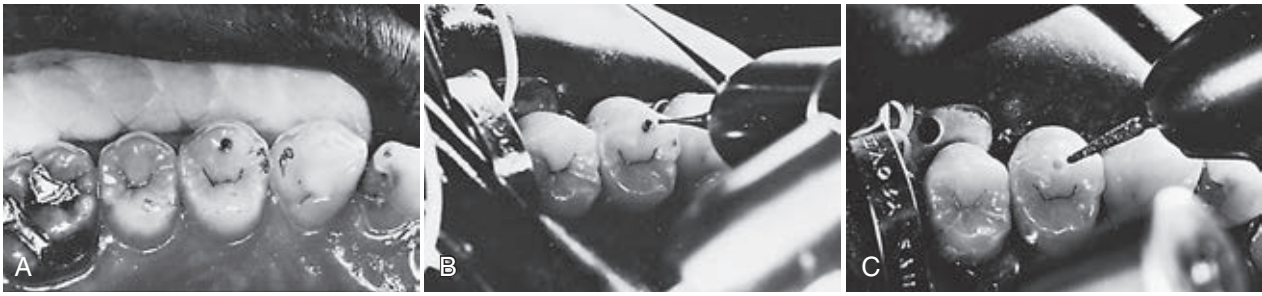


Fig. 10-7 Class VI tooth preparation for composite restoration. **A**, Class VI preparation on the facial cusp tip of the maxillary premolar. **B**, Entry with small round bur or diamond. **C**, Preparation roughened with diamond, if necessary.

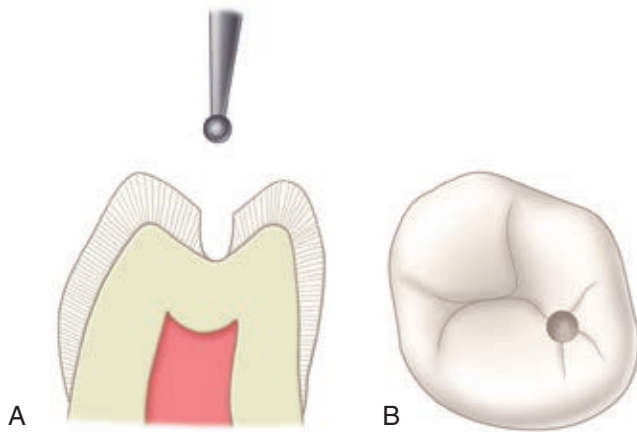


Fig. 10-8 Faciolingual cross-section of small Class I tooth preparation using round diamond.

angle may be more flared (obtuse) than if an elongated pearl instrument is used (Fig. 10-8).

Various cutting instruments may be used for Class I and II tooth preparations; the size and shape of the instrument generally are dictated by the size of the lesion or other defect or by the type of defective restoration being replaced. Both carbide and diamond instruments can be used effectively. It should be noted that diamond instruments create a thicker smear layer, however, which might make bonding more difficult for self-etch bonding systems.⁴⁰⁻⁴³

Moderate to Large Class I Direct Composite Restorations

Moderate to large Class I direct composite restorations, especially when used for larger caries lesions or to replace existing defective amalgam restorations, will typically feature flat walls that are perpendicular to occlusal forces, as well as strong tooth and restoration marginal configurations. All of these features help resist potential fracture in less conservative tooth preparations. However, the preparation should never be excessively extended beyond removal of faulty structures to justify resistance and retention forms, as this will weaken the tooth structure and can ultimately lead to failure of the tooth-restoration unit. If the occlusal portion of the restoration is expected to be extensive, elongated pearl cutting instruments with round features are preferred because they result in strong, 90-degree cavosurface margins. However, this box-like form

preparation may increase the negative effects of the configuration factor (C-factor). (See the section on inserting and light-activating the composite for other considerations regarding the C-factor for Class I direct composite restorations.) The objective of the tooth preparation is to remove all of the caries or fault as conservatively as possible. Because the composite is bonded to the tooth structure, other less involved, or at-risk, areas can be sealed as part of the conservative preparation techniques. Sealants may be combined with the Class I composite restoration, as described previously.

In large composite restorations, the tooth is entered in the area most affected by caries, with the elongated pearl diamond or bur positioned parallel to the long axis of the crown. When it is anticipated that the entire mesiodistal length of a central groove will be prepared, it is easier to enter the distal portion first and then transverse mesially. This technique permits better vision to the operator during the preparation. The pulpal floor is prepared to an initial depth that is approximately 0.2 mm internal to the DEJ (Fig. 10-9). The instrument is moved mesially, following the central groove, and any fall and rise of the DEJ (see Fig. 10-9, B). Mesial, distal, facial, and lingual extensions are dictated by the caries, old restorative material, or defect, always using the DEJ as a reference for both extensions and pulpal depth. The cuspal and marginal ridge areas should be preserved as much as possible. Although the final bonded composite restoration would help restore some of the strength of weakened, unprepared tooth structure, the outline form should be as conservative as possible. Extensions toward cusp tips should be as minimal as possible. Extensions into marginal ridges should result in at least 1.5 mm of remaining tooth structure (measured from the internal extension to the proximal height of contour) for premolars and approximately 2 mm for molars (Fig. 10-10). These limited extensions help preserve the dentinal support of the marginal ridge enamel and cusp tips.

As the instrument is moved along the central groove, the resulting pulpal floor is usually moderately flat (as a result of the shape of the tip of the instrument) and follows the rise and fall of the DEJ. If extension is required toward the cusp tips, the same depth that is approximately 0.2 mm inside the DEJ is maintained, usually resulting in the pulpal floor rising occlusally (Fig. 10-11). The same uniform depth concept also is appropriate when extending a facial or lingual groove radiating from the occlusal surface. When a groove extension is through the cusp ridge, the instrument prepares the facial (or lingual) portion of the faulty groove at an axial depth of 0.2 mm inside the DEJ and gingivally to include all caries and other defects (Fig. 10-12).

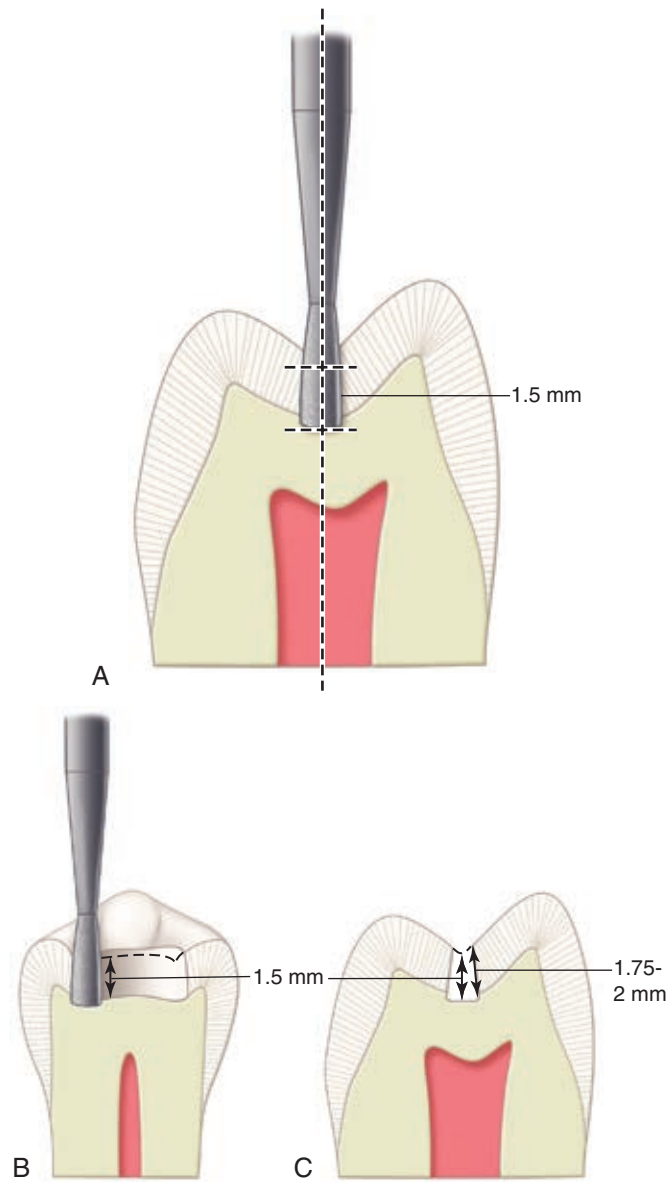


Fig. 10-9 **A**, Entry cut. Diamond or bur held parallel to the long axis of the crown. Initial pulpal depth is 1.5 mm from the central groove. When the central groove is removed, facial and lingual wall measurements usually are greater than 1.5 mm. (The steeper the wall, the greater is the height.) **B**, 1.5-mm depth from the central groove. **C**, Approximately 1.75- to 2-mm facial or lingual wall heights.

After extending the outline form to sound tooth structure, if any caries or old restorative material remains on the pulpal floor, it should be removed with the appropriately-sized round bur or hand instrument. The occlusal margin is left as prepared. No attempt is made to place additional beveling on the occlusal margin because it may result in thin composite in areas of heavy occlusal contact. Because of the occlusal surface enamel rod direction, the ends of the enamel rods already are exposed by the preparation, which further reduces the need for occlusal bevels.

Although large, extensive posterior composite restorations may have some potential disadvantages when used routinely, “real world” dentistry sometimes necessitates esthetic

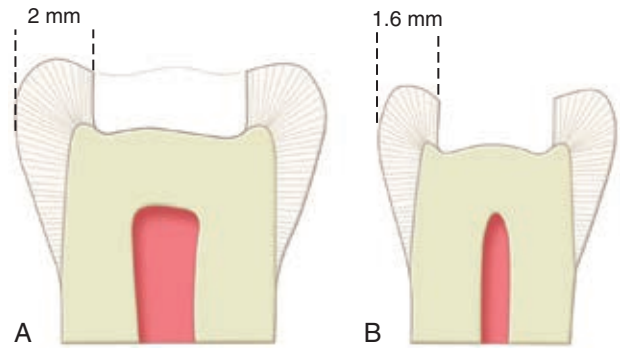


Fig. 10-10 Mesiodistal extension. Preserve dentin support of marginal ridge enamel. **A**, Molar. **B**, Premolar.

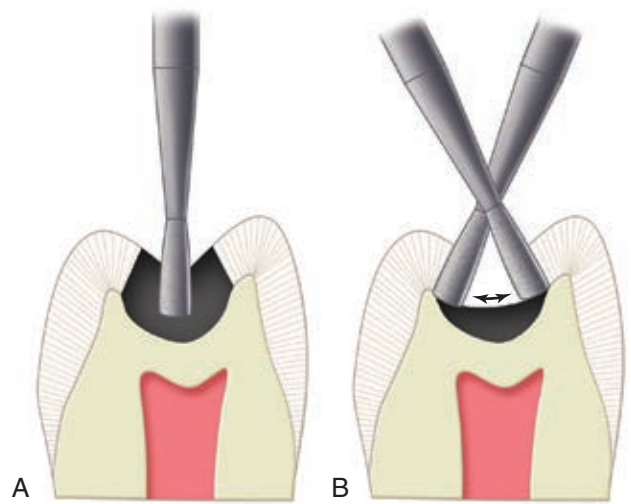


Fig. 10-11 **A**, After initial entry cut at correct initial depth (1.5 mm), the caries remains facially and lingually. **B**, Orientation of diamond or bur must be tilted as the instrument is extended facially or lingually to maintain a 1.5-mm depth.

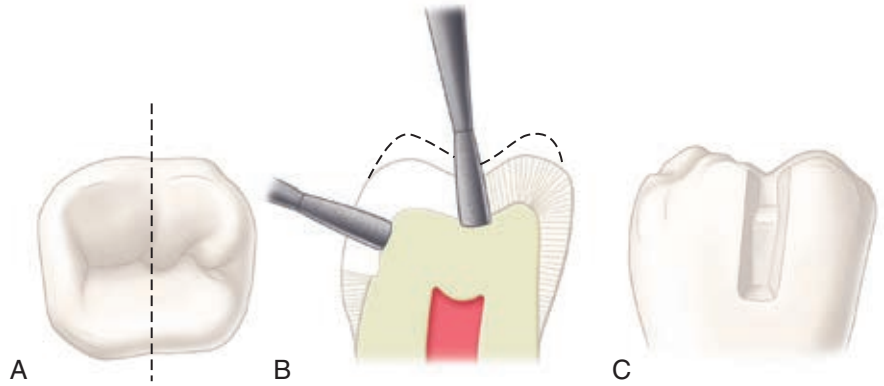
treatment alternatives that may provide a needed service to the patient. Often, patients simply cannot afford a more expensive esthetic restoration, or they may have dental or medical conditions that preclude their placement. In such instances, large posterior composite restorations sometimes can be used as a reasonable alternative when more permanent options are not possible or realistic.

Restorative Technique

Placement of the Adhesive

Techniques for the placement of the adhesive are the same as described in Chapter 9. See Chapter 4 for a more extensive discussion on adhesives. When using an etch-and-rinse adhesive, over-drying the etched dentin can compromise dentin bonding.⁴⁴⁻⁴⁶ Aqueous solutions containing glutaraldehyde and 2-hydroxyethyl methacrylate (HEMA) can be used as a re-wetting agent when using etch-and-rinse systems.⁴⁷⁻⁵⁰ The bonding agent is applied to the entire preparation with a microbrush, in accordance with the manufacturer’s instructions. After application, the adhesive is polymerized with a light-activation unit, as recommended by the manufacturer.

Fig. 10-12 Groove extension. **A**, Cross-section through the faciolingual groove area. **B**, Extension through cusp ridge at 1.5-mm initial pulpal depth; the facial wall depth is 0.2 mm inside the dentinoenamel junction (DEJ). **C**, Facial view.



When the final tooth preparation is judged to be near the pulp in vital teeth, the operator may elect to use a base material prior to placing the adhesive and the composite. If the remaining dentin thickness (RDT) is between 0.5 and 1.5 mm, a resin-modified glass ionomer (RMGI) base is used; if the RDT is less than 0.5 mm, a calcium hydroxide liner should be applied to the deepest aspect of the preparation, then protected with an RMGI base prior to adhesive placement.⁵¹

Insertion and Light-Activation of the Composite

A matrix is usually not necessary for Class I direct composite restorations, even when facial and lingual surface grooves are included. The composite should not be dispensed until it is ready to use because it may begin to polymerize from the ambient light in the operatory. Because of variations in materials, each manufacturer's specific instructions should be followed.

Composite insertion hand instruments or a compule may be used to insert the composite material. The dispenser, for example, a syringe or compule, must be kept covered when not in use to prevent premature hardening of the material. Small increments of composite material are added and successively light-activated (Fig. 10-13). It is important to place (and light-activate) the composite incrementally to maximize the polymerization depth of cure and possibly to reduce the negative effects of polymerization shrinkage.

The term "configuration factor" or "C-factor" has been used to describe the ratio of bonded to unbonded surfaces in a tooth preparation and restoration. A typical Class I tooth preparation will have a high C-factor of 5 (five bonded surfaces—pulpal, facial, lingual, mesial, and distal—vs. one unbonded surface—occlusal). The higher the C-factor of a tooth preparation, the higher the potential for composite polymerization shrinkage stress, as the composite shrinkage deformation is restricted by the bonded surfaces. Incremental insertion and light-activation of the composite may reduce the negative C-factor effects for Class I composite restorations.⁵²⁻⁵⁵

The use of an RMGI liner or a flowable composite liner also may reduce the effects of polymerization shrinkage stress because of their favorable elastic modulus (more elastic material will more effectively absorb polymerization stresses).^{56,57} When composite is placed over an RMGI material, this technique is often referred to as a "sandwich" technique. The potential advantages of this technique are (1) the RMGI

material bonds to the dentin without opening the dentinal tubules, reducing the potential for post-operative sensitivity;⁵⁸ (2) the RMGI material, because of its bond to dentin and potential for fluoride release (potential anti-cariogenicity), provides a better seal when used in cases where the preparation extends gingivally onto root structure;⁵⁹ and (3) the favorable elastic modulus of the RMGI reduces the effects of polymerization shrinkage stresses. These suggested advantages are considered controversial, as no published research based on longitudinal clinical trials evaluating the technique is available.

Flowable composites also are advocated as liners under posterior composite restorations. The purported primary advantage is that they may reduce some of the negative effects of polymerization shrinkage because of their very favorable elastic modulus.^{60,61} Again, results are equivocal with regard to the available research.

When it is necessary to extend a composite restoration onto the root surface, the use of an RMGI liner beneath the portion of the restoration on the root surface may decrease microleakage, gap formation, and recurrent caries.^{59,62-66} In those circumstances, the use of an RMGI material is a valid option. Likewise, the use of an RMGI, flowable composite, filled dentin adhesive, coupled with the incremental insertion and curing of the composite may offset the negative effects of a high C-factor for Class I composite restorations.^{56,57}

Regardless of the effect of incremental placement on shrinkage stress, posterior composites should be placed incrementally to facilitate proper light-activation and development of correct anatomy. Especially in Class I direct composite restorations, the anatomic references of the occlusal unprepared tooth structure should guide the placement and shaping of the composite increments (see Figs. 10-1, A and B, 10-13, G, and 10-14, J). If needed, very deep portions of the tooth preparation are restored first, with increments of no more than 2 mm in thickness (see Fig. 10-13, B). The "enamel layer" of the restoration, that is, the occlusal 1.5-3 mm, should be placed using an anatomic layering technique.²⁰ The operator places and shapes the composite before it is light-activated so that the composite restores the occlusal anatomy of the tooth. Typically, the operator places and light-activates one increment per cusp at a time and continues to place subsequent increments until the preparation is filled and the occlusal anatomy is fully developed (see Fig. 10-13, C through F). The uncured composite can be shaped against the unprepared cusp inclines, which will result in a very natural anatomic

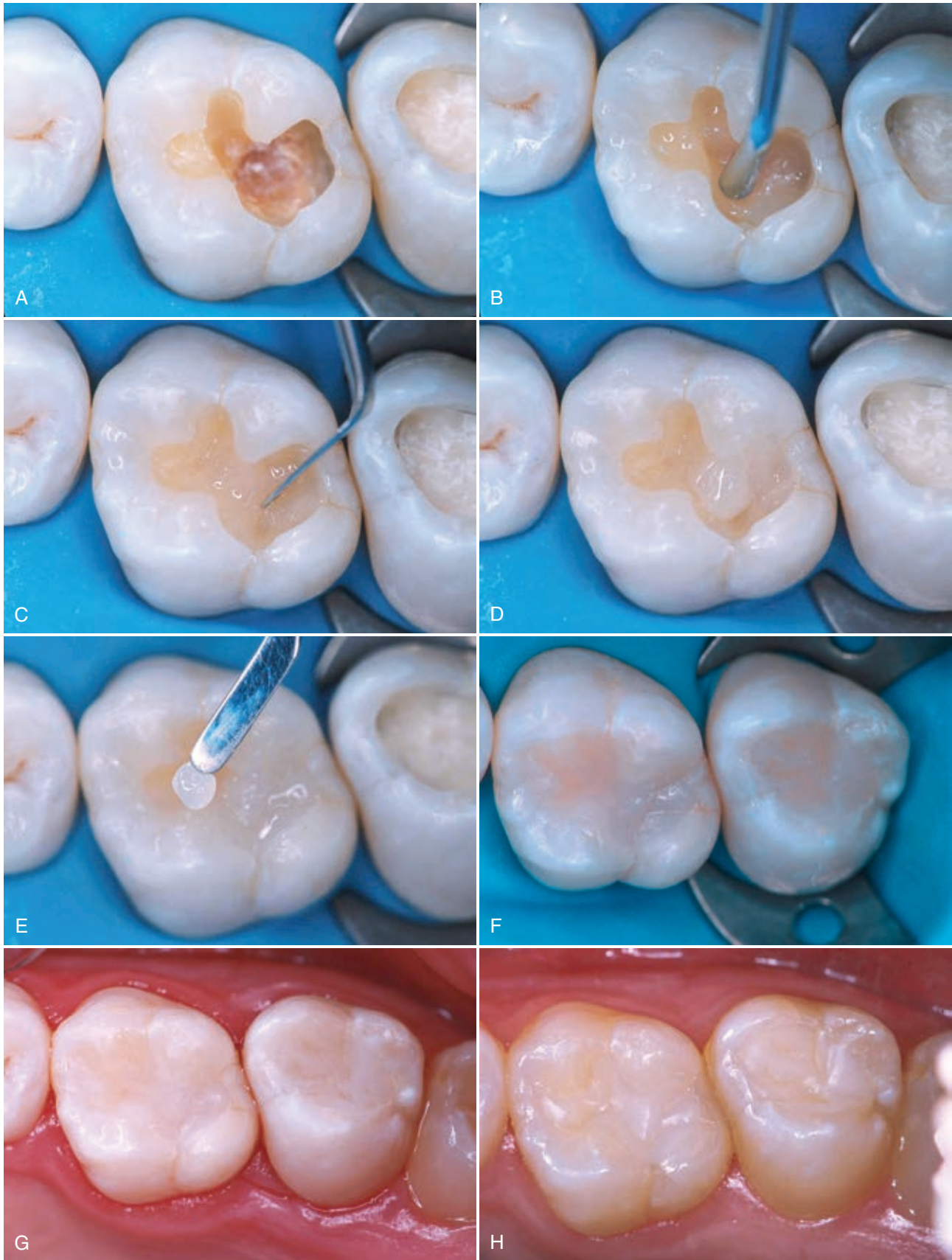


Fig. 10-13 Class I composite incremental insertion. **A**, Tooth preparation for Class I direct composite restoration. **B**, After a resin-modified glass ionomer base is placed, the first composite increment is inserted and light-activated. **C–F**, Composite is inserted and light-activated incrementally, using cusp inclines as anatomic references to sculpt the composite before light-activation. **G**, Completed restorations. **H**, At 5-year follow-up.

contour. Sculpture of the occlusal elements of the restoration following the anatomic references of the tooth respects the tooth's anatomy and occlusion and minimizes the need for contouring and finishing after the composite is polymerized. Furthermore, this technique prevents damage to the restoration margins because it minimizes the need to use rotary instruments to remove excess composite in those margins. Any suitable hand composite instruments can be used with the anatomic layering technique. Fine composite spatulas and the tine of an explorer can be used to further develop or refine the anatomy of uncured composite increments. Micro-brushes also can be used to smooth uncured composite against the preparation margin, but these should never be saturated with adhesives. Once the composite is fully cured, if additional contouring is needed, the restoration can be contoured and finished immediately after the last increment is cured.

Contouring and Polishing of the Composite

If the composite is carefully placed and shaped before light activation, as described in the previous section, additional contouring with burs is substantially minimized. However, in many cases, refined contouring may be needed, especially when occlusion adjustments are necessary. The occlusal surface is shaped with a round or oval carbide finishing bur or similarly shaped finishing diamonds. Finishing is accomplished with appropriate polishing cups, points, or both after the occlusion is adjusted as necessary (Fig. 10-14). Artful

insertion of the composite reduces the need to develop occlusal anatomy with rotary instruments.

Clinical Technique for Class II Direct Composite Restorations

Initial Clinical Procedures

The same general procedures as described previously are necessary before beginning a Class II composite restoration. Several aspects of those activities, however, need emphasis. First, an assessment of the expected tooth preparation extensions (outline form) should be made and a decision rendered on whether or not an enamel periphery will exist on the tooth preparation, especially at the gingival margin. The expected presence of an enamel periphery strengthens the choice of composite as the restorative material because of the most predictable bonding to that substrate. If the preparation is expected to extend onto the root surface, potential problems with isolation of the operating area, adequate adhesion to the root dentin, and adequate composite polymerization exist. Good technique, proper use of the material, and use of a glass ionomer material on the root surface portion may reduce these potential problems.^{59,62,63,65,66,67}

Second, the pre-operative occlusal relationship of the tooth to be restored must be assessed. The presence of heavy occlusal contacts may indicate that wear may be more of a consideration. Also, preoperative wedging in the gingival embrasure of



Fig. 10-14 Contouring and polishing of Class I composite. **A**, Mandibular molar with old amalgam restoration. **B**, Rubber dam isolation; old restoration is carefully removed to minimize increasing preparation size. **C**, Final tooth preparation. **D**, Incremental placement of composite.



Fig. 10-14, cont'd **E**, Incremental placement of composite. **F**, Rubber dam is removed and occlusion checked. **G**, Buccal view, a finishing fluted bur is used to selectively adjust the occlusion. **H**, Polishing with brush and diamond paste. **I**, Completed restoration.

the proximal surfaces to be restored should occur. Placing wedges, bitine rings, or both before tooth preparation begins the separation of teeth, which may be beneficial in the re-establishment of the proximal contact with the composite restoration.

Tooth Preparation

Similar to the tooth preparation for Class I direct composite restorations, the tooth preparation for Class II direct composites involves (1) creating access to the faulty structure, (2) removal of faulty structures (caries, defective restoration and base material, if present), and (3) creating the convenience form for the restoration. Retention, as with Class I

restorations, is obtained by bonding, so it is not necessary to use mechanical retention features in the tooth preparation of Class II composite restorations.

Small Class II Direct Composite Restorations

Small Class II direct composite restorations are often used for primary caries lesions, that is, initial restorations. A small round or elongated pearl diamond or bur with round features may be used for this preparation to scoop out the carious or faulty material from the occlusal and proximal surfaces. The pulpal and axial depths are dictated only by the depth of the lesion and are not uniform. The proximal extensions likewise are dictated only by the extent of the lesion but may require

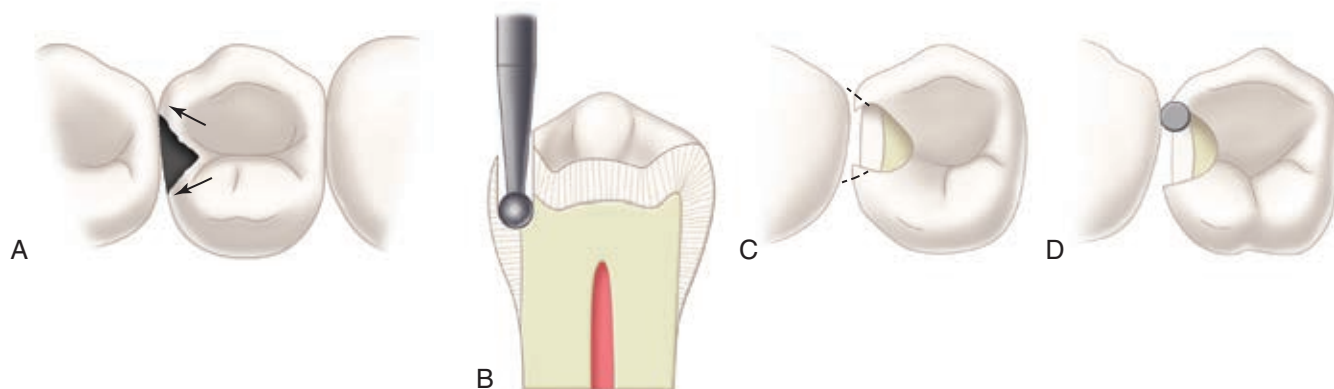


Fig. 10-15 Class II direct composite tooth preparation. **A**, Pre-operative visualization of faciolingual proximal box extensions. Arrows indicate desired extensions. **B**, Round or oval, small elongated pear instrument used. **C** and **D**, Facial, lingual, and gingival margins may need undermined cavosurface enamel (indicated by dotted lines) removed with straight-sided thin and flat-tipped rotary instrument or hand instrument.

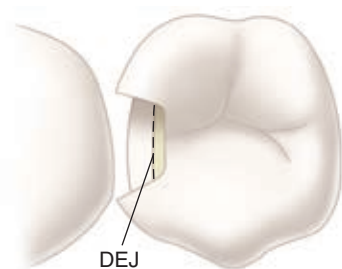


Fig. 10-16 Box-only Class II composite preparation.

the use of another instrument with straight sides to prepare walls that are 90 degrees or greater (Fig. 10-15). The objectives are to remove caries or the defect conservatively and remove friable tooth structure.

Another conservative design for small Class II composites is the box-only tooth preparation (Fig. 10-16). This design is indicated when only the proximal surface is defective, with no lesions on the occlusal surface. A proximal box is prepared with a small elongated pear or round instrument, held parallel to the long axis of the tooth crown. The instrument is extended through the marginal ridge in a gingival direction. The axial depth is dictated by the extent of the caries lesion or fault. The form of the box depends on which instrument shape is used—the more box-like with the elongated pear and the more scooped with the round. The facial, lingual, and gingival extensions are dictated by the defect or caries. No beveling or secondary retention is indicated.

A third conservative design for restoring proximal lesions on posterior teeth is the facial or lingual slot preparation (Fig. 10-17). Here, a lesion is detected on the proximal surface, but the operator believes that access to the lesion can be obtained from either a facial direction or a lingual direction, rather than through the marginal ridge in a gingival direction. Usually, a small round diamond or bur is used to gain access to the lesion. The instrument is oriented at the correct occluso-gingival position, and the entry is made with the instrument as close to the adjacent tooth as possible, preserving as much of the facial or lingual surface as possible. The preparation is

extended occlusally, facially, and gingivally enough to remove the lesion. The axial depth is determined by the extent of the lesion. The occlusal, facial, and gingival cavosurface margins are 90 degrees or greater. Care should be taken not to undermine the marginal ridge during the preparation.

Moderate to Large Class II Direct Composite Restorations

The tooth preparation for moderate to large Class II direct composite restorations has features that resemble a more traditional Class II amalgam tooth preparation and include an occlusal step and a proximal box.

OCCUSAL STEP

The occlusal portion of the Class II preparation is prepared similarly as described for the Class I preparation. The primary differences are related to technique of incorporating the faulty proximal surface. Pre-operatively, the proposed facial and lingual proximal extensions should be visualized (see Fig. 10-15, A). Initial occlusal extension toward the involved proximal surface should go through the marginal ridge area at initial pulpal floor depth, exposing the DEJ. The DEJ serves as a guide for preparing the proximal box portion of the preparation.

A No. 330 or No. 245 shaped diamond or bur is used to enter the pit next to the carious proximal surface. The instrument is positioned parallel with the long axis of the tooth crown. If only one proximal surface is being restored, the opposite marginal ridge dentinal support should be maintained (Fig. 10-18).

The pulpal floor is prepared with the instrument to a depth that is approximately 0.2 mm inside the DEJ. The instrument is moved to include caries and all defects facially or lingually or both, as it transverses the central groove. Every effort should be made, however, to keep the faciolingual width of the preparation as narrow as possible. The initial depth is maintained during the mesiodistal movement, but follows the rise and fall of the underlying DEJ. The pulpal floor is relatively flat in a faciolingual plane but may rise and fall slightly in a mesiodistal plane (see Fig. 10-9). If caries remains in dentin, it is removed

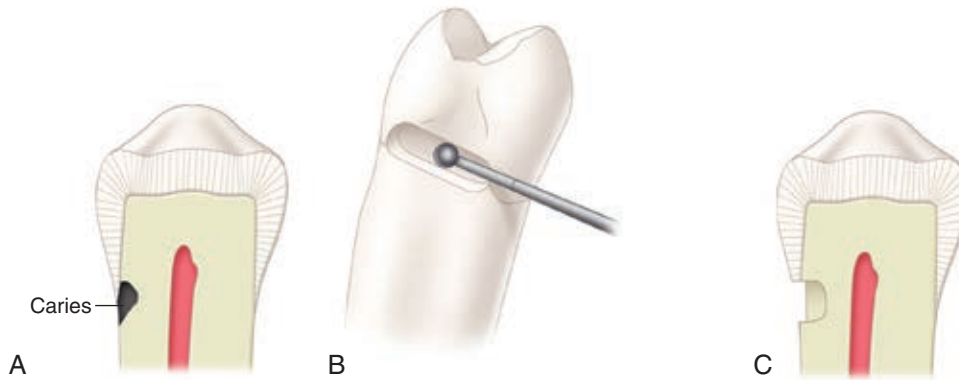


Fig. 10-17 Facial or lingual slot preparation. **A**, Cervical caries on the proximal surface. **B**, The round diamond or bur enters the tooth from the accessible embrasure, oriented to the occlusogingival middle of the lesion. **C**, Slot preparation.

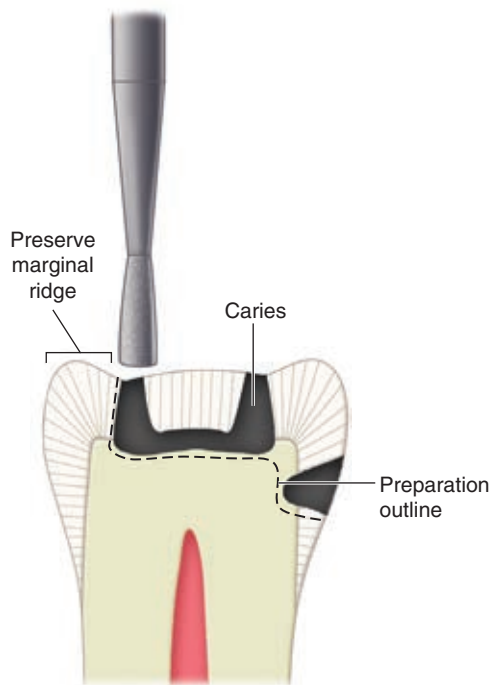


Fig. 10-18 When only one proximal surfaces is affected, the opposite marginal ridge should be maintained.

after the preparation outline, including the proximal box extensions, has been established.

Because the facial and lingual proximal extensions of the faulty proximal surface were visualized preoperatively, the occlusal extension toward that proximal surface begins to widen facially and lingually to begin to outline those extensions as conservatively as possible. Care is taken to preserve cuspal areas as much as possible during these extensions. At the same time, the instrument extends through the marginal ridge to within 0.5 mm of the outer contour of the marginal ridge. This extension exposes the proximal DEJ and protects the adjacent tooth (Fig. 10-19). At this time, the occlusal portion of the preparation is complete except for possible additional pulpal floor caries excavation. The occlusal walls

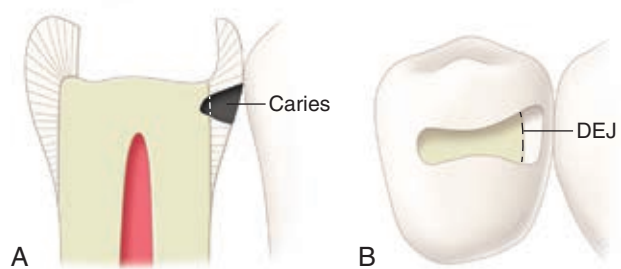


Fig. 10-19 Occlusal extension into faulty proximal surface. **A** and **B**, Extension exposes the dentinoenamel junction (DEJ) but does not hit the adjacent tooth. Facial and lingual extensions as preoperatively visualized (see Fig. 10-9 for initial pulpal floor depth).

generally converge occlusally because of the inverted shape of the instrument.

PROXIMAL BOX

Typically, caries develops on a proximal surface immediately gingival to the proximal contact. The extent of the caries lesion and amount of old restorative material are two factors that dictate the facial, lingual, and gingival extensions of the proximal box of the preparation. Although it is not required to extend the proximal box beyond contact with the adjacent tooth (i.e., provide clearance with the adjacent tooth), it may simplify the preparation, matrix placement, and contouring procedures. If all of the defect can be removed without extending the proximal preparation beyond the contact, however, the restoration of the proximal contact with the composite is simplified (Fig. 10-20, A).

Before the instrument is extended through the marginal ridge, the proximal ditch cut is initiated. The operator holds the instrument over the DEJ with the tip of the instrument positioned to create a gingivally directed cut that is 0.2 mm inside the DEJ (see Fig. 10-20, B through D). For a No. 245 instrument with a tip diameter of 0.8 mm, this would require one-fourth of the instrument's tip positioned over the dentin side of the DEJ (the other three fourths of the tip over the enamel side). The instrument is extended facially, lingually, and gingivally to include all of the caries or old material, or both. The faciolingual cutting motion follows the DEJ and is

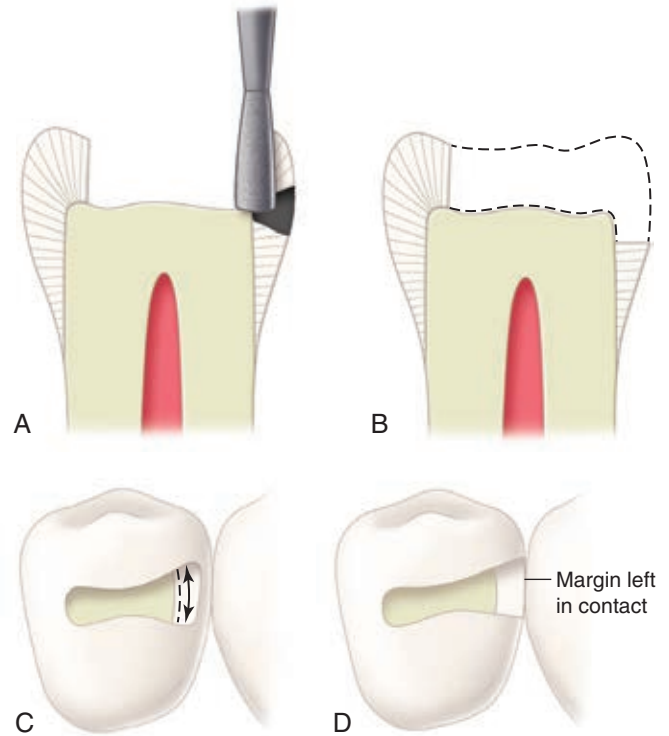


Fig. 10-20 **A**, The proximal wall may be left in contact with the adjacent tooth. **B**, Proximal ditch cut. The instrument is positioned such that gingivally directed cut creates the axial wall 0.2 mm inside the dentinoenamel junction (DEJ). **C**, Faciolingual direction of axial wall preparation follows the DEJ. **D**, Axial wall 0.2 mm inside the DEJ.

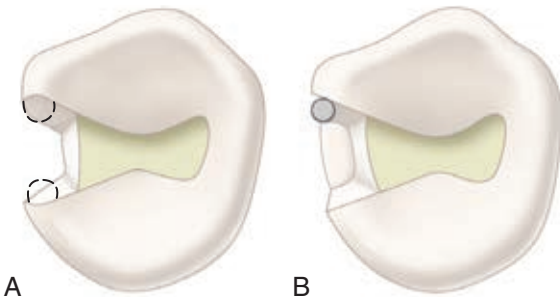


Fig. 10-21 Using a smaller instrument to prepare the cavosurface margin areas of facial and lingual proximal walls. **A**, Facial and lingual proximal margins undermined. **B**, Using a smaller instrument.

usually in a slightly convex arc outward (see Fig. 10-21, C). During this entire cutting, the instrument is held parallel to the long axis of the tooth crown. The facial and lingual margins are extended as necessary and should result in at least a 90-degree margin, more obtuse being acceptable as well. If the preparation is conservative, a smaller, thinner instrument is used to complete the faciolingual wall formation, avoiding contact with the adjacent tooth (Fig. 10-21). Alternatively, a sharp hand instrument such as a chisel, hatchet, or a gingival margin trimmer can be used to finish the enamel wall. At this point, the remaining proximal enamel that was initially maintained to prevent damage to the adjacent tooth has been removed. The gingival floor is prepared flat (because of the tip of the instrument) with an approximately 90-degree cavosurface margin. Gingival extension should be as minimal as possible, in an attempt to maintain an enamel margin. The axial wall should be 0.2 mm inside the DEJ and have a slight

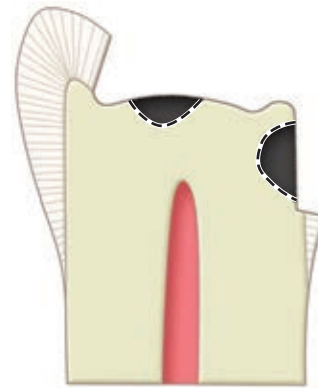


Fig. 10-22 Proximal extension. The enamel margin on the gingival floor is critical for bonding, so it should be preserved, if not compromised. Any remaining infected dentin on the axial wall (or the pulpal floor) is excavated as part of the final tooth preparation (as indicated by dotted lines).

outward convexity. For large caries lesions, additional axial wall caries excavation may be necessary later, during final tooth preparation (Fig. 10-22).

If no carious dentin or other defect remains, the preparation is considered complete at this time (Fig. 10-23). Because the composite is retained in the preparation by micro-mechanical retention, no secondary preparation retention features are necessary. No bevels are placed on the occlusal cavosurface margins because these walls already have exposed enamel rod ends because of the enamel rod direction in this area. A bevel placed on an occlusal margin may result in thin composite on the occlusal surface in areas of potentially heavy contact. This feature also could result in fracture or wear of

the composite in these areas. Beveled composite margins also may be more difficult to finish.

Bevels are rarely used on any of the proximal box walls because of the difficulty in restoring these areas, particularly when using inherently viscous packable composites. Bevels also are not recommended along the gingival margins of the proximal box; however, it is still necessary to remove any unsupported enamel rods along the margins because of the gingival orientation of the enamel rods. For most Class II preparations, this margin already is approaching the cemento-enamel junction (CEJ), and the enamel is thin. Care is taken to maintain any enamel in this area to achieve a preparation with all-enamel margins. If the preparation extends onto the root surface, more attention must be focused on keeping the area isolated during the bonding technique, but no differences in tooth preparation are required. As noted earlier, when the gingival floor is on the root surface (no enamel at the cavosurface margin), the use of a glass ionomer material may

decrease microleakage and recurrent caries.^{59,62,63,65-67} Usually, the only remaining final tooth preparation procedure that might be necessary is additional excavation of carious dentin on either the pulpal floor or the axial wall. If necessary, a round bur or appropriate spoon excavator is used to remove any remaining caries.

Figure 10-24, A, illustrates an esthetic problem seen on the mesiofacial aspect of a maxillary first premolar as a result of extensive recurrent caries and existing faulty restoration. The preoperative occlusion assessment indicates that the facial cusp of the opposing mandibular premolar (which usually occludes on the mesial marginal ridge of the maxillary premolar) does not contact that area on this tooth (see Fig. 10-24, B). The existing occlusal amalgam on the maxillary second premolar also is determined to have extensive recurrent caries and is replaced with a composite during the same appointment.

After the operator cleans the teeth, administers local anesthetic, selects the shade of composite, and isolates the area, a wedge is placed in the gingival embrasure (see Fig. 10-24, C). Early wedging helps in the separation of teeth, to compensate later for the thickness of the matrix band, fulfilling one of several requirements for a good proximal contact for the composite restoration. The placement of a bitine ring preoperatively can achieve the same goal. The lack of pressure against the matrix during placement of composite compared with pressure of amalgam during its condensation dictates the need not only for increased separation by early wedging but also the need for operator alertness to verify matrix contact with the adjacent tooth before composite placement. The wedge also depresses and protects the rubber dam and gingival tissue when the proximal area is prepared. An additional, further tightening (insertion) of the wedge during tooth preparation may be helpful. The presence of the wedge during

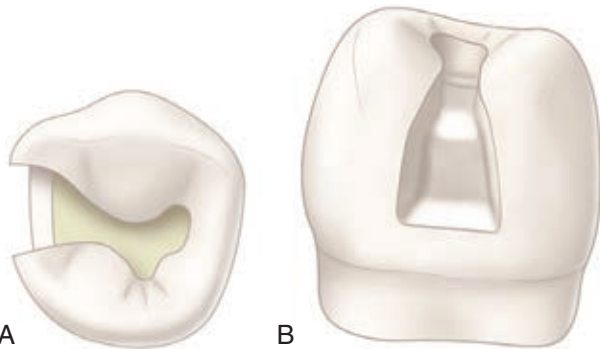


Fig. 10-23 Final Class II composite tooth preparation. **A**, Occlusal view. **B**, Proximal view.

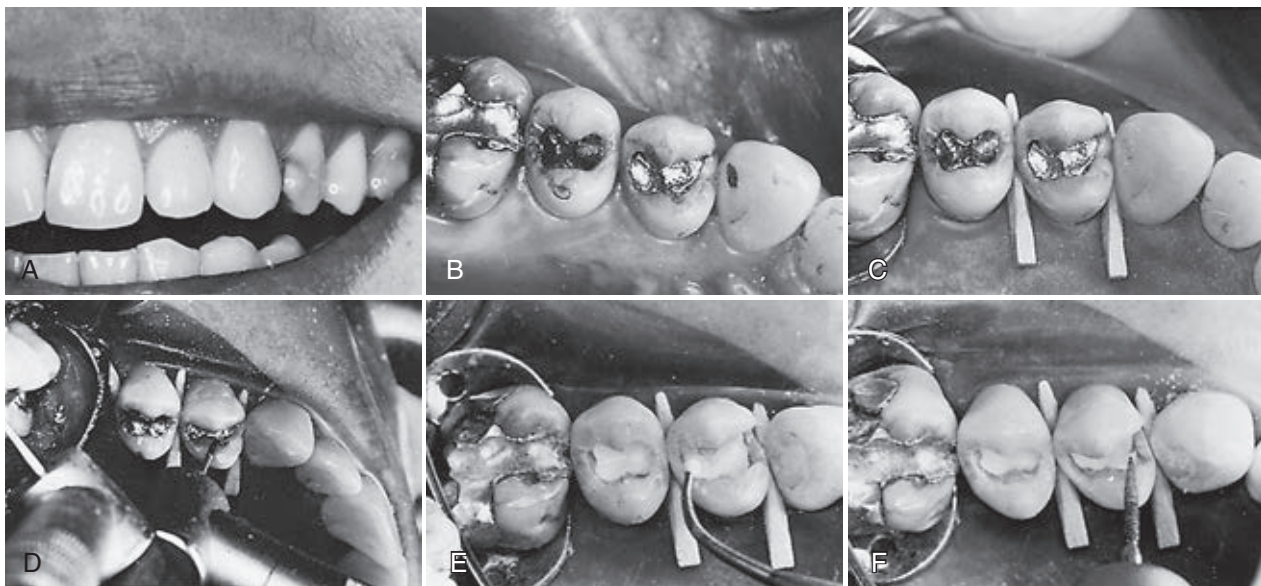


Fig. 10-24 Mesio-occlusal (MO) Class II tooth preparation for posterior composite restoration in the maxillary first premolar. **A**, Esthetic problem is caused by caries and existing amalgam restoration. **B**, In this patient, the mesial marginal ridge is not a centric holding area. **C**, Early wedging after rubber dam placement. **D**, An elongated pear bur or diamond is used for initial tooth preparations on both premolars. **E**, After extensive caries is excavated, a calcium hydroxide liner and a resin-modified glass ionomer (RMGI) base are inserted. **F**, Preparations are completed, if necessary, by roughening the prepared tooth structure with diamond instrument.



Fig. 10-25 Mesio-occlusal (MO) Class II direct composite restoration, which does not require a liner. **A**, Mesial primary caries and occlusal secondary caries exists preoperatively. **B**, Rubber dam isolation. **C**, Matrix application and placement of the adhesive. **D**, Insertion and light-activation of the composite. The completed restoration is shown in Fig. 10-28, D.

tooth preparation may serve as a guide to avoid overextension of the gingival floor.

A No. 245 bur or diamond is used to remove the existing amalgam restorations and to prepare the mesial surface of the first premolar in a conservative manner (see Fig. 10-24, D). A smaller instrument may be more appropriate if the lesion is smaller. A notable difference in the initial Class II preparation design for a composite restoration compared with that for an amalgam is the axial wall depth. When preparing the proximal box for a composite restoration, the axial wall initial depth usually is limited to 0.2 mm into dentin; this means that the tip of the No. 245 bur or diamond would be cutting approximately one-fourth in dentin and three-fourths in enamel to be most conservative. (The diameter of the No. 245 bur's tip end is 0.8 mm.) This decreased pulpal depth of the axial wall occurs because retention locks usually are unnecessary; the decreased depth provides greater conservation of the tooth structure. The occlusal walls may converge occlusally (because of the inverted shape of the No. 245 bur or diamond), and the proximal walls may be parallel or convergent occlusally. Preparing convergent proximal walls provides additional retention form, when needed.

The initial preparation is completed as previously described. With a round bur or spoon excavator, the operator removes any remaining infected dentin and any stains that show through the mesiofacial enamel. In this example, a calcium hydroxide liner and an RMGI base were applied over the

deeply excavated area (see Fig. 10-24, E). Because of the removal of the amalgam and extensive caries, many areas of the enamel are left unsupported by dentin but are not friable. This undermined, but not friable, enamel is not removed. At this time, the tooth preparation is complete (see Fig. 10-24, F).

If a composite restoration is properly bonded to the preparation walls, such as in preparations with all-enamel margins, little or no potential for microleakage and pulpal complications exists. A calcium hydroxide liner is indicated, however, to treat a near-exposure of the pulp (within 0.5 mm of the pulp), a possible micro-exposure, or an actual exposure. If used, the calcium hydroxide liner is covered with an RMGI base to protect it from dissolution during the bonding procedures.^{51,68} Otherwise, neither a liner nor a base is indicated in Class II tooth preparations for composite (Fig. 10-25). It is desirable not to cover any portion of the dentinal walls with a liner, unless necessary, because the liner would decrease dentin bonding potential.

Restorative Technique

Matrix Application

One of the most important steps in restoring Class II preparations with direct composites is the selection and proper placement of the matrix. In contrast to amalgam, which can be condensed to improve the proximal contact, Class II

composites are almost totally dependent on the contour and position of the matrix for establishing appropriate proximal contacts. Early wedging and re-tightening of the wedge during tooth preparation aid in achieving sufficient separation of teeth to compensate for the thickness of the matrix band. Before placing the composite material, the matrix band must be in absolute contact with (touching) the adjacent contact area.

Generally, the matrix is applied before adhesive placement. An ultra-thin metal matrix band generally is preferred for the restoration of a Class II composite because it is thinner than a typical metal band and can be contoured better than a clear polyester matrix. No significant problems are experienced in placing and light-activating composite material when using a metal matrix as long as small incremental additions (2 mm each or less) are used.

Although a Tofflemire-type matrix can be used for restoring a two-surface tooth preparation, pre-contoured sectional metallic matrices are preferable (Fig. 10-26), because only one thickness of metal matrix material is encountered instead of two, making contact generation easier. These sectional matrices are relatively easy to use, very thin, and come in different sizes that can be used according to the clinical situation. There are several systems available, and selection is based on

operator preference. These systems may use a bitine ring to (1) aid in stabilizing the matrix band and (2) provide additional tooth separation while the composite is inserted. The primary benefit of these systems is a simpler method for establishing an appropriate composite proximal contour and contact. Use of these systems for restoring wide faciolingual proximal preparations requires careful application; otherwise, the bitine ring prongs may cause deformation of the matrix band, resulting in a poor restoration contour.

When both proximal surfaces are involved, a Tofflemire retainer with an ultra-thin (0.001 inch), burnishable matrix band is used. The band is contoured, positioned, wedged, and shaped, as needed, for proper proximal contacts and embrasures. Before placement, the metal matrix band for posterior composites should be burnished on a paper pad to impart proper proximal contour to the band (the same as a matrix for amalgam). Alternatively, an ultra-thin precontoured metal matrix band may be used in the Tofflemire retainer.

If the Tofflemire matrix band is open excessively along the lingual margins of the preparation (usually because of the contour of the tooth), a “tinner’s joint” can be used to close the matrix band. This joint is made by grasping the lingual portion of the matrix band with No. 110 pliers and cinching the band tightly together above the height of contour of the

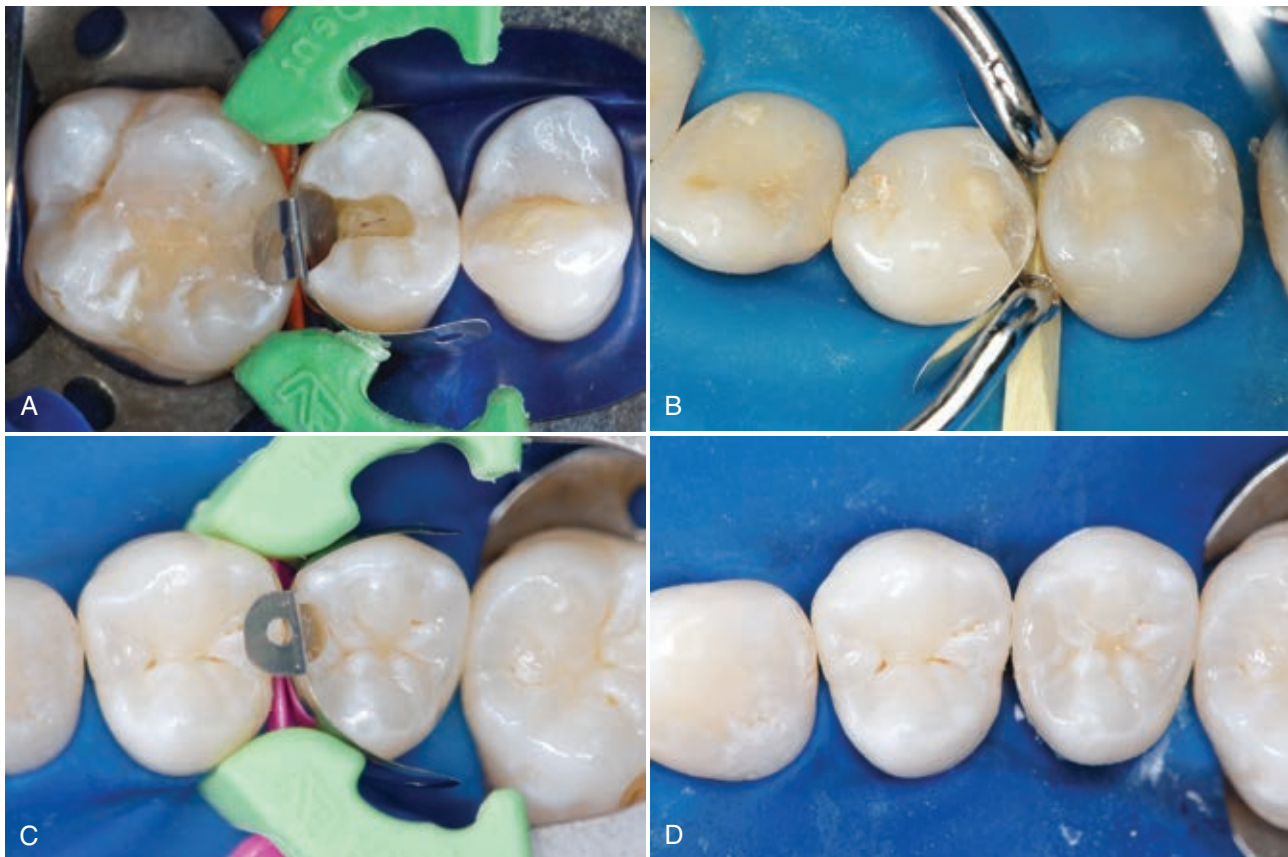


Fig. 10-26 Sectional matrix systems for posterior composites. **A**, Sectional matrix system in place with plastic wedge and bitine ring to restore the maxillary premolar with direct composite. **B**, Sectional matrix system in place with wooden wedge and bitine ring to restore the mandibular premolar with direct composite. **C**, Sectional matrix system in place with plastic wedge and bitine ring to restore the maxillary premolar with direct composite. **D**, Case presented in **C** after placement and light-activation of the composite, and matrix removal, before any contouring. Note minimal excess composite as a result of good matrix adaptation to facial and lingual embrasures.

tooth. The gathered matrix material can be folded easily to one side with a large amalgam condenser. By closing the open portion of the matrix band, significant time and effort are saved when contouring and finishing the restoration.

Placement of the Adhesive

The technique for adhesive placement is as described previously for the Class I direct composite restoration. Care should be exercised to avoid adhesive pooling along the matrix-gingival margin aspect of the preparation.

Insertion and Light-Activation of the Composite

The technique for insertion of Class II posterior composites is illustrated in Figure 10-27. It is best to restore the proximal box portion of the preparation first. Hand instruments or a “composite gun” may be used to insert the composite material. It is important to place (and light-activate) the composite incrementally to maximize the curing potential and to reduce the negative effects of polymerization shrinkage. Many techniques have been described for the restoration of the proximal box. Research comparing different insertion and light-activation techniques is not conclusive, and no single technique has been universally accepted. The number of increments will depend on the size of the proximal box. At the University of North Carolina, we recommend an oblique incremental technique: the first increment(s) should be placed along the gingival floor and should extend slightly up the facial (or lingual) wall (see Fig. 10-27). This increment (or increments for a large box) should be only approximately 1 to 2 mm thick because it is the farthest increment from the curing light and the most critical in establishing a proper gingival seal. A second increment is then placed against the lingual wall, to restore about two thirds of the box. The final increment is then placed to complete the proximal box and develop the marginal ridge. Subsequent additions, if needed, are made and light-activated (usually not exceeding 2 mm in thickness

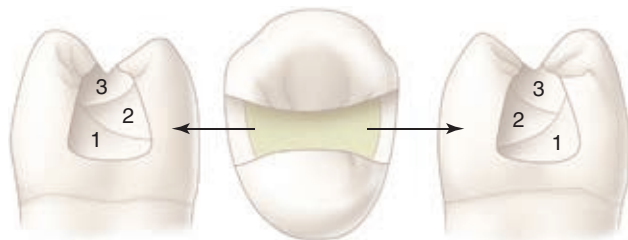


Fig. 10-27 Oblique incremental technique to restore proximal boxes in Class II direct composite restorations. The number of increments will depend on the size of the proximal box. The first increment(s) (1) should be placed along the gingival floor and should extend slightly up the facial wall. This increment should be only approximately 1 to 2 mm thick because it is the farthest increment from the curing light and the most critical in establishing a proper gingival seal. A second increment is then placed against the lingual wall, to restore about two thirds of the box. The final increment is then placed to complete the proximal box and develop the marginal ridge. Subsequent additions, if needed, are made and light-activated (usually not exceeding 2 mm in thickness

at a time) until the proximal box is fully restored (Fig. 10-28). Increments should be light-activated for as long as needed, depending on the shade and opacity of the composite used, the distance of the composite from the light tip, and the power of the unit. Regardless of the number of increments needed, when restoring the proximal box, an effort should be made to develop the anatomy of marginal ridge without excessive compositing, to reduce the amount of cutting needed during contouring and polishing.

When the proximal box is completed, the occlusal step of the preparation is restored exactly as it was described for the Class I direct composite restoration, that is, using an anatomic layering technique.

The incremental insertion and light-activation technique described provides enhanced control over the application and polymerization of individual increments of composite. The incremental technique also allows for (1) orientation of the polymerization light beam according to the position of each increment of composite, thus enhancing the curing potential; (2) intrinsic restoration characterization with darker or pigmented composites; and (3) sculpture of the restoration occlusal stratum with a more translucent material simulating the natural enamel. Tight proximal contacts can also be better achieved when composite is applied in increments. The matrix can be held in close contact with the adjacent proximal surface while the contact-related increment of composite is light-activated. A hand instrument with a large surface area (e.g., a small football-shaped or round-shaped burnisher) is well suited for that purpose. Once this increment is cured, the proximal contact is established, and remaining increments can be inserted and light-activated. The matrix is removed, and the restoration is cured from the facial and lingual directions. The restoration can be contoured and finished immediately after the last increment is cured.

Composite resin placement may be made more difficult by the stiffness and stickiness of some composite materials. Heating the composite material prior to insertion in the preparation may help overcome these problems. Commercial “composite warmers” are available (e.g., Calset, AdDent Inc., Danbury, CT) to preheat the composite resin to preset temperatures up to 68°C (155°F). The increased temperature lowers the viscosity of the composite resin, potentially resulting in better marginal adaptation and reduced microleakage, although some of these results have been shown to be composite specific.⁶⁹⁻⁷² The elevated composite temperatures have been shown to be safe for clinical use.^{73,74}

When a stiffer or packable composite is used for the restoration of the proximal box, a very small increment of a flowable composite first in the proximal box can be used to improve marginal adaptation of the restoration.^{60,61}

Contouring and Polishing of the Composite

Contouring can be initiated immediately after the composite material has been fully polymerized. If the occlusal anatomy was developed as described in the previous sections, the need for additional contouring is greatly minimized. If contouring is needed, the occlusal surface is shaped with a round or oval, 12-bladed carbide finishing bur or finishing diamond. Excess composite is removed at the proximal margins and embrasures with a flame-shaped, 12-bladed carbide finishing bur or finishing diamond and abrasive discs (see Fig. 10-28,

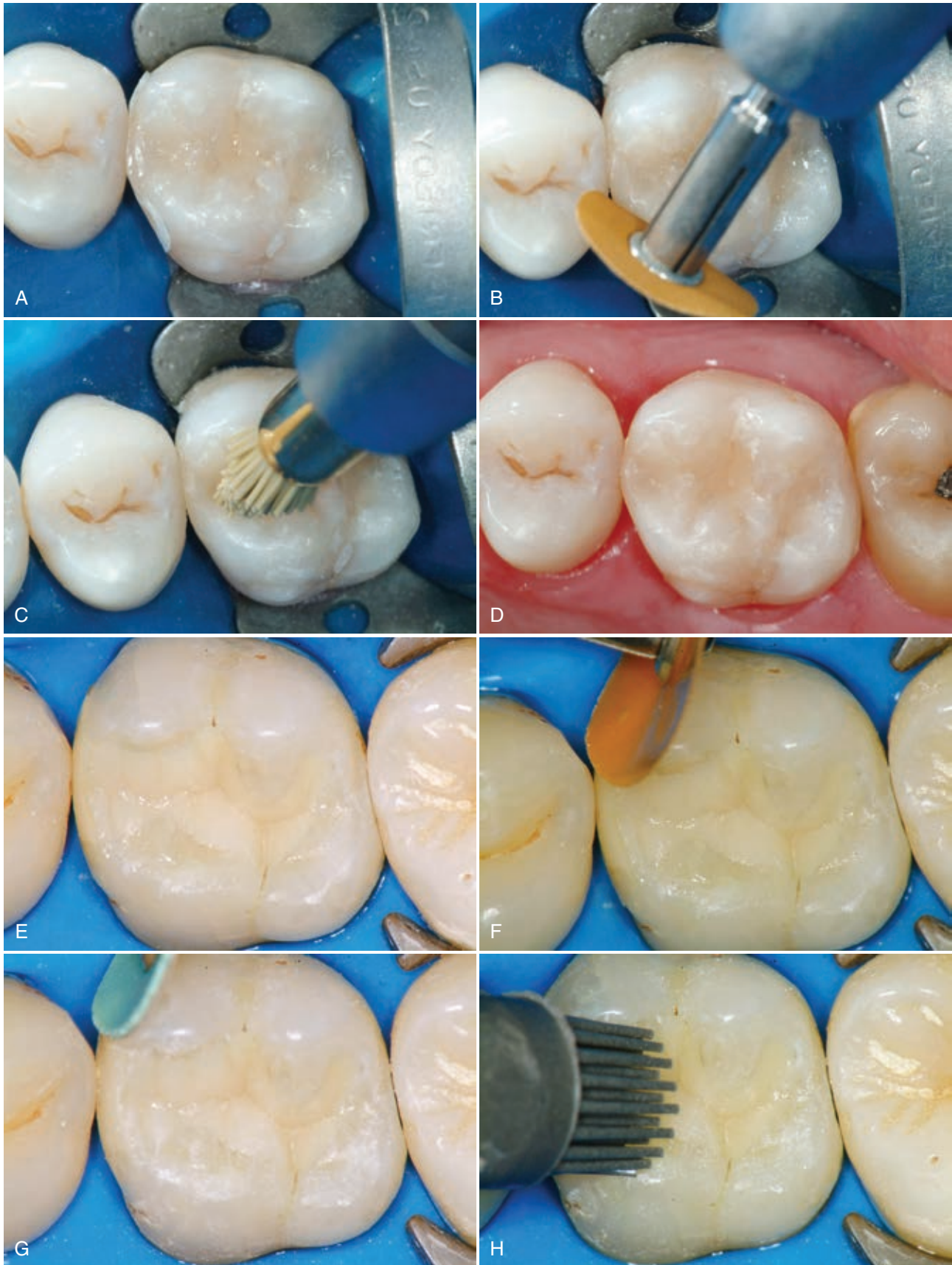


Fig. 10-28 Contouring and finishing of posterior composite restorations. **A**, After sectional matrix removal, excess composite is noted on facial and lingual proximal embrasures. **B**, Contouring lingual embrasure with finishing disk. **C**, Polishing the occlusal surface with finishing brush. **D**, Completed restoration. **E**, Note minimal excess composite after removal of sectional matrix because of good matrix adaptation to facial and lingual embrasures and careful incremental insertion of the composite. **F-H**, Contouring and polishing with disks and brush.

A and B). Any overhangs at the gingival area are removed with a No. 12 surgical blade mounted in a Bard-Parker handle with light shaving strokes to remove the excess. Narrow finishing strips may be used to smooth the gingival proximal surface. Care must be exercised in maintaining the position of the finishing strips gingival to the proximal contact area to avoid inadvertent opening of the contact. The rubber dam (or other means of isolation) is removed, and the occlusion is evaluated for proper contact. Further adjustments are made, if needed, and the restorations are finished with appropriate polishing points, cups, brushes, or discs (see Fig. 10-28, *C and D*).

Clinical Technique for Extensive Class II Direct Composite Restorations and Foundations

Direct composite is not usually indicated for extensive posterior restorations but may be indicated when economic factors prevent the patient from selecting a more expensive indirect restoration. The 12-year survival rate of large posterior composite restorations has been shown to be similar to that of large amalgam restorations, although amalgam performed better in patients with high caries risk.¹⁵ In addition to being used in selected cases for extensive restorations, composites also may be considered for use as a foundation for indirect restorations (crowns and onlays) when the operator determines that insufficient natural tooth structure remains to provide adequate retention and resistance form for the crown. The tooth first is restored with a large restoration and is then prepared for the indirect restoration. This type of restoration also may be indicated as an interim restoration while waiting to determine the pulpal response or whether or not the restoration will function appropriately.

In addition to the tooth preparation form, the primary retention form for a very large Class II composite restoration is the micromechanical bonding of the composite to enamel and dentin. When a full-coverage preparation is anticipated, secondary retention features may be incorporated, however, because of (1) the decreased amount of tooth structure available for bonding, and (2) the increased concern for retaining the composite in the tooth. These features include grooves, coves, locks, or slots.

The primary differences for these very large preparations include the following: (1) some or all of the cusps may be capped, (2) extensions in most directions are greater, (3) secondary retention features are used, and (4) more resistance form features are used. A cusp must be capped if the operator believes it is likely to fracture if left in a weakened state. Capping a cusp usually is indicated when the occlusal outline form extends more than two thirds the distance from a primary groove to a cusp tip. An operator sometimes may choose to ignore this general rule when using a bonded restoration if that cusp will be capped as part of the preparation design for the subsequent indirect restoration.

If the tooth has had endodontic treatment, the pulp chamber can be opened, and extensions can be made several millimeters into each treated canal. Because of the increased surface area for bonding and the mechanical retention from extensions into the canals, usually fewer secondary retention features are incorporated into the remaining tooth preparation.

Tooth Preparation

The elongated pear diamond or bur is used to prepare the occlusal step. As already indicated, the occlusal outline form is usually extensive. When moving the instrument from the central groove area toward a cuspal prominence, the pulpal depth that is approximately 0.2 mm inside the DEJ should be maintained, if possible. This creates a pulpal floor which rises occlusally as it is extended either facially or lingually (see Fig. 10-10). If a cusp must be capped, the side of the rotary instrument can be used first to make several depth cuts in the remaining cuspal form to serve as a guide for cusp reduction. Cusps should be capped as early in the tooth preparation procedure as possible, providing more access and visibility for the preparation. The depth cut is made with the instrument held parallel to the cuspal incline (from cusp tip to central groove) and approximately 1.5 to 2 mm deep. For a large cusp, multiple depth cuts can be made. Then, the instrument is used to join the depth cuts and extend to the remainder of the cuspal form (Fig. 10-29). The reduced cusp has a relatively flat surface that may rise and fall with the normal mesial and distal inclines of the cusp. It also should provide enough clearance with the opposing tooth to result in approximately 1.5 to 2 mm of composite material to restore form and function. The cusp reduction should be blended in with the rest of the occlusal step portion of the preparation.

The proximal boxes are prepared as described previously. The primary difference is that they may be much larger, that is, more extension in every direction. The extent of the lesion may dictate that a proximal box extend around the line angle of the tooth to include caries or faulty facial or lingual tooth structure. When the outline form has been established (the margins extended to sound tooth structure), caries at the pulpal and axial walls is excavated and the preparation is assessed carefully for additional retention form needs.

Retention form can be enhanced by the placement of grooves, locks, coves, or slots. All such retention form features must be placed entirely in dentin, not undermining and weakening any adjacent enamel. At times, bevels may be placed on available enamel margins to enhance retention form, even on occlusal areas. Retention form for foundations must be placed far enough inside the DEJ (at least 1 mm) to remain after the crown preparation is done subsequently. Otherwise, the potential retentiveness may be lost for the foundation (Fig. 10-30).

Restorative Technique

Matrix Application

Matrix placement is more demanding for these large restorations because more tooth structure is missing, and more margins may be subgingival. Proper burnishing of the matrix band to achieve appropriate axial contours is important, unless immediate full coverage of the tooth is planned. It also may be necessary to modify the matrix band to provide more subgingival extension in some areas and prevent extrusion of the composite from the matrix band–retainer tooth junction.

Placement of the Adhesive

Typical adhesive placement techniques are followed. Because much of the composite bond is to dentin, proper technique is

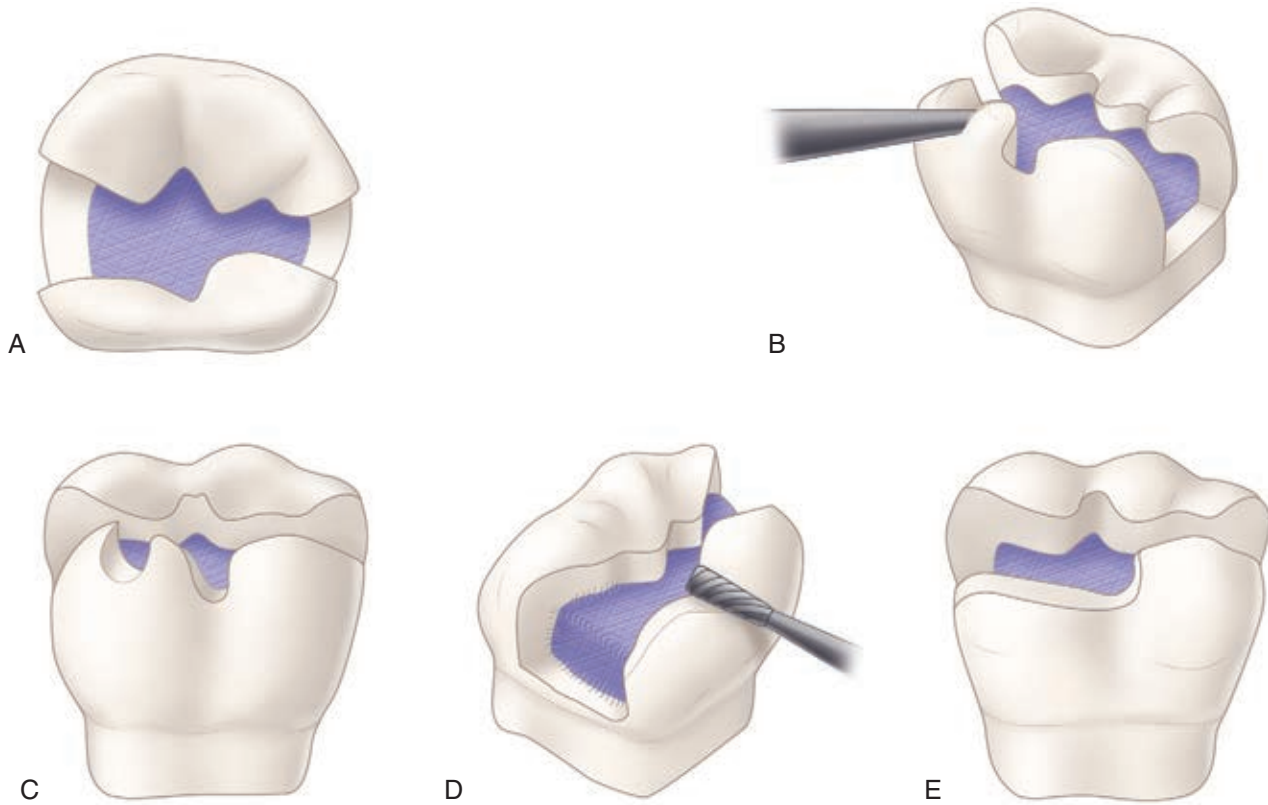


Fig. 10-29 Cusp reduction. **A**, The initial outline form weakens the mesiolingual cusp enough to necessitate capping. **B**, Depth cuts made. **C**, Depth cuts. **D**, Cusp reduction prepared. **E**, Vertical wall maintained between reduced and unreduced cusps.

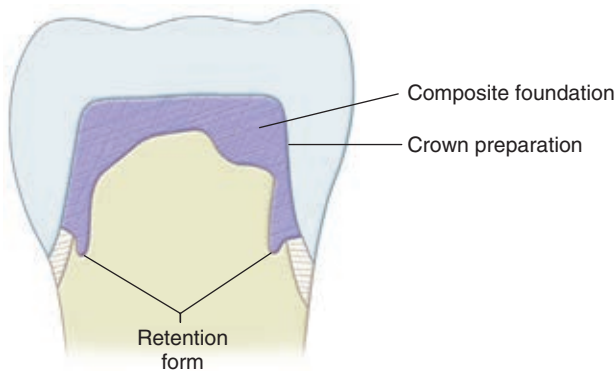


Fig. 10-30 The retention form for foundations must be internal to eventual crown preparation.

crucial. Placement of the adhesive is accomplished as previously described.

Insertion and Light-Activation of the Composite

When a light-activated composite is used, first it is placed in 1- to 2-mm increments into the most gingival areas of the proximal boxes. Each increment is cured, as directed. It may be helpful to use a hand instrument to hold the matrix against

the adjacent tooth while light-activating the composite. This may assist in restoring the proximal contact.

Self-activated and dual-activated composite resin materials are frequently used for large composite foundations because these can be injected in the preparation in a single increment. However, it is recommended that even when dual-cured composites are used, they be carefully light-activated during and after the final placement, as needed. When this technique is used, the operator should carefully select the adhesive system, as some simplified adhesives have been shown to be incompatible with some self-activated composite foundation materials. Acidic monomers in these adhesives scavenge the activators (tertiary amines) in the self-cure composite.^{75,76} If the activator does not function properly, the composite at the adhesive interface does not polymerize thoroughly and does not bond to the adhesive. Some manufacturers have introduced optional chemical catalysts that can be mixed with the light-cured adhesive to reduce or prevent this problem.

Contouring and Polishing of the Composite

Contouring the large composite also is more difficult because of the number of surfaces that may be involved and the amount of composite present. Physiologic contours and contacts are necessary for restorations, but they are less important for foundations that will be present only for a short time before the crown preparation is done. Because of the extensiveness of these restorations, a careful assessment of the contours should be made from all angles. When contouring is

completed, the occlusion is adjusted as necessary, and the restoration is polished. Because these very large restorations may stretch the limits of composite restorations, the patient should be on a frequent recall regimen.

Figure 10-31 illustrates an extensive Class II modified tooth preparation. A maxillary first premolar is badly discolored from a large, faulty, corroded amalgam restoration and caries

(see Fig. 10-31, A and B). Esthetic and economic factors resulted in the decision to replace the amalgam with a composite restoration, rather than an indirect restoration. The preparation is shown with all of the old amalgam and infected dentin removed, leaving the facial and lingual enamel walls severely weakened (see Fig. 10-31, C). After placement of a calcium hydroxide liner and an RMGI base over the deeply

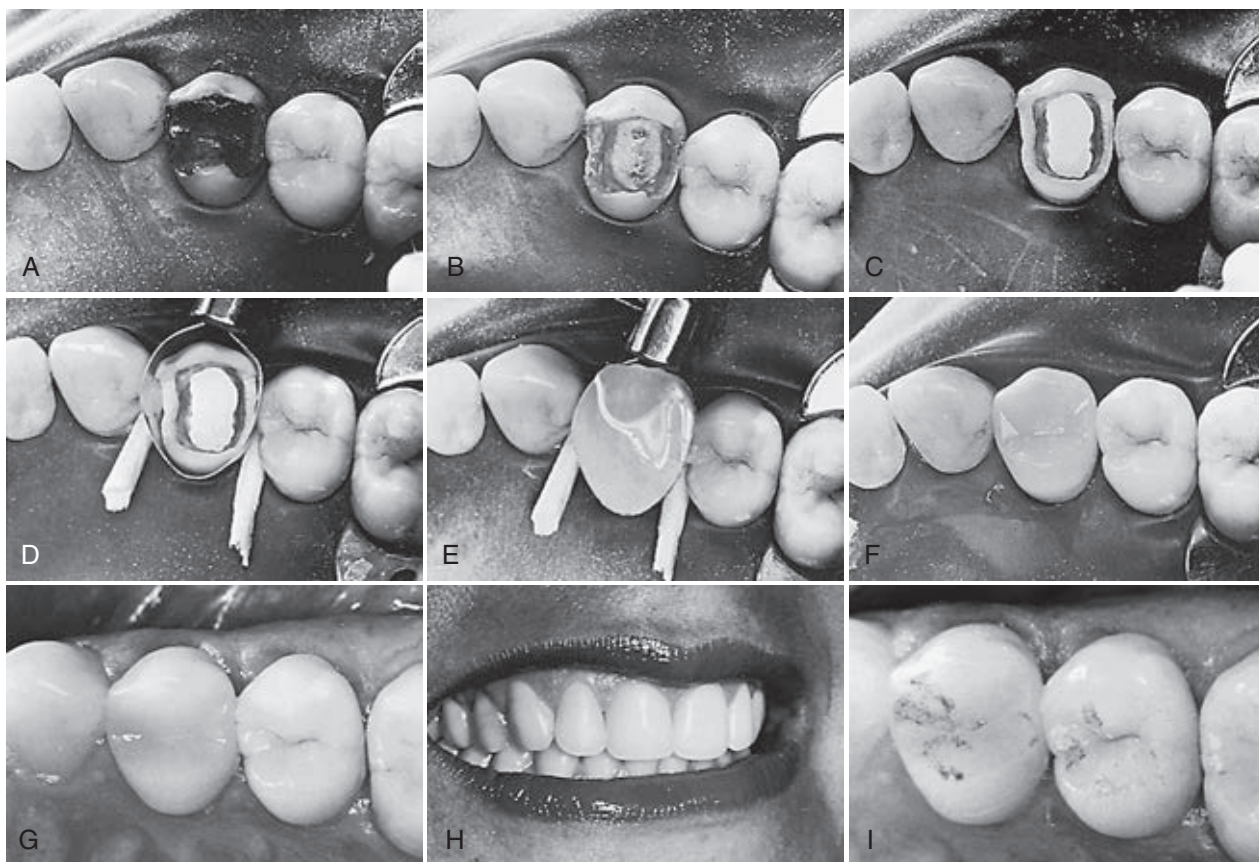


Fig. 10-31 Mesio-occluso-distal (MOD) Class II extensive direct composite restoration. **A**, Esthetics and cost are factors in the decision to replace faulty restoration with posterior composite. **B**, Amalgam and infected dentin removed. **C**, Calcium hydroxide liner and a resin-modified glass ionomer (RMGI) base inserted. **D**, Matrix in place. **E**, Composite has been placed incrementally. **F**, After inserting and polishing composite restoration. **G-I**, Occlusal (G) and facial (H) views after 5 years of service. **I**, Occlusion marked with articulating paper at 5-year follow-up appointment.

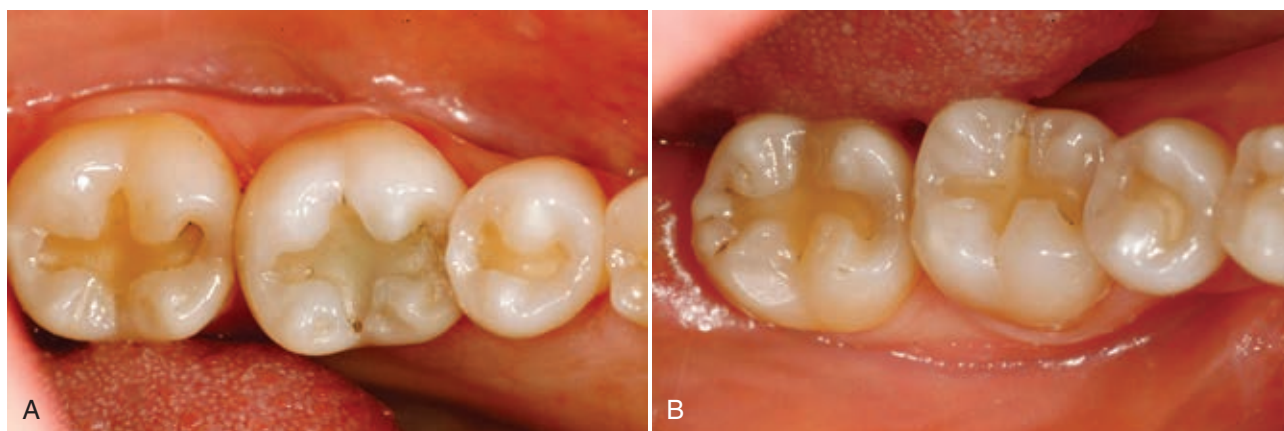


Fig. 10-32 Class I composite restorations at 30 years of service.

excavated area (see Fig. 10-31, *D*), a diamond was used to reduce the severely undermined enamel of the lingual cusp approximately 1.5 mm (functional cusp) and to place a reverse bevel with a chamfered margin on the lingual surface. The same instrument was used to reduce the facial cusp 0.75 mm (nonfunctional cusp) and to place a slight counterbevel. Figure 10-31, *E* and *F*, shows the matrix placement and composite insertion. The completed restoration is shown in Figure 10-31, *G*, and, after 5 years of service, in Figure 10-31, *H* through *I*. This extensive tooth preparation has been observed to be successful but not from controlled clinical research studies.

Summary

This chapter has presented the rationale and technique for composite use in the treatment of the occlusal and proximal surfaces of posterior teeth. The use of composite as the restorative material for many Class I and II restorations is emphasized not only by this chapter but by this entire textbook as well. This emphasis is not based on concerns about the use of amalgam as a restorative material. As subsequent chapters will show, amalgam restorations are still strongly recommended in this book. Regardless, many Class I and II lesions are best restored with composite, which presents adequate longevity when properly placed (Fig. 10-32). Typical problems, solutions, and repair techniques for composite restorations are presented in Chapter 8.

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Indirect Tooth-Colored Restorations

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Class I and II Indirect Tooth-Colored Restorations

Chapters 8, 9, and 10 describe *direct* tooth-colored composite restorations. Teeth also can be restored using *indirect* techniques, in which restorations are fabricated outside of the patient's mouth. Indirect restorations are made on a replica of the prepared tooth in a dental laboratory or by using computer-aided design/computer-assisted manufacturing (CAD/CAM) either chairside or in the dental laboratory (Fig. 11-1). This chapter reviews the indications, contraindications, advantages, disadvantages, and clinical techniques for Class I and II indirect tooth-colored restorations.

Indications

The indications for Class I and II indirect tooth-colored restorations are based on a combination of esthetic demands and restoration size and include the following:

- **Esthetics:** Indirect tooth-colored restorations are indicated for Class I and II restorations (inlays and onlays) located in areas of esthetic importance for the patient.
- **Large defects or previous restorations:** Indirect tooth-colored restorations should be considered for restoration of large Class I and II defects or replacement of large compromised existing restorations, especially those that are wide faciolingually or require cusp coverage. Large intracoronal preparations are best restored with adhesive restorations that strengthen the remaining tooth structure.¹⁻³ The contours of large restorations are more easily developed using indirect techniques. Wear resistance of direct composite resins has improved greatly over the years and is not a concern with small- to moderate-sized restorations.⁴ However, in larger restorations, indirect restorative materials should be considered.⁵

Contraindications

Contraindications for indirect tooth-colored restorations include the following:

- **Heavy occlusal forces:** Ceramic restorations can fracture when they lack sufficient thickness or are subject to excessive occlusal stress, as in patients who have bruxing or clenching habits.⁶ Heavy wear facets or a lack of occlusal enamel are good indicators of bruxing and clenching habits (Fig. 11-2).
- **Inability to maintain a dry field:** Despite limited research suggesting that some contemporary dental adhesives might counteract certain types of contamination, adhesive techniques require near-perfect moisture control to ensure successful long-term clinical results.⁷⁻⁹
- **Deep subgingival preparations:** Although this is not an absolute contraindication, preparations with deep subgingival margins generally should be avoided. These margins are difficult to record with an elastomeric or even a digital impression and are difficult to evaluate and finish. Additionally, dentin bond strengths at gingival floors are not particularly good, so bonding to enamel margins is greatly preferred, especially along gingival margins of proximal boxes.^{10,11}

Advantages

Except for the higher cost and increased time, the advantages of indirect tooth-colored restorations are similar to the advantages of direct composite restorations. Indirect tooth-colored restorations have the following additional advantages:

- **Improved physical properties:** A wide variety of high-strength tooth-colored restorative materials, including laboratory-processed and computer-milled ceramics, can

be used with indirect techniques. These have better physical properties than direct composite materials because they are fabricated under relatively ideal laboratory conditions. For CAD/CAM restorations, although some are fabricated chairside, the materials themselves are manufactured under nearly ideal industrial conditions.¹²

- *Variety of materials and techniques:* Indirect tooth-colored restorations can be fabricated with ceramics using traditional laboratory processes or using chairside or laboratory CAD/CAM methods.
- *Wear resistance:* Ceramic restorations are more wear resistant than direct composite restorations, an especially important factor when restoring large occlusal areas of posterior teeth.
- *Reduced polymerization shrinkage:* Polymerization shrinkage and its resulting stresses are a major shortcoming of direct composite restorations. With indirect techniques, the bulk of the preparation is filled with the indirect tooth-colored restoration, and stresses are reduced because little resin cement is used during cementation. Although shrinkage of resin materials in thin bonded layers can produce relatively high stress, clinical studies indicate ceramic

inlays and onlays have better marginal adaptation, anatomic form, color match, and overall survival rates than do direct composite restorations.^{5,13,14}

- *Support of remaining tooth structure:* Teeth weakened by caries, trauma, or preparation can be strengthened by adhesively bonding indirect tooth-colored restorations.¹⁻³ The reduced polymerization shrinkage stress associated with the indirect technique also is desirable when restoring such weakened teeth.
- *More precise control of contours and contacts:* Indirect techniques usually provide better contours (especially proximal contours) and occlusal contacts than do direct restorations because of the improved access and visibility outside the mouth.
- *Biocompatibility and good tissue response:* Ceramics are considered chemically inert materials with excellent biocompatibility and soft tissue response.¹⁵ The pulpal biocompatibility of the indirect techniques is related more to the resin cements than to the ceramic materials used.
- *Increased auxiliary support:* Most indirect techniques allow the fabrication of the restoration to be delegated totally or partially to the dental laboratory. Such delegation allows for more efficient use of the dentist's time.



Fig. 11-1 Ceramic inlays after 23 years of clinical service. These were fabricated with an early computer-aided design/computer-assisted manufacturing (CAD/CAM) device.

Disadvantages

The following are disadvantages of indirect tooth-colored restorations:

- *Increased cost and time:* Most indirect techniques, except for chairside CAD/CAM methods, require two patient appointments plus fabrication of a provisional restoration. These factors, along with laboratory fees, contribute to the higher cost of indirect restorations in comparison with direct restorations. Although indirect tooth-colored inlays and onlays are more expensive than amalgam or direct composite restorations, they are usually less costly than more invasive esthetic alternatives such as all-ceramic or porcelain-fused-to-metal (PFM) crowns.
- *Technique sensitivity:* Restorations made using indirect techniques require a high level of operator skill. A devotion



Fig. 11-2 **A**, Clenching and bruxing habits can cause extensive wear of occlusal surfaces. This patient is not a good candidate for ceramic inlays. **B**, Example of a fractured onlay in a patient with heavy occlusion.

to excellence is necessary during preparation, impression, try-in, bonding, and finishing the restoration.

- *Difficult try-in and delivery:* Indirect composite restorations can be polished intraorally using the same instruments and materials used to polish direct composites, although access to some marginal areas can be difficult. Ceramics are more difficult to polish because of potential resin-filled marginal gaps and the hardness of the ceramic surfaces.
- *Brittleness of ceramics:* A ceramic restoration can fracture if the preparation does not provide adequate thickness to resist occlusal forces or if the restoration is not appropriately supported by the resin cement and the preparation. With weaker ceramic materials, fractures can occur even during try-in and bonding procedures.¹⁶
- *Wear of opposing dentition and restorations:* Some ceramic materials can cause excessive wear of opposing enamel or restorations.¹⁷ Improvements in materials have reduced this problem, but ceramics, particularly if rough and unpolished, can wear opposing teeth and restorations.
- *Short clinical track record:* Compared with traditional methods such as cast gold or even amalgam restorations, bonded indirect tooth-colored restorations have a relatively short record of clinical service. They have become popular only in recent years, and relatively few controlled clinical trials are available, although these are increasing in number.^{5,18-35}
- *Low potential for repair:* When a partial fracture occurs in a ceramic inlay or onlay, repair is usually not a definitive treatment. The actual procedure (mechanical roughening, etching with hydrofluoric [HF] acid, and application of a silane coupling agent before restoring with adhesive and composite) is relatively simple. However, because many ceramic inlays and onlays are indicated in areas where occlusal wear, esthetics, and fracture resistance are important, composite repairs frequently are not appropriate or successful.

Types of Ceramic Inlays and Onlays

Although some laboratory-processed composite systems have been available, and at least one machinable composite (Paradigm MZ100, 3M ESPE, St. Paul, MN) is available for CAD/CAM, most tooth-colored indirect posterior restorations are fabricated from ceramic materials.¹² Therefore, this chapter will address ceramic inlays and onlays only, with the understanding that the techniques for composite inlays and onlays are generally similar.

Ceramic inlays and onlays have become popular not only because of patient demand for esthetic, durable restorative materials but also because of improvements in materials, fabrication techniques, adhesives, and resin-based cements. Among the ceramic materials used are feldspathic porcelain, leucite-reinforced pressed ceramics, lithium disilicate, and various types of machinable (milled) ceramics designed for use with either chairside or laboratory CAD/CAM systems.³⁶

Feldspathic Porcelain

Dental porcelains are partially crystalline minerals (feldspar, silica, alumina) dispersed in a glass matrix.³⁶ Porcelain

restorations are made from finely ground ceramic powders that are mixed with distilled water or a special liquid, shaped into the desired form, and then fired and fused together to form a translucent material that looks like tooth structure. Currently, some ceramic inlays and onlays are fabricated in the dental laboratory by firing dental porcelains on refractory dies, but more are fabricated by pressing or milling methods, which are described later. The fabrication steps for fired ceramic inlays and onlays are summarized as follows:

- After tooth preparation, an impression is made, and a diestone master working cast is poured (Fig. 11-3, A).
- The die is duplicated and poured with a refractory investment capable of withstanding porcelain firing temperatures. The duplication method must result in the master die and the refractory die being accurately interchangeable (see Fig. 11-3, B).
- Porcelain is added into the preparation area of the refractory die and fired in an oven. Multiple increments and firings are necessary to compensate for sintering shrinkage (see Fig. 11-3, C).
- The ceramic restoration is recovered from the refractory die, cleaned of all investment, and seated on the master die and working cast for final adjustments and finishing (see Fig. 11-3, D).

Although feldspathic porcelain inlays and onlays are less popular than in the past, some dental laboratories continue to use this method because of its low startup cost. The ceramic powders and investments are relatively inexpensive, and the technique is compatible with most existing ceramic laboratory equipment such as firing furnaces. The major disadvantage is its technique sensitivity, both for the technician and the dentist. Inlays and onlays fabricated with this technique must be handled gently during try-in and bonding to avoid fracture. Feldspathic porcelains are weak, so even after bonding, the incidence of fracture can be relatively high.³⁶

Pressed Glass-Ceramics

Over 40 years ago, it was discovered that certain glasses could be modified with nucleating agents and, on heat treatment, be changed into ceramics with organized crystalline forms. Such “glass-ceramics” were stronger, had a higher melting point than noncrystalline glass, and had variable coefficients of thermal expansion.³⁷ At first, these glass-ceramics were developed primarily for cookware and other heat-resistant products. However, in 1984, the glass-ceramic material Dicor (DENTSPLY International, York, PA) was patented and became a popular ceramic for dental restorations. A major disadvantage of Dicor was its translucency, which necessitated external application of all shading.

Dicor restorations were made using a lost-wax, centrifugal casting process. Newer leucite-reinforced glass-ceramic systems (e.g., IPS Empress, Ivoclar Vivadent, Amherst, NY) also use the lost-wax method, but the material is heated to a high temperature and pneumatically pressed, rather than centrifuged, into a mold. Although some studies indicate that hot pressed ceramics are not substantially stronger than fired feldspathic porcelains, they do provide better clinical service.^{28,29,38,39} The fabrication steps for one type of

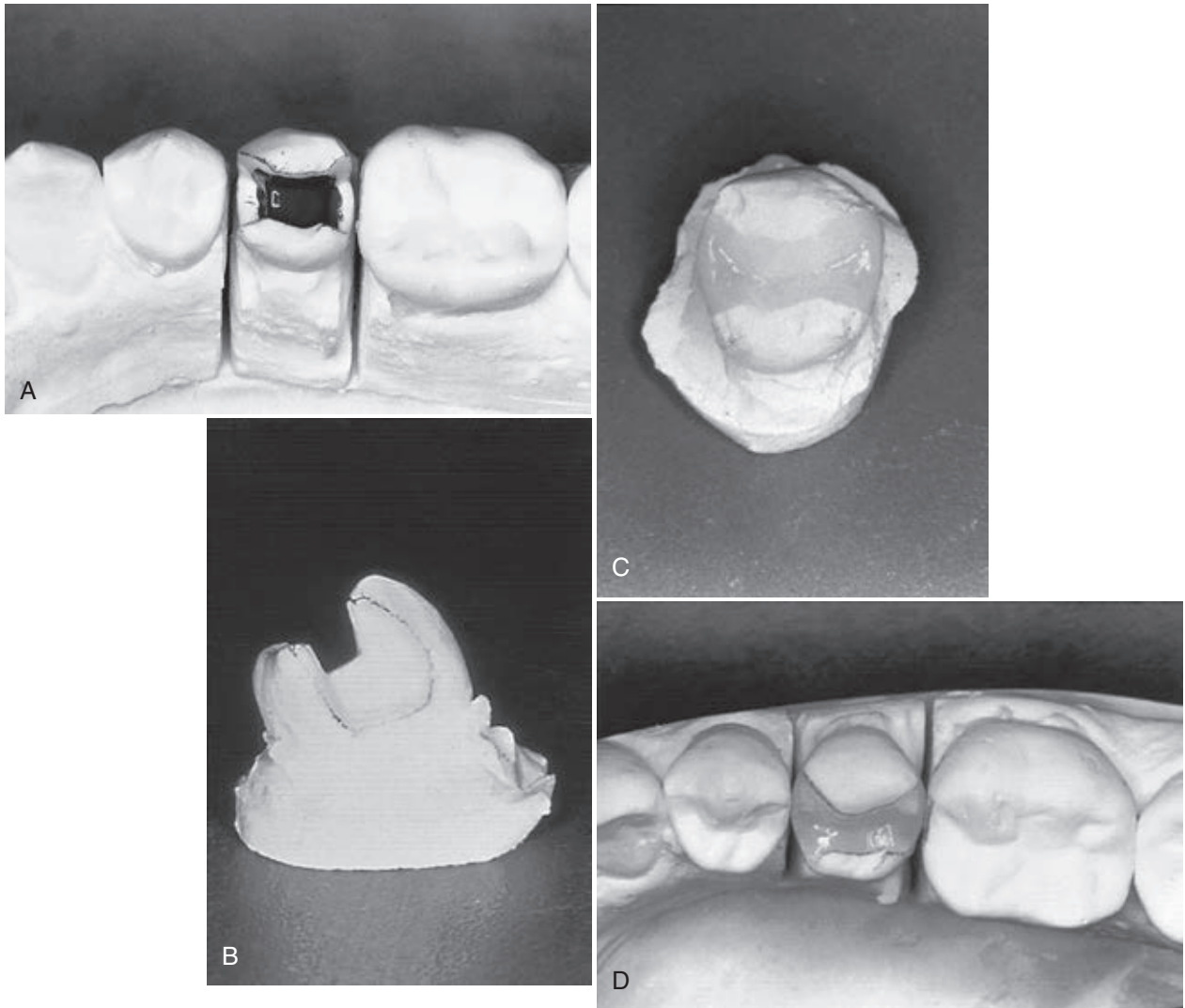


Fig. 11-3 **A**, Master cast for mesio-occluso-distal (MOD) ceramic inlay. Die spacer usually is applied to axial walls and pulpal floor before duplication. **B**, Master die is impressed, and then a duplicate die is poured with refractory investment. **C**, Dental porcelains are added and fired in increments until the inlay is the correct shape. **D**, The inlay is cleaned of all investment and then seated on master die for final adjustments and finishing. The ceramic inlay is now ready for delivery. (**D**, Courtesy of Dr. G. Sheen)

leucite-reinforced pressed ceramic restoration (IPS Empress) are summarized as follows:

1. After tooth preparation, an impression is made, and a working cast is poured in die-stone. A wax pattern of the restoration is made using conventional techniques (Fig. 11-4, A).
2. After spruing (see Fig. 11-4, B), investing, and wax pattern burnout, a shaded ceramic ingot and aluminum oxide plunger are placed into a special furnace (see Fig. 11-4, C). The shade and opacity of the selected ingot (see Fig. 11-4, D) are based on the information provided by the clinician, specifically the desired shade of the final restoration and the shade of the prepared tooth.
3. At approximately 2012°F (1100°C), the ceramic ingot becomes plastic and is slowly pressed into the mold by an automated mechanism.
4. After being separated from the mold, the restoration is seated on the master die and working cast for final adjustments and finishing.
5. To reproduce the tooth shade accurately, a heavily pigmented surface stain is typically applied. The ceramic ingots are relatively translucent and available in a variety of shades, so staining for hot pressed ceramic inlay and onlay restorations is typically minimal.

The advantages of leucite-reinforced pressed ceramics are their (1) similarity to traditional “wax-up” processes, (2) excellent marginal fit, (3) moderately high strength, and (4) surface hardness similar to that of enamel.^{40,41} Although pressed ceramic inlays and onlays are stronger than porcelain inlays made on refractory dies, they are still somewhat fragile during try-in and must be bonded rather than conventionally cemented. IPS Empress inlays and onlays have performed well in clinical trials ranging up to 12 years in duration.^{22,24,28,29,42}



Fig. 11-4 Fabrication of a pressed ceramic onlay. **A**, Wax pattern. **B**, Wax pattern on sprue base, ready to be invested. **C**, Device for pressing heated ceramic (Programat EP 5000). **D**, Selection of ceramic ingots used for forming the restoration. (Courtesy of Ivoclar Vivadent Inc., Amherst, NY.)

Lithium Disilicate

A newer type of ceramic, lithium disilicate (e.max, Ivoclar Vivadent Inc., Amherst, NY), is available in both pressed (IPS e.max Press) and machinable (IPS e.max CAD) forms, and either can be used to fabricate inlays and onlays.⁴³ The two forms of e.max are slightly different in composition, but lithium disilicate is a moderately high-strength glass ceramic that also can be used for full crowns or ultra-thin veneers. In vitro testing of this ceramic material has shown very positive results, and it has become a highly popular alternative for inlays and onlays. However, because the material is relatively new, long-term clinical studies to demonstrate superior performance are lacking.

CAD/CAM

Improvements in technology have spawned increasingly sophisticated computerized devices that can fabricate restorations from high-quality ceramics in a matter of minutes. Some

CAD/CAM systems are expensive laboratory-based units requiring the submission of an elastomeric or digital impression of the prepared tooth. The CEREC system was the first commercially available CAD/CAM system developed for the rapid chairside design and fabrication of ceramic restorations. The most popular dental CAD/CAM systems in use today are the CEREC 3D (Sirona Dental Systems, LLC, USA, Charlotte, NC) and E4D (D4D Technologies, LLC, Richardson, TX) (Fig. 11-5).

Generation of a chairside CAD/CAM restoration begins after the dentist prepares the tooth and uses a scanning device to collect information about the shape of the preparation and its relationship with the surrounding structures (Fig. 11-6). This step is termed *optical impression*. The system projects an image of the preparation and surrounding structures on a monitor, allowing the dentist or the auxiliary personnel to use the CAD portion of the system to design the restoration. The operator must input or confirm some of the restoration design such as the position of the gingival margins (Fig. 11-7).

Fig. 11-5 CEREC AC (A) and E4D (B) computer-aided design/computer-assisted manufacturing (CAD/CAM) devices. These chairside units are compact and mobile. (A, Courtesy Sirona Dental Systems LLC, Charlotte, NC. B, Courtesy D4D Technologies, LLC, Richardson, TX.)



Fig. 11-6 A small handheld scanner is used to make an optical impression of the tooth preparation. (Courtesy of Sirona Dental Systems LLC, Charlotte, NC.)

After the restoration has been designed, the computer directs a milling device (CAM portion of the system) that mills the restoration out of a block of high-quality ceramic or composite in minutes (Fig. 11-8). The restoration is removed from the milling device and is ready for try-in, any needed adjustment, bonding, and polishing.

A major advantage of CAD/CAM systems, both laboratory and chairside, is the quality of the restorative material.^{12,44} Manufacturers make blocks of “machinable ceramics” or “machinable composites” specifically for computer-assisted milling devices. Because these materials are fabricated under ideal industrial conditions, their physical properties have been optimized. Several different types of ceramics are available for chairside CAD/CAM restoration fabrication. These

include the feldspathic glass ceramics Vitablocs Mark II (Vident, Brea, CA) and CEREC Blocs (Sirona, manufactured by Vita Zahnfabrik, Bad Säckingen, Germany). The ceramic blocks are available in various shades and opacities, and some are even layered to mimic the relative opacity or translucency in different areas of a tooth.¹²

Two leucite-reinforced glass ceramics are available—IPS Empress CAD (Ivoclar Vivadent) and Paradigm C (3M ESPE). As mentioned above, lithium disilicate also is available in machinable form as IPS e.max CAD blocks. Although newer materials are stronger than the original ceramics, less is known about their long-term performance.¹²

The major disadvantages of chairside CAD/CAM systems are the high initial cost and the need for special training. CAD/CAM technology is changing rapidly, however, with each new generation of devices having more capability, accuracy, and ease of use.⁴⁵ In addition, clinical studies have reported good results on the longevity of CAD/CAM ceramic restorations.^{30,46-50}

Clinical Procedures

Many of the clinical procedures described are common to laboratory-fabricated and chairside CAD/CAM restorations. Some specific procedural details for CAD/CAM restorations are described in the section below on CAD/CAM techniques.

Tooth Preparation

Preparations for specific types of indirect tooth-colored inlays and onlays may vary because of differences in fabrication steps for each commercial system and variations in the physical properties of the restorative materials. Before beginning any procedure, the clinician must decide which type of restoration

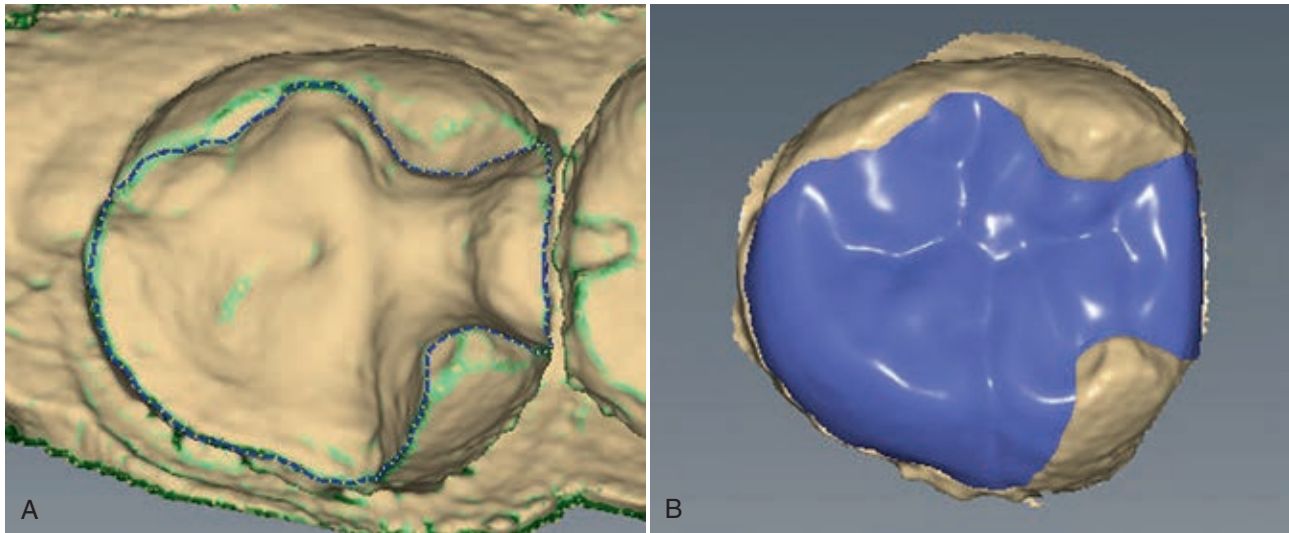


Fig. 11-7 Screen captures of two phases of an onlay restoration design. (Courtesy of D4D Technologies, LLC, Richardson, TX.)

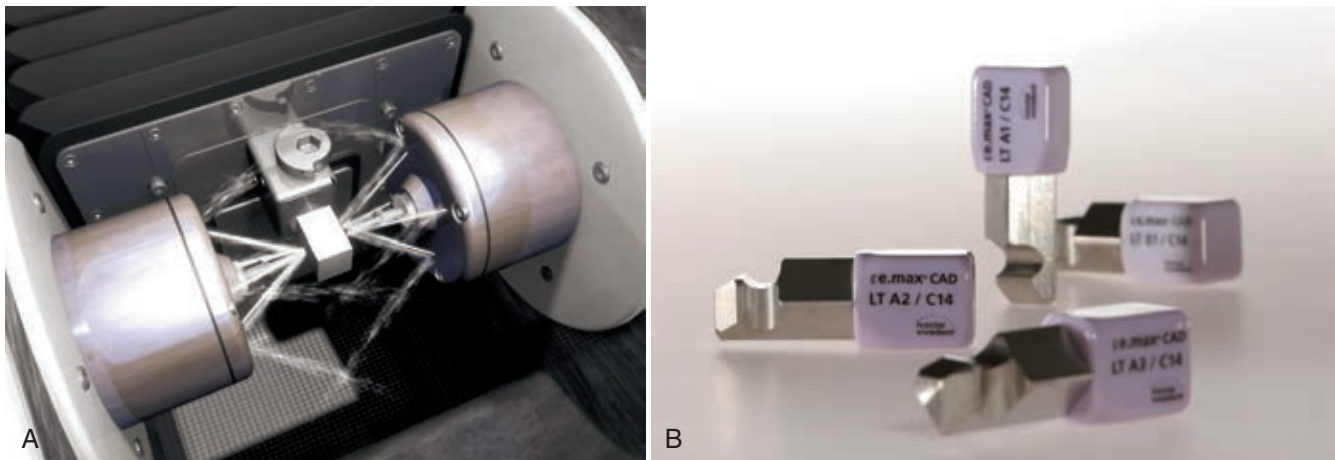


Fig. 11-8 **A**, Computer-driven software controls small, diamond-coated milling devices that mill the restoration out of a block of high-quality ceramic (as shown in **B**). (Courtesy of D4D Technologies, LLC, Richardson, TX.)

is indicated, according to the factors discussed in the previous sections in this chapter. If the clinician is not familiar with the technique, it is helpful to consult the manufacturer's literature and, if necessary, the dental laboratory to ensure the best results.

As a first clinical step, the patient is anesthetized and the area is isolated, preferably using a rubber dam. The compromised restoration (if present) is completely removed, and all caries is excavated. During preparation, stains on the external walls, such as those often left by corrosion products of old amalgam restorations, should be removed. Such stains could appear as black or gray lines at the margin after cementation. (This comment does not apply to stained but noncarious dentin on pulpal and axial walls.)

Preparations for indirect tooth-colored inlays and onlays are designed to provide adequate thickness for the restorative material and a passive insertion pattern with rounded internal angles and well-defined margins. All margins should have a 90-degree butt-joint cavosurface angle to ensure marginal

strength of the restoration. All line and point angles, internal and external, should be rounded to avoid stress concentrations in the restoration and tooth, reducing the potential for fractures (Figs. 11-9, 11-10, and 11-11).

The carbide bur or diamond used for tooth preparation should be a tapered instrument that creates occlusally divergent facial and lingual walls (Fig. 11-12), which allows for passive insertion and removal of the restoration. The junction of the sides and tip of the cutting instrument should have a rounded design to avoid creating sharp, stress-inducing internal angles in the preparation. Although the optimal gingival-occlusal divergence of the preparation is unknown, it should be greater than the 2 to 5 degrees per wall recommended for cast gold inlays and onlays. Divergence can and should be increased because the tooth-colored restoration is adhesively bonded and because only light pressure is applied during try-in and bonding. However, resistance and retention form are required to help preserve the adhesive interface, so excessive divergence must be avoided.

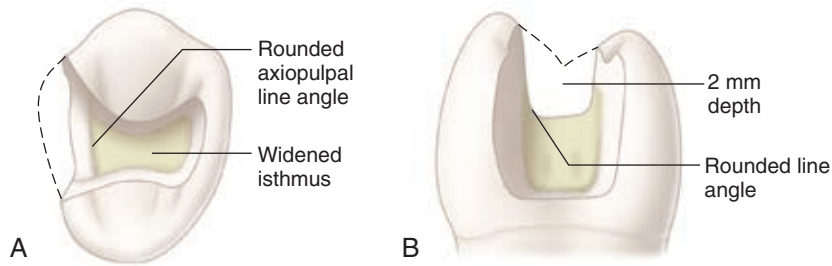


Fig. 11-9 **A**, Mesio-occlusal (MO) onlay preparation for tooth-colored inlay in maxillary first premolar (occlusal view). Isthmus should be at least 2 mm wide to prevent inlay fracture. The axiopulpal line angle should be rounded to avoid seating errors and to lower stress concentrations. **B**, Mesio-occluso-distal (MOD) onlay preparation for tooth-colored inlay in the maxillary first premolar (proximal view). The pulpal floor should be prepared to a depth of 2 mm, and the axiopulpal line angles should be rounded. The proximal margins should be extended to allow at least 0.5 mm clearance of contact with the neighboring tooth. Gingival margins in enamel are greatly preferred.

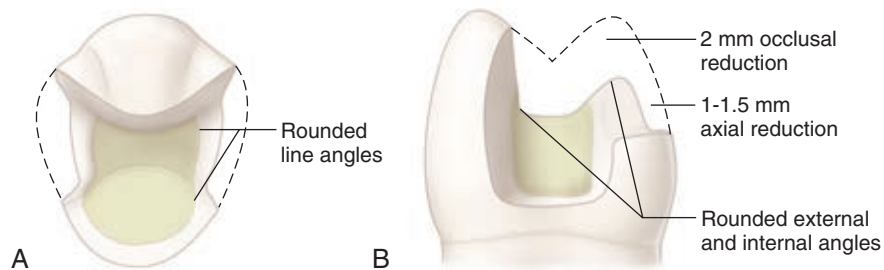


Fig. 11-10 Occlusal (**A**) and proximal (**B**) views of mesio-occluso-disto-lingual (MODL) onlay preparation on maxillary first premolar. The lingual cusp has been reduced and the lingual margin extended beyond any possible contact with opposing tooth by preparing a “collar.” Functional cusps require 2 mm of occlusal reduction. All internal and external line angles are rounded.

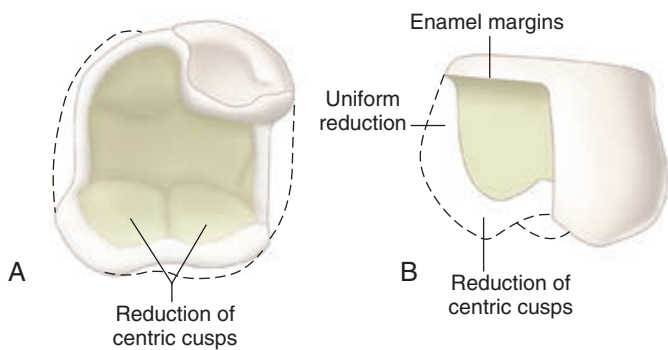


Fig. 11-11 Mesio-occluso-disto-facio-lingual (MODFL) onlay preparation on the maxillary right first molar. Distofacial (DF), mesiolingual (ML), and distolingual (DL) cusps are reduced. **A**, Occlusal view. **B**, Facial view.

Throughout preparation, the cutting instruments used to develop vertical walls are oriented to a single path of draw, usually the long axis of the tooth crown. The occlusal portion of the preparation should be 2 mm deep. Based on input from laboratory technicians, many failures of ceramic inlays and onlays can be attributed to insufficient thickness resulting from insufficient occlusal reduction. Most ceramic systems require that any isthmus be at least 2 mm wide to decrease the possibility of fracture of the restoration. The facial and lingual walls should be extended to sound tooth structure and should go around the cusps in smooth curves. Ideally, there should be no undercuts that would prevent the insertion or removal



Fig. 11-12 Typical diamond rotary instruments used for ceramic inlay or onlay tooth preparations.

of the restoration. Small undercuts, if present, can be blocked out using a resin-modified glass ionomer (RMGI) liner. The pulpal floor should be smooth and relatively flat. After removal of extensive caries or previous restorative material from any internal wall, the floor is restored to more nearly ideal form with a material that has a reasonably high compressive strength such as an RMGI liner or base.

The facial, lingual, and gingival margins of the proximal boxes should be extended to clear the adjacent tooth by at least 0.5 mm. These clearances provide adequate access to the

margins for the impression and for finishing and polishing instruments. For all walls, a 90-degree cavosurface margin is ideal because ceramic materials are fragile in thin sections. The gingival margin should be extended as minimally as possible because margins in enamel are greatly preferred for bonding and because deep gingival margins are difficult to impress and to isolate properly during bonding. When a portion of the facial or lingual surface is affected by caries or other defect, it might be necessary to extend the preparation (with a gingival shoulder) around the transitional line angle to include the defect. The axial wall of the shouldered extension should be prepared to allow for adequate restoration thickness (i.e., 1–1.5 mm).

When extending through or along the cuspal inclines to reach sound tooth structure, a cusp usually should be capped if the extension is two-thirds or greater than the distance from any primary groove to the cusp tip (see Figs. 11-10 and 11-11). If the cusps must be capped, they should be reduced by 2 mm and should have a 90-degree cavosurface angle. When capping cusps, especially centric holding cusps, it might be necessary to prepare a shoulder to move the facial or lingual cavosurface margin away from any possible contact with the opposing tooth, either in maximum intercuspal position or during functional movements. Contacts directly on margins can lead to premature deterioration of marginal integrity. The axial wall of the resulting shoulder should be sufficiently deep to allow for adequate thickness of the restorative material and should have the same path of draw as the main portion of the preparation.

Impression

Tooth-colored inlay or onlay systems require an elastomeric or optical impression of the prepared tooth and the adjacent teeth and interocclusal records, which allow the restoration to be fabricated on a working cast in the laboratory. Of course, with chairside CAD/CAM systems, no working cast is necessary.

Provisional Restoration

A provisional or temporary restoration is necessary when using indirect systems that require two appointments. The provisional restoration protects the pulp–dentin complex in vital teeth, maintains the position of the prepared tooth in the arch, and protects the soft tissues adjacent to the prepared areas. The provisional can be made using conventional techniques and bis-acryl composite materials. Care should be taken to avoid bonding of the temporary material to the preparation at this phase of the procedure. A lubricant of some sort (e.g., glycerin) can be applied to the preparation, if desired, especially if a resin-based material was used to block out undercuts or level the floor of the preparation. Temporary restorations for PFM and cast gold restorations typically are cemented with eugenol-based temporary cements. Eugenol is believed to interfere with resin polymerization, however, and potentially could reduce the adhesion of the permanent composite cement to tooth structure.^{51,52} Although some studies report this does not occur if the tooth is thoroughly cleaned using pumice, excavator, or air abrasion before cementation of the permanent restoration, use of a non-eugenol temporary cement is recommended.^{53,54} For

exceptionally nonretentive preparations, or when the temporary phase is expected to last longer than 2 to 3 weeks, zinc phosphate or polycarboxylate cement can be used to increase retention of the provisional restoration. Resin-based temporary cements are also available (e.g., TempBond Clear, Kerr Corporation, Orange, CA).

CAD/CAM Techniques

Clinical procedures for CAD/CAM systems differ somewhat from the procedures previously described. Tooth preparations for CAD/CAM inlays must reflect the capabilities of the CAD software and hardware and the CAM milling devices that fabricate the restorations. One example of how preparations are modified when using the CEREC system pertains to undercuts. Laboratory-fabricated indirect systems require the preparation to have a path of draw that allows insertion and removal of the restoration without interferences from undercuts. In contrast, the CEREC system automatically “blocks out” any undercuts during the optical impression (Fig. 11-13). Of course, large undercuts should be avoided.

Using a chairside CAD/CAM system, an experienced dentist can prepare the tooth, fabricate an inlay, and deliver it in approximately 1 hour (Fig. 11-14). This system eliminates the need for a conventional impression, provisional restoration, and multiple patient appointments.

Try-in and Bonding

Try-in and bonding of tooth-colored inlays or onlays are more demanding than those for cast gold restorations because of (1) the relatively fragile nature of some ceramic materials, (2) the requirement of near-perfect moisture control, and (3) the use of resin cements. Occlusal evaluation and adjustment generally are delayed until after the restoration is bonded, to avoid fracture of the ceramic material.¹⁶

Preliminary Steps

The use of a rubber dam is strongly recommended to prevent moisture contamination of the conditioned tooth or restoration surfaces during cementation and to improve access and visibility during delivery of the restoration. After removing the provisional restoration, all of the temporary cement is cleaned from the preparation walls.

Restoration Try-in and Proximal Contact Adjustment

The inlay or onlay is placed into the preparation using light pressure to evaluate its fit. If the restoration does not seat completely, the most likely cause is an over-contoured proximal surface (Fig. 11-15). Using the mouth mirror, where needed, the embrasures should be viewed from the facial, lingual, and occlusal aspects to determine where the proximal contour needs adjustment to allow final seating of the restoration, while producing the correct position and form of the contact. Passing thin dental floss through the contact reveals tightness and position of the proximal contact, signifying to the experienced operator the degree and location of excess contact. Articulating paper also can be used successfully to identify overly tight proximal contacts. Abrasive disks or

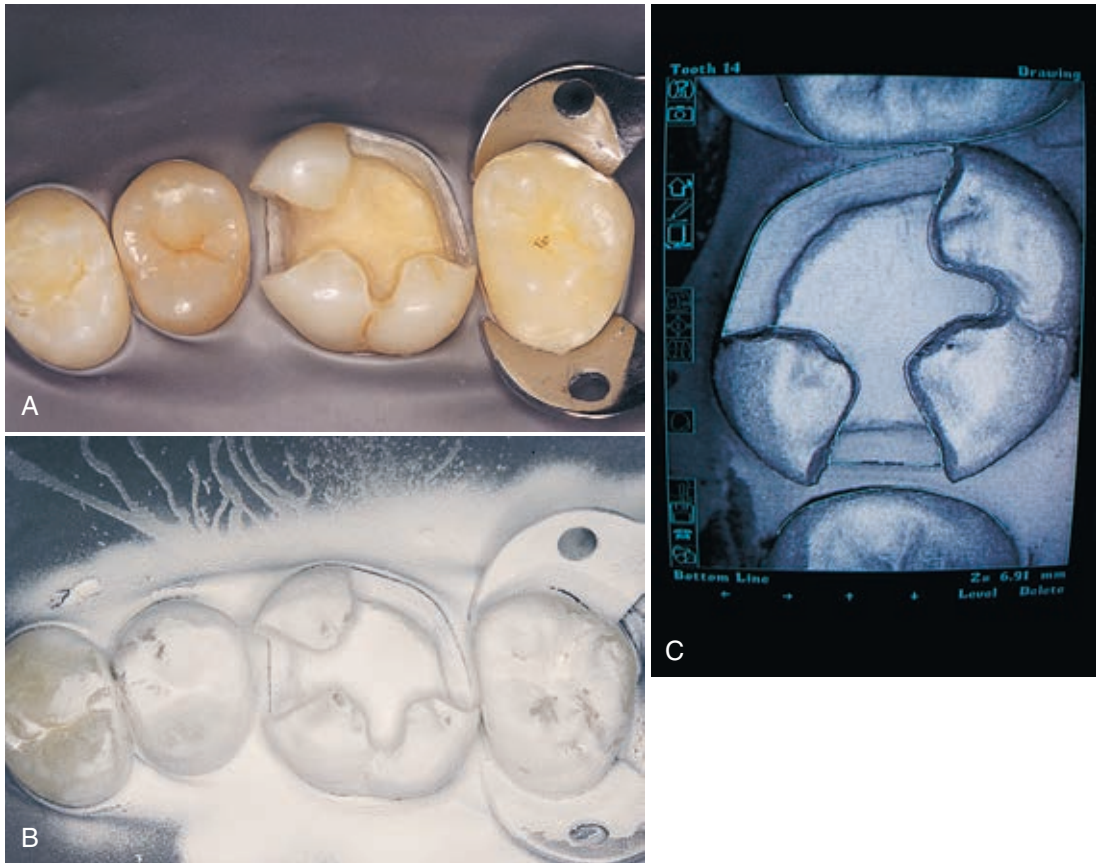


Fig. 11-13 **A**, Preparation for mesio-occluso-disto-facial (MODF) ceramic onlay on maxillary first molar. **B**, Preparation coated with special powder for capture with optical impression by CEREC device. **C**, Optical impression.

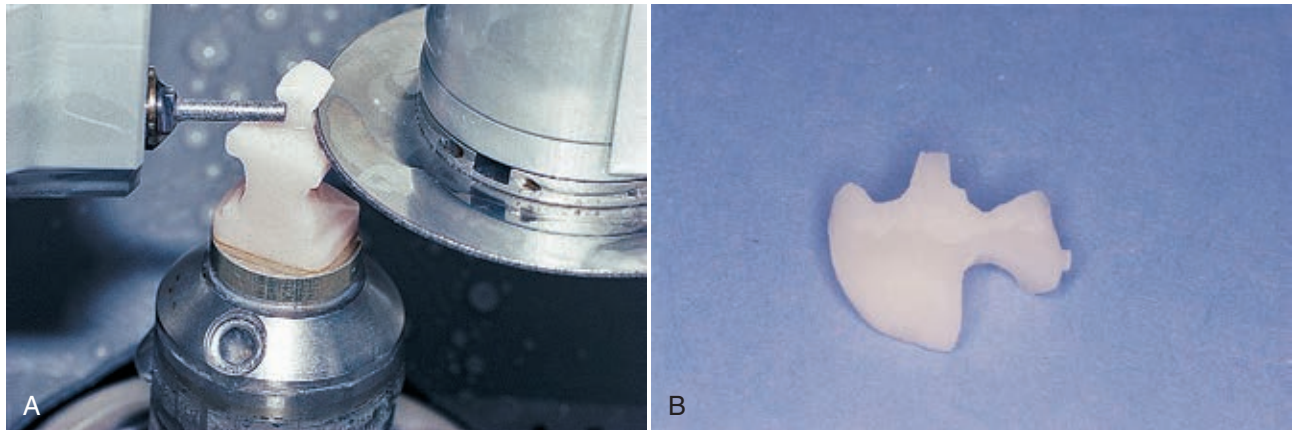


Fig. 11-14 **A**, Ceramic onlay being milled. **B**, Milled onlay.

points are used to adjust the proximal contour and contact relationship. While adjusting the intensity and location of the proximal contacts, increasingly finer grits of abrasive instruments are used to polish the proximal surfaces because they will be inaccessible for polishing after cementation.

If the proximal contours are not over-contoured and the restoration still does not fit completely, the preparation should be checked again for residual temporary materials or debris. If the preparation is clean, internal or marginal interferences

also might prevent the restoration from seating completely. When these interferences have been identified through careful visual inspection of the margins or using “fit-checker” materials, they can be adjusted on the restoration, in the preparation, or both. These interferences are rare because contemporary impression materials and ceramic fabrication systems are accurate. In the event of a significant discrepancy between the preparation and the restoration, a new impression must be taken.

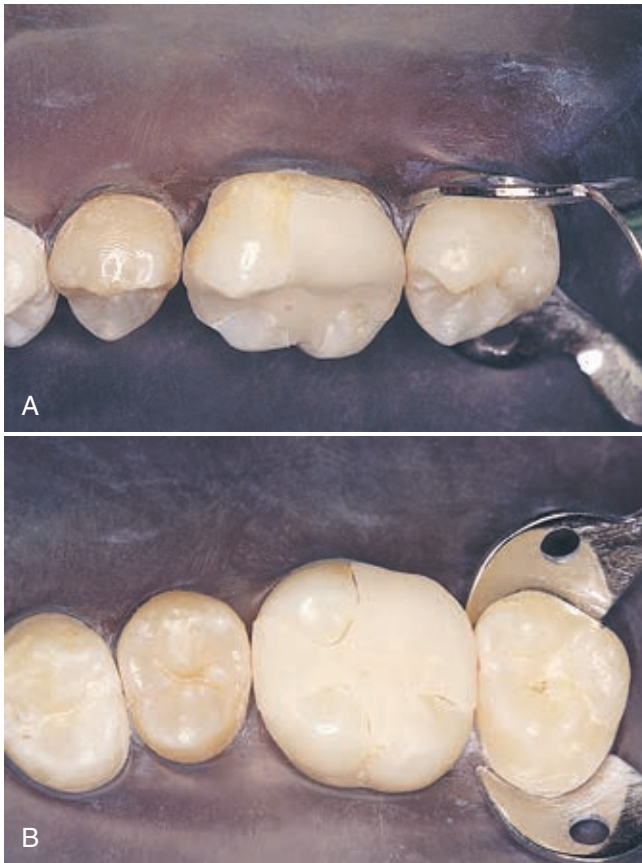


Fig. 11-15 Initial try-in of ceramic onlay. **A**, Facial view. **B**, Occlusal view.

Marginal fit is verified after the restoration is completely seated. Ceramic inlays and onlays typically have slightly larger marginal gaps than comparable gold restorations.^{55,56} Slight excesses of contour can be removed, if access allows, using fine-grit diamond instruments or 30-fluted carbide finishing burs. These adjustments are done preferably after the restoration is bonded so that marginal fractures are avoided.

Bonding

For proper adhesive bonding, the internal surface of the inlay or onlay must be treated appropriately. HF acid or a similar acid usually is used to etch the internal surfaces of the restoration (Fig. 11-16).⁵⁷ Such acid-etching increases surface relief and not only increases the surface area but also results in micromechanical bonding of the composite cement to the ceramic restoration. HF etching generally is done by the laboratory. The clinician should check the internal surface of the restoration, however, to confirm the etching, which is evident by a white-opaque appearance similar to acid-etched enamel. Chairside ceramic etching can be done with a brief application of 5% to 10% HF acid on the internal surfaces of the inlay or onlay. Application time depends on the type of ceramic material being used. After etching, the ceramic is treated with a silane coupling agent to facilitate chemical bonding of the resin cement.^{58,59}

Clear plastic matrix strips can be applied in each affected proximal area and wedged (Fig. 11-17, A). Care should be



Fig. 11-16 Applying HF acid to the internal surface of the ceramic onlay. After rinsing and drying, etched ceramic surfaces should have a frosty white appearance.

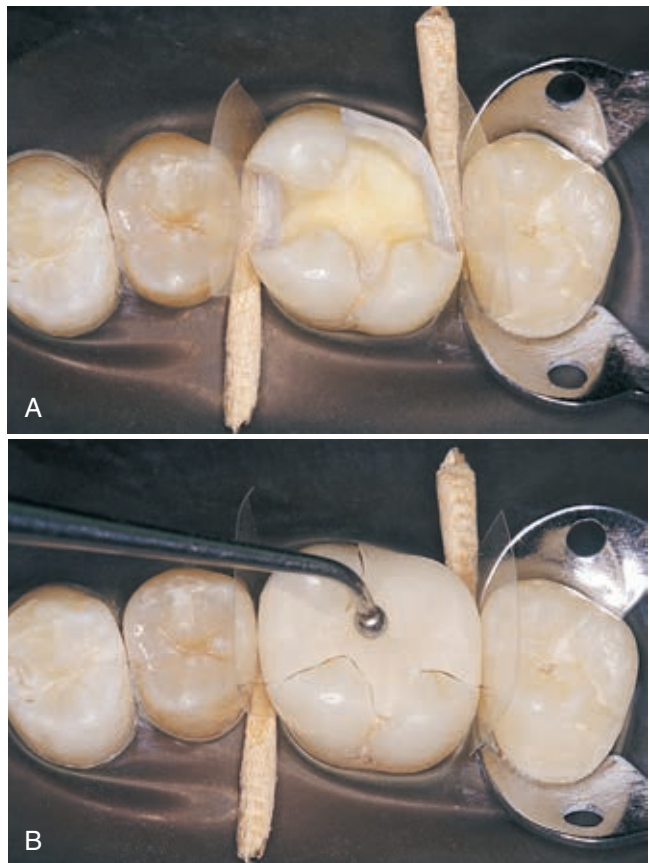


Fig. 11-17 **A**, If desired, clear plastic matrix strips are applied and wedged before etching and bonding. **B**, The fit of the onlay is verified with the matrix and wedges in place.

taken to avoid interference of the wedges with the seating of the restoration. (Matrix and wedge are not mandatory for these procedures, and some operators may prefer not to use them.) The inlay or onlay is tried-in again and checked for fit (see Fig. 11-17, B). The preparation surfaces are etched with phosphoric acid (Fig. 11-18, A) and treated with the components of an appropriate adhesive system. With resin

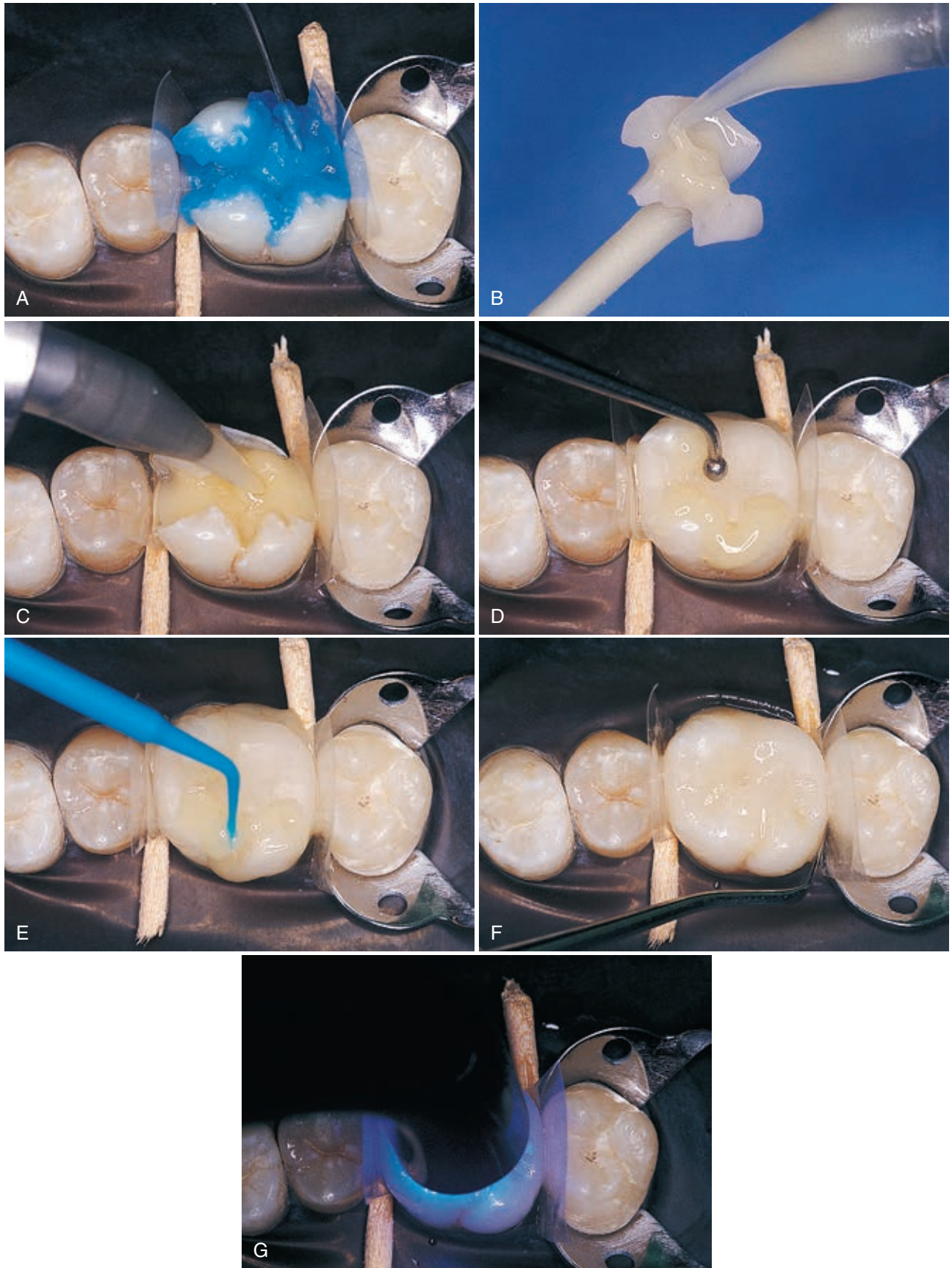


Fig. 11-18 **A**, Enamel and dentin are etched with phosphoric acid. **B**, Dual-cured resin cement is applied to the onlay. **C**, After application of the adhesive system, cement is applied to the preparation. **D**, The ceramic onlay is seated into preparation. **E** and **F**, Before curing, excess resin cement is removed with explorer, brushes, and/or other appropriate instruments. **G**, The resin cement is light-activated from occlusal, facial, and lingual directions.

cements that require an etch-and-rinse adhesive, enamel and dentin are both etched. For cements that use a self-etch primer, the enamel margins are selectively etched. Contact of phosphoric acid with dentin decreases the bond strengths of most self-etch materials. Typically, the final step of the adhesive system also is applied to the internal surfaces of the restoration previously etched and silanated. Self-adhesive, resin-based cements (e.g., RelyX Unicem, 3M ESPE) have been introduced in recent years, and early *in vitro* and *in vivo* results with tooth-colored inlays and onlays have been good.^{60,61} Nevertheless, because these typically have low bond strengths to enamel, long-term appropriateness for ceramic inlays and onlays is unproven.⁶²

A dual-cure resin cement is mixed and inserted into the preparation with a paddle-shaped instrument or a syringe.^{20,63} The internal surfaces of the restoration also are coated with the resin cement (see Fig. 11-18, B and C), and using light pressure, the restoration is immediately inserted into the prepared tooth. A ball burnisher or similar instrument applied with a slight vibrating motion is usually sufficient to seat the restoration (see Fig. 11-18, D). Excess resin cement is removed with thin-bladed composite instruments, brushes, micro-brush, or an explorer (see Fig. 11-18, E and F). The operator must be careful not to remove any resin from the marginal interface between the tooth and the restoration. Because the ceramic material attenuates the curing light intensity, the cement is light-activated with multiple exposures from occlusal, facial, and lingual directions, according to the manufacturer's recommendations for the specific cement and light-curing device (see Fig. 11-18, G).⁶⁴

Finishing and Polishing Procedures

After light-curing the cement, the plastic matrix strips and the wedges (if used) are removed, and the setting of the resin cement is verified. All marginal areas are checked with an explorer tine. Medium-grit or fine-grit diamond rotary instruments are used initially to remove any excess resin cement at the margins. Care must be taken to preserve the glazed surface of ceramic restorations as much as possible. Slender flame shapes are used interproximally (Fig. 11-19, A), whereas larger oval or cylindrical shapes are used on the occlusal surface. After using the fine-grit diamond instruments, 30-fluted carbide finishing burs can be used to obtain a smoother finish (see Fig. 11-19, B).²⁷

Interproximally, a No. 12 scalpel blade can be used to remove excess resin cement when access permits (Fig. 11-20, A). Abrasive strips of successively finer grits also can be used to remove slight interproximal excesses (see Fig. 11-20, B). Much care must be exercised to avoid damaging the gingiva or the root surfaces when using such instruments interproximally. With care and appropriate instrumentation, ceramic restorations can be polished to a surface as smooth as glazed porcelain using the abrasive sequence shown in Table 11-1.²⁷ The same fine-grit diamonds used to adjust margins may be used to adjust contour, followed by the use of 30-fluted carbide finishing burs. Further smoothing is accomplished with a series of rubber abrasive points and cups used at slow speed with air-water spray (Fig. 11-21, A). Final polishing of the ceramic restoration may be achieved by applying a diamond polishing paste with a bristle brush or another suitable instrument (see Fig. 11-21, B). Ceramic restorations properly

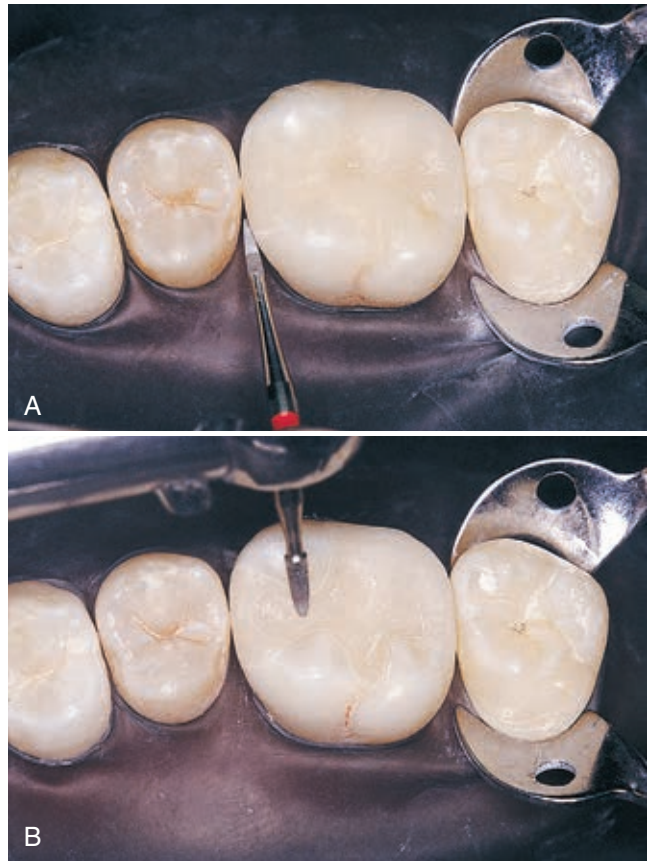


Fig. 11-19 A, Slender, fine-grit, flame-shaped, diamond instruments are used to remove flash along facial and lingual margins of ceramic onlay. B, 30-fluted finishing burs are used to smooth areas that were adjusted with diamonds.

Table 11-1 Instrumentation for Finishing and Polishing Ceramic Restorations

Sequence	Instruments
1	Medium-grit to fine-grit diamond rotary instrument
2	30-fluted carbide burs
3	Sequence of rubber, abrasive-impregnated porcelain polishing points
4	Diamond polishing paste

polished with this series of instruments have a remarkably beautiful, smooth surface (see Fig. 11-21, C).

The rubber dam is removed after all of the excess resin cement has been removed, marginal integrity has been verified, and the restoration has been polished, as needed. The occlusion is now checked and adjusted, if necessary. With good occlusal records and careful laboratory work, little, if any, correction should be necessary. Premature occlusal contacts can be adjusted using fine-grit diamond instruments, followed by 30-fluted carbide finishing burs and appropriate polishing steps. Achieving a highly polished surface is critical to remove flaws that could be initiation points for ceramic



Fig. 11-20 **A**, Removing excess resin cement using a surgical blade. **B**, Smoothing the interproximal area with an abrasive finishing strip.

fracture. In selected cases, the occlusion can be adjusted on the opposing dentition. This is feasible only if such adjustment is done to correct the occlusal plane of opposing teeth or to reduce a pronounced cusp present on the tooth opposing the restoration to avoid occlusal trauma.

Clinical Procedures for CAD/CAM Inlays and Onlays

When delivering a CAD/CAM inlay, adjustments are usually necessary for try-in, finishing, and polishing. The original CEREC system milled the occlusal surface relatively flat without any significant surface detail and did not take into account the opposing occlusion. However, contemporary CAD/CAM systems are able to mill in occlusal contours in a variety of manners. They can extrapolate existing contours beyond the cavosurface margin to the central groove, or can build the surface up to the level of a scanned wax bite. Adjacent teeth, in particular the marginal ridges and cusp heights, also can be used as references for the design of the occlusal surface of a CAD/CAM restoration. If the pre-operative contours of the tooth were satisfactory, the system can reproduce them in the restoration. When adjusting the occlusion of a CAD/CAM inlay, it may be necessary to use medium-grit or fine-grit diamonds with air-water spray coolant for initial contouring of the occlusal surface, followed by the instrumentation previously discussed for finishing and polishing.

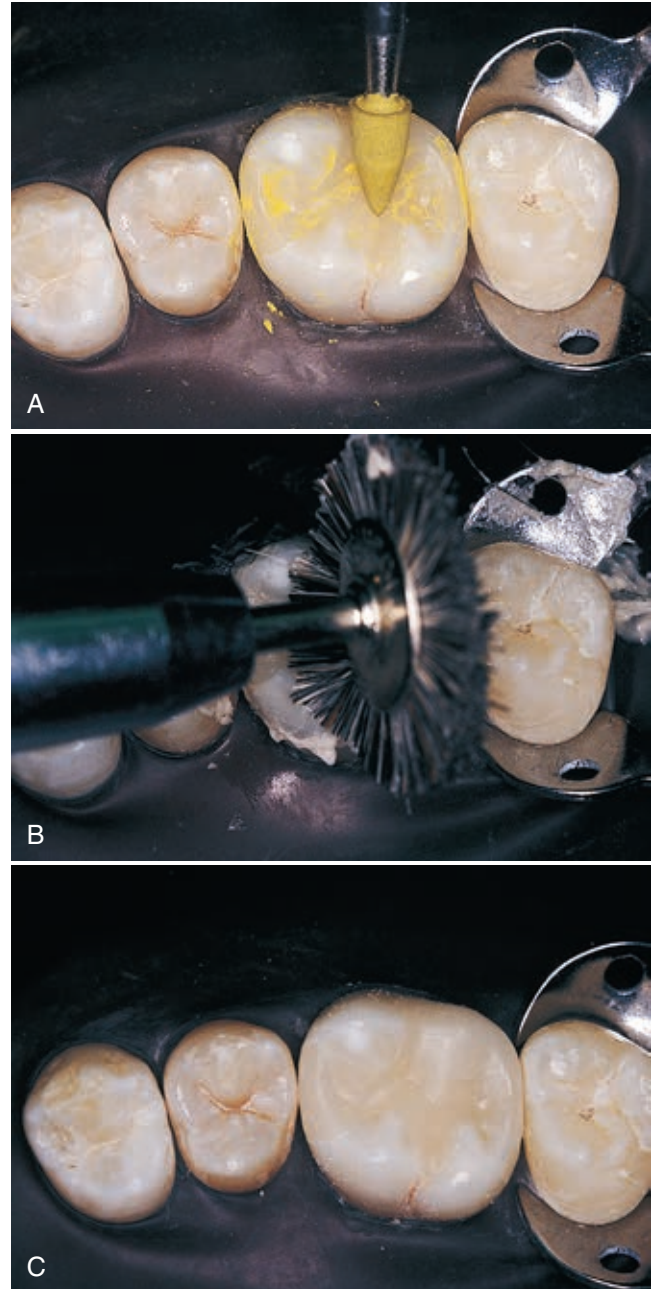


Fig. 11-21 Polishing sequence for ceramic inlays and onlays. **A**, After using fine-grit diamonds and 30-fluted carbide finishing burs to adjust contours and margins, rubber abrasive points and cups of increasingly fine grits are used at slow speed. **B**, Final polish imparted by diamond polishing paste applied with bristle brush. **C**, Occlusal view of the polished ceramic onlay.

Common Problems and Solutions

The most common cause of failure of tooth-colored inlays or onlays is bulk fracture. Fractures can result from placing the restoration in a tooth where it was not indicated, such as in bruxers and clencher, or from lack of appropriate restoration thickness resulting from insufficient tooth preparation or from restoration contours that introduce excursive interferences in occlusal function. If bulk fracture occurs, replacement of the restoration is almost always indicated.

Repair of Ceramic Inlays and Onlays

Minor defects in ceramic restorations can be repaired, but before initiating any repair procedure, the operator should determine whether replacement, rather than repair, is the appropriate treatment. If repair is appropriate, the dentist should attempt to identify the cause of the problem and correct it, if possible. For example, a small fracture resulting from occlusal trauma might indicate that some adjustment of the opposing occlusion is required.

The repair procedure is initiated by mechanical roughening of the involved surface. Although a coarse diamond may be used, a better result is obtained with the use of airborne particle abrasion using aluminum oxide particles and a special intraoral device.⁶⁵ This initial mechanical roughening is followed by brief (typically 2 minutes) application of 5% to 10% HF acid gel. HF acid etches the surface, creating further micro-defects to facilitate mechanical bonding. The next step in the repair procedure is application of a silane coupling agent. Silanes mediate chemical bonding between ceramics and resins and may improve the predictability of resin–resin repairs.⁵⁹ The manufacturer's guidelines should be followed when using silanes because they can differ substantially from one product to another. After the silane has been applied, a resin adhesive is applied and light-cured. A composite of the appropriate shade is placed, cured, contoured, and polished.

Summary

Advances in ceramic, polymer, and adhesive technologies have resulted in the development of a variety of tooth-colored indirect Class I and II restorations. These restorations offer an excellent alternative to direct composite restorations, especially for large restorations, and are more conservative than full-coverage restorations. Because the clinical procedures are relatively technique-sensitive, however, proper case selection, operator skill, and attention to detail are crucial to success.

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Additional Conservative Esthetic Procedures

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Significant improvements in tooth-colored restorative materials and adhesive techniques have resulted in numerous conservative esthetic treatment possibilities. Although restorative dentistry is a blend of art and science, conservative esthetic dentistry truly emphasizes the artistic component. As Goldstein stated, “Esthetic dentistry is the art of dentistry in its purest form.”¹ As with many forms of art, conservative esthetic dentistry provides a means of artistic expression that feeds on creativity and imagination. Dentists find performing conservative esthetic procedures enjoyable, and patients appreciate the immediate esthetic improvements rendered, often without the need for local anesthesia.

One of the greatest assets a person can have is a smile that shows beautiful, natural teeth (Fig. 12-1). Children and teenagers are especially sensitive about unattractive teeth. When teeth are discolored, malformed, crooked, or missing, often the person makes a conscious effort to avoid smiling and tries to “cover up” his or her teeth. Correction of these types of dental problems can produce dramatic changes in appearance, which often result in improved confidence, personality, and social life. The restoration of a smile is one of the most appreciated and gratifying services a dentist can render. The positive psychological effects of improving a patient’s smile often contribute to an improved self-image and enhanced self-esteem. These improvements make conservative esthetic dentistry particularly gratifying for the dentist and represent a new dimension of dental treatment for patients.

This chapter presents conservative esthetic procedures in the context of their clinical applications. The principles and clinical steps involved in adhesive bonding for the treatment alternatives discussed in this chapter are similar to those described in Chapters 8 to 10. Only specific conservative esthetic clinical procedures or variations from previously described techniques are presented in this chapter.

Artistic Elements

Regardless of the result desired, certain basic artistic elements must be considered to ensure an optimal esthetic result. In

conservative esthetic dentistry, these elements include the following:

- Shape or form
- Symmetry and proportionality
- Position and alignment
- Surface texture
- Color
- Translucency

Some or all of these elements are common to virtually every conservative esthetic dental procedure; a basic knowledge and understanding of these artistic elements is required to attain esthetic results consistently.

Shape or Form

The shape of teeth largely determines their esthetic appearance. To achieve optimal dental esthetics, it is imperative that natural anatomic forms be achieved. A basic knowledge of normal tooth anatomy is fundamental to the success of any conservative esthetic dental procedure.

When viewing the clinical crown of an incisor from a facial (or lingual) position, the crown outline is trapezoidal. Subtle variations in shape and contour produce very different appearances, however. Rounded incisal angles, open incisal and facial embrasures, and softened facial line angles typically characterize a youthful smile. A smile characteristic of an older individual having experienced attrition secondary to aging, typically exhibits incisal embrasures that are more closed and incisal angles that are more prominent (i.e., less rounded). Frequently, minor modification of existing tooth contours, sometimes referred to as *cosmetic contouring*, can effect a significant esthetic change (see section on alterations of shape of natural teeth). Reshaping enamel by rounding incisal angles, opening incisal embrasures, and reducing prominent facial line angles can produce a more youthful appearance (Fig. 12-2).

Significant generalized esthetic changes are possible when treating all anterior teeth (and occasionally the first

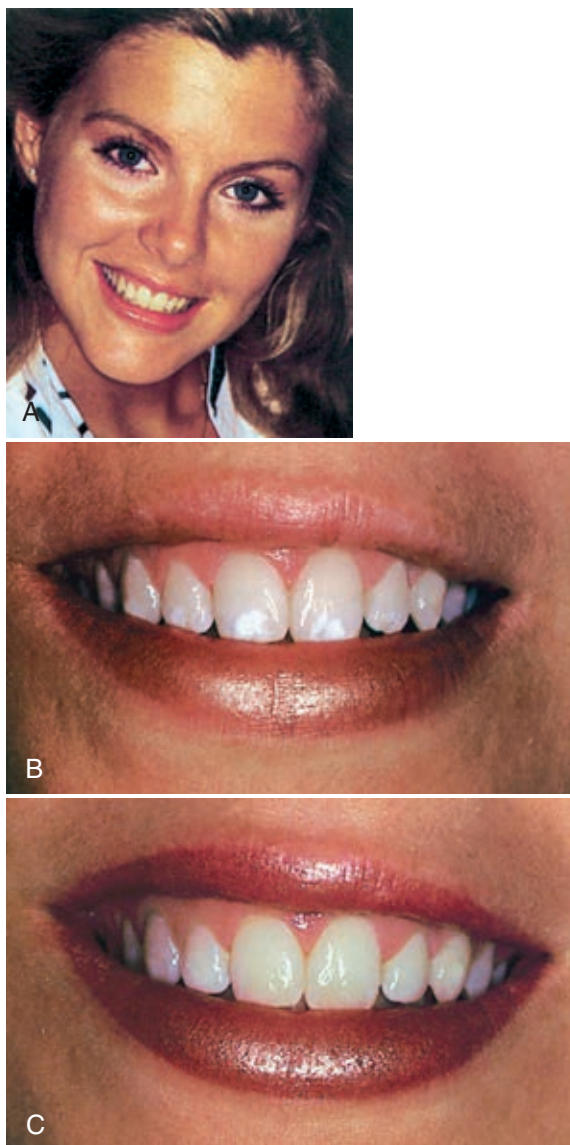


Fig. 12-1 Examples of conservative esthetic procedures. **A**, A beautiful radiant smile is one of the greatest assets a person can have. **B**, The appearance of this aspiring young model was marred by hypocalcified areas of maxillary anterior teeth. **C**, A simple treatment consisted of removing part of the discolored enamel, acid etching the preparations, and restoring with direct-composite partial veneers. (Courtesy of Dr. C. L. Sockwell.)

premolars) visible in the patient's smile. This fact is particularly true when placing full-coverage facial restorations such as veneers (see the section on Veneers). With this treatment method, the dentist can produce significant changes in tooth shapes and forms to yield a variety of different appearances.

Although less extensive, restoring an individual tooth rather than all anterior teeth simultaneously may require greater artistic ability. Generalized restoration of all anterior teeth with full facial veneers affords the dentist significant control of the contours generated. When treating an isolated tooth, however, the success of the result is determined largely by how well the restored tooth esthetically matches the surrounding natural teeth. The contralateral tooth to the one being restored should be examined closely for subtle characterizing features such as developmental depressions, embrasure form, prominences, or other distinguishing characteristics of form. A high degree of realism must be reproduced artfully to achieve optimal esthetics when restoring isolated teeth or areas.

Illusions of shape also play a significant role in dental esthetics. The border outline of an anterior tooth (i.e., facial view) is primarily two-dimensional (i.e., length and width). The third dimension of depth is crucial, however, in creating illusions, especially those of apparent width and length.

Prominent areas of contour on a tooth typically are highlighted with direct illumination, making them more noticeable, whereas areas of depression or diminishing contour are shadowed and less conspicuous. By controlling the areas of light reflection and shadowing, full facial coverage restorations (in particular) can be esthetically contoured to achieve various desired illusions of form.

The apparent size of a tooth can be changed by altering the position of facial prominences or heights of contour without changing the actual dimension of the tooth. Compared with normal tooth contours (Fig. 12-3, A), a tooth can be made to appear narrower by positioning the mesiofacial and distofacial line angles closer together (see Fig. 12-3, B). Developmental depressions also can be positioned closer together to enhance the illusion of narrowness. Similarly, greater apparent width can be achieved by positioning the line angles and developmental depressions further apart (see Fig. 12-3, C).

Although more difficult, the apparent length of teeth also can be changed by illusion. Compared with normal tooth contours (Fig. 12-4, A), a tooth can be made to appear shorter by emphasizing the horizontal elements such as gingival perikymata and by positioning the gingival height of contour further incisally (see Fig. 12-4, B). Slight modification of the

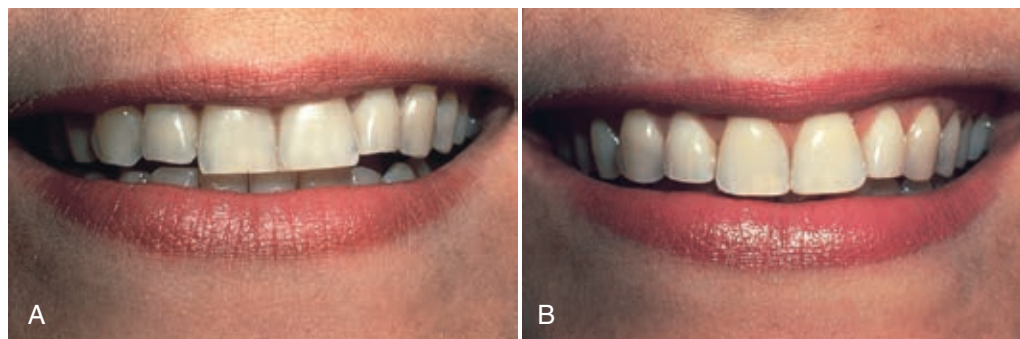


Fig. 12-2 Cosmetic contouring. **A**, Anterior teeth before treatment. **B**, By reshaping teeth, a more youthful appearance is produced.

incisal area, achieved by moving the incisal height of contour further gingivally, also enhances the illusion of a shorter tooth. The opposite tenets are true for increasing the apparent length of a tooth. The heights of contour are moved farther apart incisogingivally, and vertical elements such as developmental depressions are emphasized (see Fig. 12-4, C).

Used in combination, these illusionary techniques are particularly valuable for controlling the apparent dimension of teeth in procedures that result in an actual increased width of teeth, such as in diastema (i.e., space) closure (see the section on Correction of Diastemas). By contouring the composite additions in such a way that the original positions of the line angles are maintained, the increased widths of the restored teeth are less noticeable (Fig. 12-5). If full facial coverage

restorations are placed in conjunction with a diastema closure, vertical elements can be enhanced and horizontal features de-emphasized to control further the apparent dimension of teeth.

Symmetry and Proportionality

The overall esthetic appearance of a human smile is governed largely by the symmetry and proportionality of the teeth that constitute the smile. Asymmetric teeth or teeth that are out of proportion to the surrounding teeth disrupt the sense of balance and harmony essential for optimal esthetics. Assuming that the patient's teeth are aligned normally (i.e., rotations or faciolingual positional defects are not present), dental symmetry can be maintained if the sizes of contralateral teeth are equivalent. A dental caliper should be used in conjunction with any conservative esthetic dental procedure that would alter the mesiodistal dimension of teeth. This recommendation is particularly true for procedures such as diastema closure or other procedures involving augmentation of proximal surfaces with composite. By first measuring and recording the widths of the interdental space and the teeth to be augmented, the appropriate amount of contour to be generated with composite resin addition can be determined (Fig. 12-6). In this manner, symmetric and equal tooth contours can be generated (see the section on Correction of Diastemas). When dealing with restorations involving the midline, particular attention also must be paid to the incisal and gingival embrasure forms; the mesial contours of both central incisors must be mirror images of one another to ensure an optimally symmetric and esthetic result.

In addition to being symmetric, anterior teeth must be in proper proportion to one another to achieve maximum esthetics. The quality of proportionality is relative and varies greatly, depending on other factors (e.g., tooth position, tooth

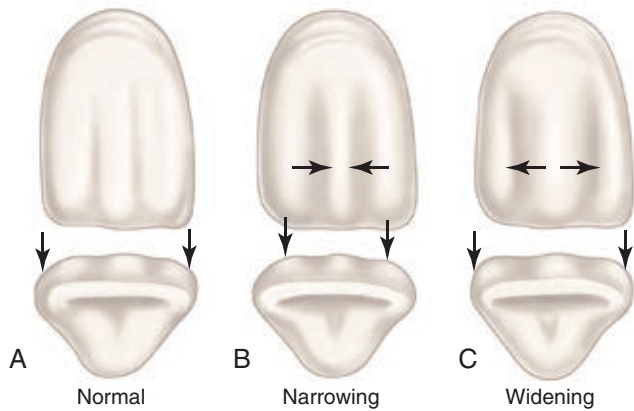


Fig. 12-3 Creating illusions of width. **A**, Normal width. **B**, A tooth can be made to appear narrower by positioning mesial and distal line angles closer together and by more closely approximating developmental depressions. **C**, Greater apparent width is achieved by positioning line angles and developmental depressions farther apart.

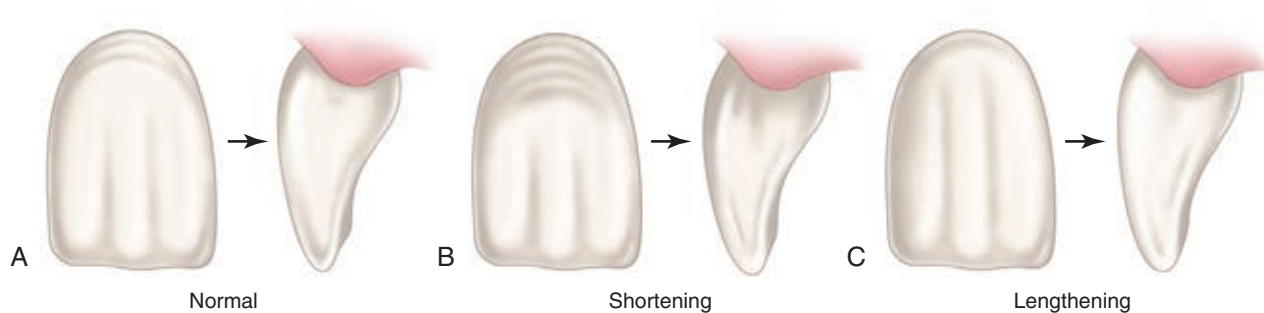


Fig. 12-4 Creating illusions of length. **A**, Normal length. **B**, A tooth can be made to appear shorter by emphasizing horizontal elements and by positioning the gingival height of contour farther incisally. **C**, The illusion of length is achieved by moving the gingival height of contour gingivally and by emphasizing vertical elements, such as developmental depressions.

Fig. 12-5 Controlling apparent tooth size when adding proximal dimension. **A**, Teeth before treatment. **B**, By maintaining original positions of the facial line angles (see areas of light reflection), increased widths of teeth after composite augmentations are less noticeable.



Fig. 12-6 Diastema closure. **A**, Teeth before composite additions. **B**, Symmetrical and equal contours are achieved in the final restorations.



Fig. 12-7 Tooth proportions. **A**, The rule of the golden proportion. The exact ratios of proportionality. **B**, The anterior teeth of this patient are in golden proportion to one another. **C**, Width-to-length ratios. Pre-operative view reveals width-to-length ratio of 1 : 1. **D**, Following a periodontal surgical crown lengthening procedure, a more esthetic width-to-length ratio of 0.80 exists. **E**, Final result with etched porcelain veneers. A width-to-length ratio of 0.80 is maintained. **F**, A 7-year post-operative view reveals a stable and esthetic long-term result.

alignment, arch form, configuration of the smile). One long-accepted theorem of the relative proportionality of maxillary anterior teeth typically visible in a smile involves the concept of *the golden proportion*.² Originally formulated as one of Euclid's elements, this theorem has been relied on through the ages as a geometric basis for proportionality in the beauty of art and nature.³ On the basis of this formula, a smile, when viewed from the front, is considered to be esthetically pleasing if each tooth in that smile (starting from the midline) is approximately 60% of the size of the tooth immediately mesial to it. The exact proportion of the distal tooth to the mesial tooth is 0.618 (Fig. 12-7, A). These recurring esthetic dental proportions are based on the apparent sizes of teeth when viewed straight on and not the actual sizes of individual teeth. An example of an esthetically pleasing smile that meets the golden proportion can be seen in Figure 12-7, B.

Although the golden proportion is not the absolute determinant of dental esthetics, it does provide a practical and proven guide for establishing proportionality when restoring anterior teeth, especially if these teeth are considered long. However,

according to a study by Preston, only 17% of the population naturally exhibits smiles that meet the golden proportion as the recurring esthetic dental proportion.⁴ According to a survey of dentists by Ward, a recurring esthetic dental proportion of 70% (as opposed to 61.8% as with the golden proportion) is preferred when teeth are of normal dimension.⁵

Little scientific information is available regarding the proper proportions of individual anterior teeth. A study by Sterrett et al. revealed that the average width-to-length ratio for a maxillary central incisor in men was 0.85 and in women was 0.86.⁶ The actual width-to-length ratios found in this same study for maxillary lateral incisors in men and women were 0.76 and 0.79, respectively. Another study by Magne et al. reported average width-to-length ratios of 0.87 for worn maxillary central incisors and 0.78 for unworn maxillary central incisors.⁷ An accepted theorem for achieving esthetically pleasing central incisors maintains that the ideal width-to-length ratio should be 0.75 to 0.80.⁸ This ratio represents the ideal proportions needed to optimize the esthetic result and can help guide the treatment planning process. Considering

the range of recommended width-to-length ratios, 0.80 seems to be a good benchmark for achieving optimally esthetic results when restoring maxillary central incisors and 0.75 for maxillary lateral incisors.

A good example can be seen in Figure 12-7, C through F. Because of altered passive eruption, this teenaged patient exhibited a preoperative width-to-length ratio of 1:1 for her maxillary central incisors (see Fig. 12-7, C). She revealed excessive gingival tissues relative to the display of her anterior teeth. To achieve a more esthetic appearance, it was determined that a width-to-length ratio of 0.80 would be desirable. After a periodontal surgical crown-lengthening procedure, a more esthetic width-to-length ratio of 0.80 was attained (see Fig. 12-7, D). After placement of eight etched porcelain veneers for the treatment of fluorosis discoloration, the same 0.80 width-to-length ratio can be seen (see Fig. 12-7, E). A 7-year postoperative photograph reveals the long-term esthetic result (see Fig. 12-7, F).

Because central incisors are the dominant focal point in dental composition, the dentist must avoid narrow, elongated, or short-and-wide contours. Adequate treatment planning and a fundamental knowledge of the importance of the ideal width-to-length ratios can optimize the final esthetic outcome. The importance of interdisciplinary treatment involving orthodontics, periodontics, or both cannot be underestimated.

Position and Alignment

The overall harmony and balance of a smile depend largely on proper position of teeth and their alignment in the arch. Malposed or rotated teeth disrupt the arch form and may interfere with the apparent relative proportions of teeth. Orthodontic treatment of such defects always should be considered, especially if other positional or malocclusion problems exist in the mouth. If orthodontic treatment is either impractical or unaffordable, however, minor positional defects often can be treated with composite augmentation or full facial veneers indirectly made from composite or porcelain. Only problems that can be treated conservatively without significant alteration of the occlusion or gingival contours of teeth should be treated in this manner.

Minor rotations can be corrected by reducing the enamel in the area of prominence and augmenting the deficient area with composite resin (Fig. 12-8, A and B). Care must be taken to restrict all recontouring of prominent areas to enamel. If the rotation is to be treated with an indirectly fabricated

composite or porcelain veneer, an intra-enamel preparation is recommended, with greater reduction provided in the area of prominence. This preparation allows subsequent restoration to appropriate physiologic contours.

Malposed teeth are treated in a similar manner. Teeth in mild linguoversion can be treated by augmentation with full facial veneers placed directly with composite or made indirectly from processed composite or porcelain (see Fig. 12-8, C and D). Care must be exercised in maintaining physiologic gingival contours that do not impinge on tissue or result in an emergence profile of the restoration that is detrimental to gingival health. A functional incisal edge should be maintained by appropriate contouring of the restoration (an excessively thick incisal edge should be avoided). If the occlusion allows, limited reduction of enamel on the lingual aspect can be accomplished to reduce the faciolingual dimension of the incisal portion of the tooth. Lingual areas participating in protrusive functional contact should not be altered, however. Individual teeth that are significantly displaced facially (i.e., facioversion) are best treated orthodontically.

Surface Texture

The character and individuality of teeth are determined largely by their surface texture and existing characteristics. Realistic restorations closely mimic the subtle areas of stippling, concavity, and convexity that are typically present on natural teeth. Teeth in young individuals characteristically exhibit significant surface characterization, whereas teeth in older individuals tend to possess a smoother surface texture caused by abrasional wear. Even in older patients, however, restorations that are devoid of surface characterizations are rarely indicated.

The surfaces of natural teeth typically break up light and reflect it in many directions. Consequently, anatomic features (e.g., developmental depressions, prominences, facets, perikymata) should be examined closely and reproduced to the extent that they are present on the surrounding surfaces. The restored areas of teeth should reflect light as in the unrestored adjacent surfaces. In addition, as alluded to earlier, by controlling areas of light reflection and shadowing, various desired illusions also can be created.

Color

Color is the most complex and least understood artistic element. It is an area in which numerous interdependent

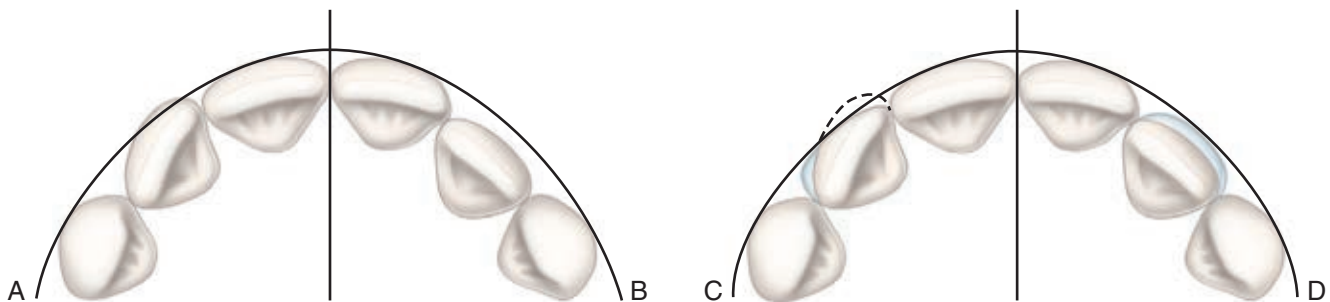


Fig. 12-8 Position and alignment. **A**, A minor rotation is first treated by reducing enamel in the area of prominence. **B**, The deficient area is restored to proper contour with composite. **C**, Maxillary lateral incisor is in slight linguoversion. **D**, Restorative augmentation of facial surface corrects malposition.

factors exist, all of which contribute to the final esthetic outcome of the restoration. Although complex, a basic knowledge of color is imperative to producing consistently esthetic restorations.

Three fundamental elements of color are *hue*, *value*, and *chroma*. Hue is the intrinsic quality or shade of the color. Value refers to the relative lightness or darkness of a hue. It is determined by the amount of white or black in a hue. Chroma is the intensity of any particular hue. Some current shade guides are based first on value because of the importance of this element of color.

Dentists also must understand the coloration of natural teeth to select the appropriate shades of restorative materials accurately and consistently. Teeth typically are composed of a multitude of colors. A gradation of color usually occurs from the gingival region to the incisal region, with the gingival region being typically darker because of thinner enamel. Use of several different shades of restorative material may be required to restore a tooth esthetically. Exposed root surfaces are particularly darker (i.e., dentin colored) because of the absence of overlying enamel. In most individuals, canines are slightly darker than are incisors.

Young individuals with thick enamel characteristically exhibit lighter teeth. Individuals with darker complexions usually appear to have lighter teeth because of the contrast that exists between teeth and the surrounding facial structures. Women can enhance the apparent lightness of their teeth simply by using a darker shade of makeup or lipstick. By increasing the contrast between teeth and the surrounding facial tissue, the illusion of lighter teeth can be created.

Color changes associated with aging also occur, primarily owing to wear. As the facial enamel is worn away, the underlying dentin becomes more apparent, resulting in a darker tooth. Incisal edges are often darker because of the thinning of enamel or the exposure of dentin because of normal attrition. Cervical areas also tend to darken because of abrasion.

An understanding of normal tooth coloration enhances the dentist's ability to create a restoration that appears natural. Several clinical factors also must be considered, however, to enhance the color-matching quality of the restoration. Many shade guides for composite materials are inaccurate. Not only are they often composed of a material dissimilar to that of the composite, but they also do not take into consideration color changes that occur from batch to batch or changes caused by aging of the composite. Accurate shade selection is best attained by applying and curing a small amount of the

composite restorative material in the area of the tooth that may need restoration. Shade selection should be determined before isolating teeth so that color variations that can occur as a result of drying and dehydration of teeth are avoided.

Problems in color perception also complicate selection of the appropriate shade of restorative material. Various light sources produce different perceptions of color. This phenomenon is referred to as *metamerism*.⁹ The color of the surrounding environment influences what is seen in the patient's mouth. Color perception also is influenced by the physiologic limitations of the dentist's eye. On extended viewing of a particular tooth site, eyes experience color fatigue, resulting in a loss of sensitivity to yellow-orange shades.⁷ By looking away at a blue object or background (i.e., the complementary color), the dentist's eyes quickly recover and are able to distinguish subtle variations in yellow-orange hues again. Because of the many indirect factors that influence color perception, it is recommended that the dentist, the assistant, and especially the patient all be involved in shade selection.

Translucency

Translucency is another factor that affects the esthetic quality of the restoration. The degree of translucency is related to how deeply light penetrates into the tooth or restoration before it is reflected outward. Normally, light penetrates through enamel into dentin before being reflected outward (Fig. 12-9, A); this affords the realistic esthetic vitality characteristic of normal, unrestored teeth. Shallow penetration of light often results in loss of esthetic vitality. This phenomenon is a common problem encountered when treating severely intrinsically stained teeth such as teeth affected by tetracycline with direct or indirect veneers. Although opaque resin media can mask the underlying stain, esthetic vitality is usually lost because of reduced light penetration (see Fig. 12-9, B). Indirect veneers of processed composite or porcelain fabricated to include inherent opacity also may have this problem.

Illusions of translucency also can be created to enhance the realism of a restoration. Color modifiers (also referred to as *tints*) can be used to achieve apparent translucency and tone down bright stains or to characterize a restoration. Figure 12-10 shows a case in which the maxillary right central incisor with intrinsic yellow staining caused by trauma to the tooth warranted restoration. When bleaching treatments were unsuccessful because of calcific metamorphosis, a direct composite veneer was used in this patient. After an intra-enamel

Fig. 12-9 Translucency and light penetration. **A**, Light normally penetrates deeply through enamel and into dentin before being reflected outward. This affords realistic esthetic vitality. **B**, Light penetration is limited by opaquing resin media under veneers. Esthetic vitality is compromised.

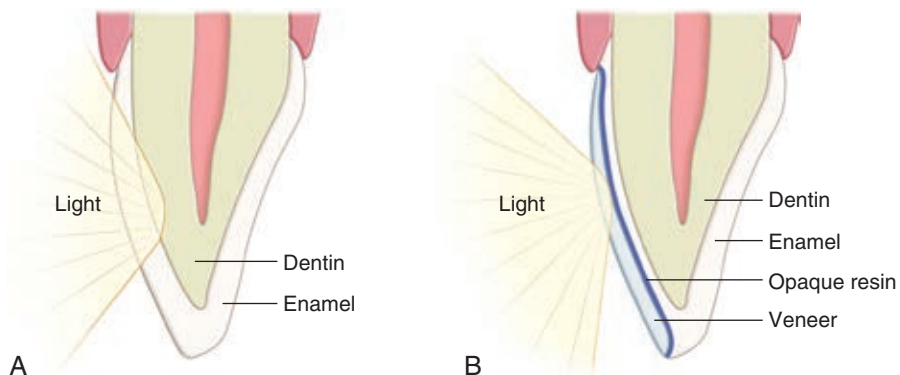
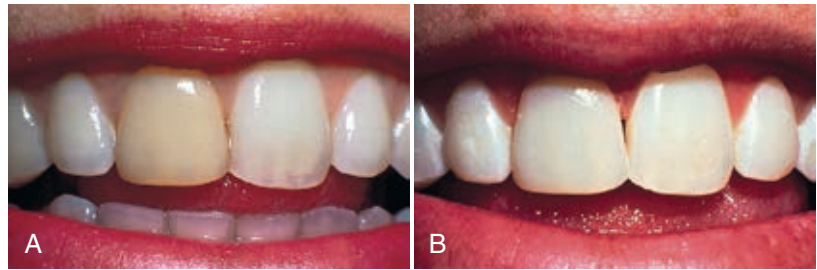


Fig. 12-10 Use of internally placed color modifiers. **A**, The maxillary right central incisor exhibits bright intrinsic yellow staining as a result of calcific metamorphosis. **B**, Color modifiers under direct-composite veneer reduce brightness and intensity of stain and simulate vertical areas of translucency.



preparation and acid-etching, a violet color modifier (the complementary color of yellow) was applied to the prepared facial surface to reduce the brightness and intensity of the underlying yellow tooth. Additionally, a mixture of gray and violet color modifiers was used to simulate vertical areas of translucency. The final restoration is shown in Figure 12-10, *B*. Color modifiers also can be incorporated in the restoration to simulate maverick colors, to check lines, or to surface spots for further characterization. Color modifiers always should be placed within a composite restoration, not on its surface.

Clinical Considerations

Although an understanding of basic artistic elements is imperative to successfully placing esthetic restorations, certain clinical considerations must be addressed concomitantly to ensure the overall quality of the restoration. In addition to being esthetic, restorations must be functional. Dawson stated, “Esthetics and function go hand in hand. The better the esthetics, the better the function is likely to be and vice versa.”¹⁰

The occlusion always must be assessed before any conservative esthetic procedure. Anterior guidance, in particular, must be maintained and occlusal harmony ensured when treating areas involved in occlusion. Another requirement of all conservative esthetic restorations is that they possess physiologic contours that promote good gingival health. Particular care must be taken in all treatments to finish the gingival areas of the restoration adequately and to remove any gingival excess of material. Emergence angles of the restorations must be physiologic and not impinge on gingival tissue.

Conservative Alterations of Tooth Contours and Contacts

Many unsightly tooth contours and diastemas can be corrected or the appearance greatly improved by several conservative methods. Often, these procedures can be incorporated into routine restorative treatment. The objective is to improve esthetics and yet preserve as much healthy tooth structure as possible, consistent with the acceptable occlusion and health of surrounding tissue. These procedures include reshaping natural teeth, correcting embrasures, and closing diastemas.

Alterations of Shape of Natural Teeth

Some esthetic problems can be corrected conservatively without the need for tooth preparation and restoration.

Consideration always should be given to reshaping and polishing natural teeth to improve their appearance and function (Fig. 12-11). In addition, the rounding of sharp angles can be considered a prophylactic measure to reduce stress and to prevent chipping and fractures of the incisal edges.

Etiology

Attrition of the incisal edges often results in closed incisal embrasures and angular incisal edges (see Fig. 12-11, *A*). Anterior teeth, especially maxillary central incisors, often are fractured in accidents. Other esthetic problems, including attrition and abnormal wear from poor dental habits (e.g., biting fingernails, holding objects with teeth), often can be corrected or the appearance improved by reshaping natural teeth.

Treatment

Consultation and examination are necessary before any changes are made to the shapes of teeth. Photographs, study models, line drawings, and esthetic imaging devices enable the patient to envision the potential improvement before any changes are made.

As noted earlier, cosmetic contouring to achieve youthful characteristics often includes rounding incisal angles, reducing facial line angles, and opening incisal embrasures. The opposite characteristics typically are considered more mature features. Cosmetic reshaping to smooth rough incisal edges and improve symmetry is equally beneficial to women and men.

The patient must understand what is involved and must want to have the alteration made. If reshaping is desired, it is helpful to mark, by using a pencil or alcohol-marking pen, an outline of the areas of the teeth to be reshaped (see Fig. 12-11, *B*). By marking the anticipated areas for enamel reshaping, the patient is provided some indication of what the post-operative result may look like (see Fig. 12-11, *C*). If available, esthetic computer imaging also can be used to illustrate the possible result before treatment.

Because all reshaping is restricted to enamel, anesthesia is not required. A cotton roll is recommended for isolation. Diamond instruments and abrasive disks and points are used for contouring, finishing, and polishing (see Fig. 12-11, *D* and *E*). Through careful reshaping of appropriate enamel surfaces, a more esthetic smile (characterized by youthful features) is attained. Rounded incisal edges also are less likely to chip or fracture (see Fig. 12-11, *F*).

A second example involves the irregular, fractured incisal surfaces of maxillary central incisors (Fig. 12-12, *A*). An esthetic result can be accomplished by slightly shortening the

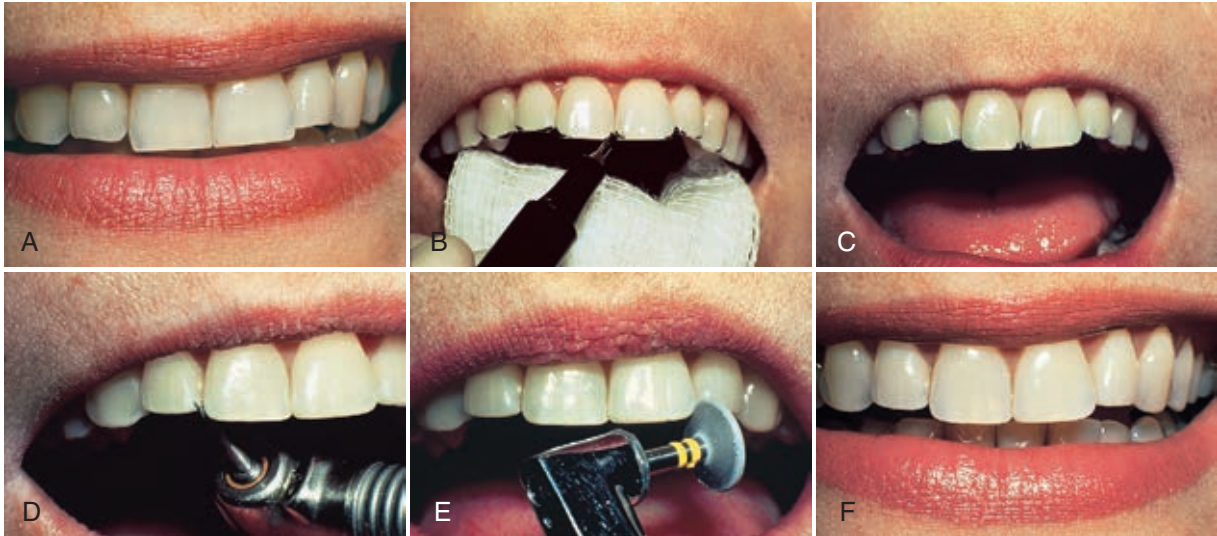


Fig. 12-11 Reshaping natural teeth. **A**, Maxillary anterior teeth with worn incisal edges. **B**, Areas to be reshaped are outlined. **C**, Outlined areas give the patient an idea of what the final result will look like. **D**, A diamond instrument is used to reshape the incisal edges. **E**, A rubber abrasive disk is used to polish the incisal edges. **F**, Reshaping results in a more youthful smile.



Fig. 12-12 Irregular incisal edges. **A**, Central incisors have rough, fractured incisal edges. **B**, Esthetic result is obtained by recontouring incisal edges.



Fig. 12-13 Loss of incisal embrasures from attrition. Before (**A**) and after (**B**) recontouring teeth to produce a more youthful appearance and improve resistance to fracture.

incisal edges and reshaping both teeth to a symmetrical form. Photographs, line drawings, esthetic imaging, or marking the outline on the patient's teeth enables the patient to envision the potential improvement before any changes are made. Protrusive function always should be evaluated to prevent inadvertent elimination of this occlusal contact. Conservative treatment consists of using diamond instruments and abrasive disks and points for contouring and polishing the central incisors. The finished result is illustrated in [Figure 12-12, B](#).

As some patients grow older or have the habit of bruxism, the incisal surfaces often wear away, leaving sharp edges that chip easily. This is also accompanied by loss of the incisal

embrasures ([Fig. 12-13, A](#)). To lessen the chance of more fractures and to create a more youthful smile, the incisal embrasures are opened, and the incisal angles of teeth are rounded (see [Fig. 12-13, B](#)).

Alterations of Embrasures

Etiology

Anterior teeth can have embrasures that are too open as a result of the shape or position of teeth in the arch. When the permanent lateral incisors are congenitally missing, canines and posterior teeth may drift mesially, or the space may be

Fig. 12-14 Closing incisal embrasures. **A**, Maxillary canines moved to close spaces left by missing lateral incisors. The mesial incisal embrasures are too open. **B**, Canines reshaped to appear like lateral incisors.



closed orthodontically. The facial surface and cusp angle of some canines can be reshaped to appear like lateral incisors. In many instances, the mesio-incisal embrasures remain too open (Fig. 12-14, A).

Treatment

Composite can be added to establish an esthetic contour and correct the open embrasures. Evaluation of the occlusion before restoration determines if the addition would be compatible with functional movements. The patient should understand the procedures involved and should want to have the change made. Line drawings, esthetic imaging, or photographs of similar examples are often helpful in explaining the procedure and allaying patient concerns. Another patient aid involves adding ivory-colored wax or composite to teeth (unetched) to fill the embrasure temporarily to simulate the final result.

Preliminary procedures include cleaning the involved teeth, selecting the shade, and isolating the area. Local anesthesia usually is not required because the preparation does not extend subgingivally and involves only enamel. A coarse, flame-shaped diamond instrument is used to remove overly convex enamel surfaces (if present) and to roughen the enamel surface area to be augmented with composite material. It may be necessary to place a wedge and use an abrasive strip to prepare the proximal surface. The final contour of the restoration should be envisioned before the preparation is made so that all areas to be bonded are adequately roughened.

A polyester strip is inserted to protect the adjacent tooth during acid etching. After etching, rinsing, and drying, the contoured strip is positioned. A light-cured composite material is inserted, and the strip is closed during polymerization. The incisal embrasures of both canines are corrected, and both restorations are finished by routine procedures (see Fig. 12-14, B). The occlusion should be evaluated to assess centric contacts and functional movements, and any adjustments or corrections should be made, if indicated.

Correction of Diastemas

Etiology

The presence of diastemas between anterior teeth is an esthetic problem for some patients (Fig. 12-15). Before treatment, a diagnosis of the cause is made, including an evaluation of the occlusion. Probably the most frequent site of a diastema is between maxillary central incisors. A prominent labial frenum with non-elastic fibers extending proximally often prevents the normal approximation of erupting central incisors.¹¹ Other causative factors include congenitally missing teeth,

undersized or malformed teeth, interarch tooth size discrepancies (i.e., Bolton discrepancy), supernumerary teeth, and heredity. Diastemas also may result from other problems such as tongue thrusting, periodontal disease, or posterior bite collapse. Diastemas should not be closed without first recognizing and treating the underlying cause, as merely treating the cause may correct the diastema.

Treatment

Traditionally, diastemas have been treated by surgical, periodontal, orthodontic, and prosthetic procedures. These types of corrections can be impractical or unaffordable and often do not result in permanent closure of the diastema. In carefully selected cases, a more practical alternative is use of the acid-etch technique and composite augmentation of proximal surfaces (see Figs. 12-5 and Fig. 12-6). All treatment options (including no treatment) should be considered before resorting immediately to composite augmentation. Line drawings, photographs, computer imaging, models with spaces filled, and direct temporary additions of ivory-colored wax or composite material on natural teeth (unetched) are important preliminary procedures.

The correction of a diastema between maxillary central incisors is described and illustrated in Figure 12-15. After the teeth are cleaned and the shade selected, a Boley gauge or other suitable caliper is used to measure the width of the diastema and the individual teeth (see Fig. 12-15, B and C). Occasionally, one central incisor is wider, requiring a greater addition to the narrower tooth. Assuming the incisors are of equal width, symmetrical additions can be ensured by using half of the total measurement of the diastema to gauge the width of the first tooth restored. Cotton rolls, instead of a rubber dam, are recommended for isolation because of the importance of relating the contour of the restoration directly to the proximal tissue. Usually, the restoration must begin slightly below the gingival crest to appear natural and to be confluent with the tooth contours.

With cotton rolls in place, a gingival retraction cord of an appropriate size is tucked in the gingival crevice of each tooth from midfacial mesially to midlingual (see Fig. 12-15, D). The cord retracts the soft tissue and prevents seepage from the crevice. In some instances, the retraction cord may need to be inserted for one tooth at a time to prevent strangulation of interproximal tissue during preparation and restorative procedures. To enhance retention of the composite, a coarse, flame-shaped diamond instrument is used to roughen the proximal surfaces, extending from the facial line angle to the lingual line angle (see Fig. 12-15, E). More extension may be needed to correct the facial or lingual contours, depending on



Fig. 12-15 Diastema closure. **A**, Esthetic problem created by space between central incisors. **B** and **C**, Interdental space and size of central incisors measured with caliper. **D**, Teeth isolated with cotton rolls and retraction cord tucked into the gingival crevice. **E**, A diamond instrument is used to roughen enamel surfaces. **F**, Etched enamel surface indicated by arrow. **G**, Composite inserted with composite instrument. **H**, Matrix strip closed with thumb and forefinger. **I**, Composite addition is cured. **J**, Finishing strip used to finalize contour of first addition. **K**, A tight contact is attained by displacing the second tooth being restored in a distal direction with thumb and forefinger, while holding matrix in contact with adjacent restoration. **L**, Flame-shaped finishing bur used to contour restoration. **M**, Finishing strip used to smooth the subgingival areas. **N**, The restoration is polished with a rubber abrasive point. **O**, Final luster attained with polishing paste applied with Prophy cup. **P**, Unwaxed floss used to detect any excess composite. **Q**, Diastema closed with symmetrical and equal additions of composite.

the anatomy and position of the individual tooth. The enamel is acid-etched approximately 0.5 mm past the prepared, roughened surface. The acid should be applied gingivally only to the extent of the anticipated restoration. After rinsing and drying, the etched enamel should display a lightly frosted appearance (see Fig. 12-15, *F*). A 2 × 2 inch (5 × 5 cm) gauze is draped across the mouth and tongue to prevent inadvertent contamination of the etched preparations by the patient. After both preparations are completed, the teeth are restored one at a time.

A polyester strip is contoured and placed proximally, with the gingival aspect of the strip extending below the gingival crest. Additional contouring may be required to produce enough convexity in the strip. In most cases, a wedge cannot be used. The strip is held (with the index finger) on the lingual aspect of the tooth to be restored, while the facial end is reflected for access. A light-cured composite is used for the restoration. After the bonding agent is applied, the composite material is inserted with a hand instrument (see Fig. 12-15, *G*). Careful attention is given to pressing the material lingually to ensure confluence with the lingual surface. The matrix is gently closed facially, beginning with the gingival aspect (see Fig. 12-15, *H*). Care must be taken not to pull the strip too tightly because the resulting restoration may be under-contoured faciolingually, mesiodistally, or both. The light-cured composite material is polymerized with the light directed from the facial and lingual directions for an appropriate amount of time. Note that curing times may vary according to the type of light source, the composite used, and the thickness of the material (see Fig. 12-15, *I*). Initially, it is better to over-contour the first restoration slightly to facilitate finishing it to an ideal contour.

When polymerization is complete, the strip is removed. Contouring and finishing are achieved with appropriate carbide finishing burs, fine diamonds, or abrasive disks (see Fig. 12-15, *L*). Finishing strips are invaluable for finalizing the proximal contours (see Fig. 12-15, *J* and *M*). Final polishing is deferred until the contralateral restoration is completed. It

is imperative for good gingival health that the cervical aspect of the composite addition be immaculately smooth and continuous with the tooth structure. Overhangs must not be present. Removal of the gingival retraction cord facilitates inspection and smoothing of this area. Flossing with a length of unwaxed floss verifies that the gingival margin is correct and smooth if no fraying of the floss occurs (see Fig. 12-15, *P*). It is important that the correct mesiodistal dimension of the first tooth be established before the second tooth is restored.

After etching, rinsing, and drying, the second restoration is completed. A tight proximal contact can be attained by displacing the second tooth being restored in a distal direction (with the thumb and the index finger) while holding the matrix in contact with the adjacent restoration (see Fig. 12-15, *K*). Contouring is accomplished with a 12-fluted carbide bur and finishing strips (see Fig. 12-15, *L* and *M*). Articulating paper should be used to evaluate the patient's occlusion to ensure that the restorations are not offensive in centric or functional movements; adjustments can be made with a carbide finishing bur or abrasive disks. Final polishing is achieved with rubber polishing points or polishing paste applied with a Prophy cup in a low-speed handpiece (see Fig. 12-15, *N* and *O*). Unwaxed floss is used to detect any excess material or overhang (see Fig. 12-15, *P*). The final esthetic result is seen in Figure 12-15, *Q*.

Multiple diastemas among the maxillary anterior teeth are shown in Figure 12-16, *A*. Closing the spaces by orthodontic movement was considered in this patient; however, because the patient's teeth were under-contoured mesiodistally, the diastemas were closed by etching the teeth and bonding composite to the proximal surfaces. The teeth after treatment are shown in Figure 12-16, *B*. In the presence of defective Class III restorations or proximal caries, it is recommended that the teeth be restored with the same composite used for closing the diastema. Often, these restorations can be performed at the same time the diastema is closed with composite additions (Fig. 12-17).

Fig. 12-16 Multiple diastemas occurring among maxillary anterior teeth. **A**, Before correction. **B**, Appearance after diastemas are closed with composite augmentation.



Fig. 12-17 **A**, Diastema closure and cosmetic contouring. **B**, Significant esthetic improvement is achieved by replacing defective Class III restorations and closing diastemas with conservative-composite additions and cosmetically reshaping teeth.





Fig. 12-18 Space distribution. **A**, Midline diastema too large for simple closure with composite additions. **B** and **C**, Space distributed among four incisors with orthodontic treatment. **D**, Final result after composite additions.

Occasionally, diastemas are simply too large to close esthetically with composite augmentation alone (Fig. 12-18, *A*). Closing a large space of this magnitude with composite would merely create an alternative esthetic problem, that is, excessively large central incisors, which would further exacerbate the existing discrepancy in proportionality among anterior teeth. In such cases, large spaces are best redistributed orthodontically among anterior teeth so that symmetric and equal composite additions can be made to the central and lateral incisors (see Fig. 12-18, *B* and *C*). This approach that involves space distribution results in improved proportionality among anterior teeth (see the earlier section on Artistic Elements). The final result, immediately after completion, is shown in Figure 12-18, *D*.

Conservative Treatments for Discolored Teeth

One of the most frequent reasons patients seek dental care is discolored anterior teeth. Patients with teeth of normal color request whitening procedures. Treatment options include removal of surface stains, bleaching, microabrasion or macroabrasion, veneering, and placement of porcelain crowns. Many dentists recommend porcelain crowns as the best solution for badly discolored teeth. If crowns are done properly with the highly esthetic ceramic materials currently available, they have great potential for being esthetic and long lasting. Increasing numbers of patients do not want their teeth “cut down” for crowns and choose an alternative, conservative approach such as veneers (see the subsequent section on Veneers) that preserves as much of the natural tooth as possible. This treatment is performed with the understanding that the corrective measures may be less permanent.

Discolorations are classified as extrinsic or intrinsic. Extrinsic stains are located on the outer surfaces of teeth, whereas intrinsic stains are internal. The etiology and treatment of extrinsic and intrinsic stains are discussed in the following sections.

Extrinsic Discolorations

Etiology

Stains on the external surfaces of teeth (referred to as *extrinsic discolorations*) are common and may be the result of numerous factors. In young patients, stains of almost any color can be found and are usually more prominent in the cervical areas of teeth (Fig. 12-19, *A*). These stains may be related to remnants of Nasmyth’s membrane, poor oral hygiene, existing restorations, gingival bleeding, plaque accumulation, eating habits, or the presence of chromogenic microorganisms.¹² In older patients, stains on the surfaces of teeth are more likely to be brown, black, or gray and occur on areas adjacent to gingival tissue. Poor oral hygiene is a contributing factor, but coffee, tea, and other types of chromogenic foods or medications can produce stains (even on plaque-free surfaces). Tobacco stains also are observed frequently. Existing restorations may be discolored for the same reasons.

An example of one of the most interesting and unusual types of external staining is illustrated in Figure 12-19, *B*. In Southeast Asia, some women traditionally dye their teeth with betel nut juice to match their hair and eyes as a sign of beauty.¹³ Slices of lemon are held in contact with the teeth before applying the betel nut juice to make the staining process more effective. This example was probably one of the first applications of the acid-etch technique. A weak acid, such as that found in citrus fruits, is known to cause rapid decalcification of enamel.

Treatment

Most surface stains can be removed by routine prophylactic procedures (Fig. 12-20). Some superficial discolorations on tooth-colored restorations and decalcified areas on teeth, however, cannot be corrected by such cleaning. Conservative correction may be accomplished by mild microabrasion or by surfacing the thin, outer, discolored layer with a flame-shaped, carbide finishing bur or diamond instrument (i.e., macroabrasion), followed by polishing with abrasive disks or points to obtain an acceptable result. (See subsequent sections on

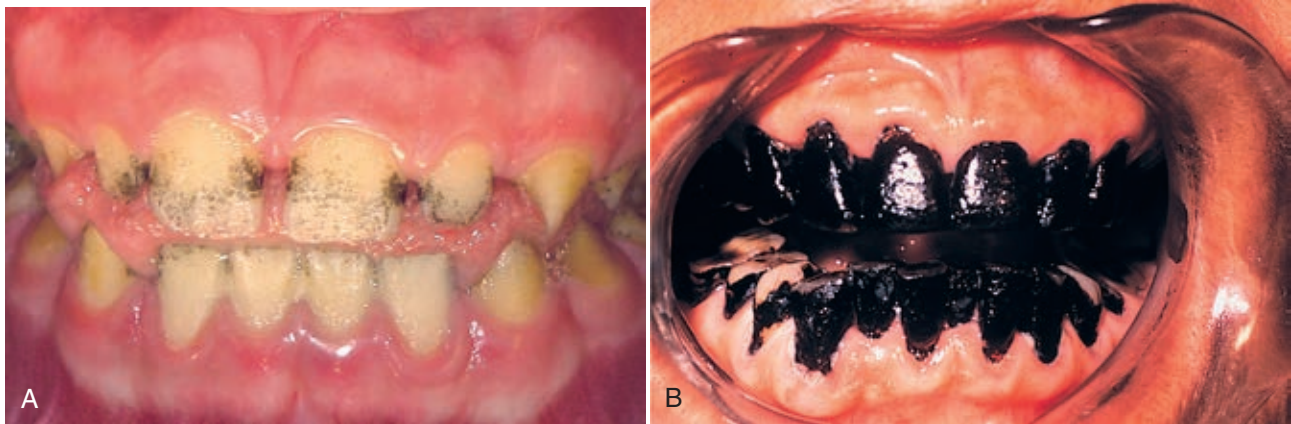


Fig. 12-19 Extrinsic stains. **A**, Surface stains on facial surfaces in a young patient. **B**, Exotic decoration of anterior teeth by etching with citrus fruit juice and applying black pigment (betel nut stain). (**A**, Courtesy of Dr. Tim Wright. **B**, From Daniel SJ, Harfst SA, Wilder RS: *Mosby's dental hygiene: Concepts, cases, and competencies*, ed 2, St. Louis, Mosby, 2008, Courtesy of Dr. George Taybos, Jackson, MS.)



Fig. 12-20 Treatment of surface stains. **A**, Tobacco stains. **B**, Pumicing teeth with rubber cup. **C**, Shade guide used to confirm normal color of natural teeth.



Fig. 12-21 Intrinsic stains. **A**, Staining by tetracycline drugs. **B**, Staining of the maxillary left central incisor from tooth trauma and degeneration of the pulp.

Microabrasion and Macroabrasion for details of clinical technique.)

Intrinsic Discolorations

Etiology

Intrinsic discolorations are caused by deeper (not superficial) internal stains or enamel defects; these stains are more complex to treat than are external types. Teeth with vital or non-vital pulps as well as root canal-treated teeth can be affected. Vital teeth may be discolored at the time the crowns are forming, and the abnormal condition usually involves several teeth. Causative factors include hereditary disorders, medications (particularly tetracycline preparations), excess fluoride, high fevers associated with early childhood illnesses, and other types of trauma.¹² The staining may be located in enamel or

dentin. Discolorations restricted to dentin still may show through enamel. Discoloration also may be localized or generalized, involving the entire tooth.

Various preparations of the antibiotic drug tetracycline can cause the most distracting, generalized type of intrinsic discoloration (Fig. 12-21, A).¹⁴ The severity of the staining depends on the dose, the duration of exposure to the drug, and the type of tetracycline analogue used. Different types of tetracyclines induce different types of discoloration, varying from yellow-orange to dark blue-gray. Dark blue-gray, tetracycline-stained teeth are considerably more difficult to treat than are teeth with mild yellow-orange discolorations. Staining from tetracycline-type drugs most frequently occurs at an early age and is caused by ingestion of the drug concomitant with the development of permanent teeth. Studies indicate that permanent teeth in adults also can experience a

graying discoloration, however, as a result of long-term exposure to minocycline, a tetracycline analogue.¹⁴

The presence of excessive fluoride in drinking water and other sources at the time of teeth formation can result in another type of intrinsic stain called *fluorosis*. The staining usually is generalized. Localized areas of discoloration may occur on individual teeth because of enamel or dentin defects induced during tooth development. High fevers and other forms of trauma can damage the tooth during its development, resulting in unesthetic hypoplastic defects. Additionally, localized areas of dysmineralization, or the failure of the enamel to calcify properly, can result in hypocalcified white spots. After eruption, poor oral hygiene also can result in decalcified white spots. Poor oral hygiene during orthodontic treatment frequently results in these types of decalcified defects. White or discolored spots with intact enamel surface (i.e., surface not soft) are often evidence of intraoral remineralization, however, and such spots are not indications for invasive treatment (unless for esthetic concerns). Additionally, caries, metallic restorations, corroded pins, and leakage or secondary caries around existing restorations can result in various types of intrinsic discoloration.

As noted earlier, aging effects also can result in yellowed teeth. As patients grow older, the tooth enamel becomes thinner because of wear and allows underlying dentin to become more apparent. Also, often, continuing deposition of secondary dentin occurs in older individuals, resulting in greater dentin thickness. This deposition results in a yellowing effect, depending on the intrinsic color of dentin. Additionally, the permeability of teeth usually allows the infusion (over time) of significant organic pigments (from chromogenic foods, drinks, and tobacco products) that produce a yellowing effect.

Nonvital teeth also can become discolored intrinsically. These stains usually occur in individual teeth after eruption has taken place. The pulp may become infected or degenerate as a result of trauma, deep caries, or irritation from restorative procedures. If these teeth are properly treated by root canal therapy, they usually retain their normal color. If treatment is delayed, discoloration of the crown is more likely to occur. The degenerative products from the pulp tissue stain dentin, and this is readily apparent because of the translucency of enamel (see Fig. 12-21, B). Trauma resulting in calcific metamorphosis (i.e., calcification of the pulp chamber, root canal, or both) also can produce significant yellowing of the tooth. This condition is extremely difficult to treat (see Fig. 12-10).

Treatment

Some people definitely have esthetic problems because of intrinsic stains, but some others worry needlessly about the overall color of their teeth. In the latter instance, the dentist must decide if the color of teeth can be improved enough to justify treatment, even though the patient insists on having something done. Individuals with light complexions may believe that their teeth are too dark, when actually they are normal in color (Fig. 12-22, A). Positioning a shade tab from a shade guide of tooth colors next to such teeth often shows these patients that the color of their teeth is well within the normal range of shades. As stated earlier, tanned skin, darker makeup, or darker lipstick usually make teeth appear much



Fig. 12-22 Illusion of a lighter appearance of teeth by use of darker makeup. **A**, Before. **B**, After. (From Freedman G: Contemporary esthetic dentistry, St. Louis, Mosby, 2012.)

whiter by increasing the contrast between teeth and the surrounding facial features (see Fig. 12-22, B).

The patient should be told that many discolorations can be corrected or the appearance of teeth greatly improved through conservative methods such as bleaching, microabrasion or macroabrasion, and veneering. Mild discolorations are best left untreated, are bleached, or are treated conservatively with microabrasion or macroabrasion because no restorative material is as good as the healthy, natural tooth structure. The patient should be informed that the gingival tissue adjacent to restorative material will never be as healthy as that next to normal tooth structure.

Color photographs of previously treated teeth with intrinsic staining (i.e., before and after treatment) are excellent adjuncts to help the patient make an informed decision. Esthetic imaging with modern computer simulation of the postoperative result also can be an effective educational tool. Patients appreciate knowing what the cause of the problem is, how it can be corrected, how much time is involved, and what the cost will be. They also should be informed of the life expectancy of the various treatment alternatives suggested. Vital bleaching usually results in tooth lightening for only 1 to 3 years, whereas an etched porcelain veneer should last 10 to 15 years or longer. With continuous improvements in materials and techniques, a much longer lifespan may be possible with any of these procedures. The clinical longevity of esthetic restorations also is enhanced in patients with good oral hygiene, proper diet, a favorable bite relationship, and little or no contact with agents that cause discoloration or deterioration.

Correction of intrinsic discolorations caused by failing restorations entails replacement of the faulty portion or the entire restoration. Correction of discolorations caused by carious lesions requires appropriate restorative treatment. Esthetic inserts for metal restorations are described later in this chapter. For the other types of intrinsic discolorations previously discussed, detailed treatment options are presented in the following three sections.

Bleaching Treatments

The lightening of the color of a tooth through the application of a chemical agent to oxidize the organic pigmentation in the tooth is referred to as *bleaching*. In keeping with the overall conservative philosophy of tooth restoration, consideration should be given first to bleaching anterior teeth when intrinsic discolorations are encountered. Bleaching techniques may be classified as to whether they involve vital or non-vital teeth and whether the procedure is performed in the office or outside the office. Bleaching of non-vital teeth was first reported in 1848; in-office bleaching of vital teeth was first reported in 1868.¹⁵ By the early 1900s, in-office vital bleaching had evolved to include the use of heat and light for activation of the process. Although a 3% ether and peroxide mouthwash used for bleaching in 1893 has been reported in the literature, the “dentist-prescribed, home-applied” technique (also referred to as *nightguard vital bleaching* or *at-home bleaching*) for bleaching vital teeth outside the office began around 1968, although it was not commonly known until the late 1980s.¹⁶

Most bleaching techniques use some form or derivative of hydrogen peroxide in different concentrations and application techniques. The mechanism of action of bleaching teeth with hydrogen peroxide is considered to be oxidation of organic pigments, although the chemistry is not well understood. Bleaching generally has an approximate lifespan of 1 to 3 years, although the change may be permanent in some situations.

With all bleaching techniques, a transitory decrease occurs in the potential bond strength of composite when it is applied to bleached enamel and dentin. This reduction in bond strength results from residual oxygen or peroxide residue in the tooth that inhibits the setting of the bonding resin, precluding adequate resin tag formation in the etched enamel. No loss of bond strength is noted if the composite restorative treatment is delayed at least 1 week after cessation of any bleaching.¹⁷

Nonvital Bleaching Procedures

The primary indication for nonvital bleaching is to lighten teeth that have undergone root canal therapy. Discoloration may be a result of bleeding into dentin from trauma before root canal therapy, degradation of pulp tissue left in the chamber after such therapy, or staining from restorative materials and cements placed in the tooth as a part of the root canal treatment. Most posterior teeth that have received root canal therapy require full-coverage restorations that encompass the tooth to prevent subsequent fracture. Anterior teeth needing restorative treatment and that are largely intact may be restored with composite rather than with partial-coverage or



Fig. 12-23 Radiograph revealing the presence of extensive cervical resorption.

full-coverage restorations without significantly compromising the strength of the tooth.¹⁸ This knowledge has resulted in a resurgence in the use of non-vital bleaching techniques. Non-vital bleaching techniques include an in-office technique and an out-of-office procedure referred to as *walking bleach*. (See the following sections for details of these two techniques.)

Although nonvital bleaching is effective, a slight potential (i.e., 1%) exists for a deleterious side effect termed *external cervical resorption* (Fig. 12-23).¹⁹ This sequela requires prompt and aggressive treatment. In animal models, cervical resorption has been observed most when using a thermocatalytic technique with high heat.²⁰ The walking bleach technique or an in-office technique that does not require the use of heat is preferred for nonvital bleaching. To reduce the possibility of resorption, immediately after bleaching, a paste of calcium hydroxide powder and sterile water is placed in the pulp chamber as described in the following sections.²¹ Also, sodium perborate alone, rather than in conjunction with hydrogen peroxide, should be used as the primary bleaching agent. Although sodium perborate may bleach more slowly, it is safer and less offensive to the tooth.²² Periodic radiographs should be obtained after bleaching to screen for cervical resorption, which generally has its onset in 1 to 7 years.²³

In-Office Nonvital Bleaching Technique

The in-office bleaching for nonvital teeth historically has involved a thermocatalytic technique consisting of the placement of 35% hydrogen peroxide liquid into the debrided pulp chamber and acceleration of the oxidation process by placement of a heating instrument into the pulp chamber. The thermocatalytic technique is not recommended, however, because of the potential for cervical resorption.¹⁹ A more current technique uses 30% to 35% hydrogen peroxide pastes or gels that require no heat. This technique is frequently the preferred in-office technique for bleaching non-vital teeth. In both techniques, it is imperative that a sealing cement (resin-modified glass ionomer [RMGI] cement is recommended) be placed over the exposed root canal filling before application of the bleaching agent to prevent leakage and penetration of the bleaching material in an apical direction. It is also recommended that the bleaching agent be applied in the coronal portion of the tooth incisal to the level of the periodontal ligament (not down into the root canal space) to prevent unwanted

Fig. 12-24 Indication for bleaching root canal-filled tooth. **A**, Before. **B**, After intracoronal, nonvital bleaching.



leakage of the bleaching agent through the lateral canals or canaliculi to the periodontal ligament.

Walking Bleach Technique

Before beginning the walking bleach technique, the dentist needs to evaluate the potential for occlusal contact on the area of the root canal access opening. The dentist places a rubber dam to isolate the discolored tooth and removes all materials in the coronal portion of the tooth (i.e., access opening). The dentist removes gutta-percha (to approximately 1–2 mm apical of the clinical crown) and enlarges the endodontic access opening sufficiently to ensure complete debridement of the pulp chamber. Next, the dentist places an RMGI liner to seal the gutta-percha of the root canal, filling from the coronal portion of the pulp chamber. After this seal has hardened, the dentist trims any excess material from the seal so that the discolored dentin is exposed peripherally.

Sodium perborate is used with this technique because it is deemed extremely safe.²⁴ Using a cement spatula, with heavy pressure on a glass slab, one drop of saline or sterile anesthetic solution is blended with enough sodium perborate to form a creamy paste. A spoon excavator or similar instrument is used to fill the pulp chamber (with the bleaching mixture) to within 2 mm of the cavosurface margin, avoiding contact with the enamel cavosurface margins of the access opening. The dentist uses a cotton pellet to blot the mixture and places a temporary sealing material (e.g., Intermediate Restorative Material [DENTSPLY Caulk, Milford, DE], or Cavit [3M ESPE, St. Paul, MN]) to seal the access opening. The area should remain isolated for approximately 5 minutes after closure to evaluate the adequacy of the seal of the temporary restoration. If bubbles appear around the margins of the temporary material indicating leakage, the temporary restoration must be replaced. If no bubbles appear, the dentist removes the rubber dam and checks the occlusion to assess the presence or absence of contact on the temporary restoration.

The sodium perborate should be changed weekly. On successful bleaching of the tooth, the chamber is rinsed and filled to within 2 mm of the cavosurface margin with a paste consisting of calcium hydroxide powder in sterile saline. (The enamel walls and margins are kept clean and free of the calcium hydroxide paste.) As noted earlier, a paste of calcium hydroxide powder and sterile water is placed immediately after bleaching in the pulp chamber to reduce the possibility of resorption.²¹ The dentist reseals the access opening with a temporary restorative material, as previously described, and allows the calcium hydroxide material to remain in the pulp chamber for 2 weeks. Subsequently, the dentist removes the temporary restorative material, rinses away the calcium

hydroxide, and dries the pulp chamber. Next, the dentist etches enamel and dentin and restores the tooth with a light-cured composite (Fig. 12-24).

Occasionally, a tooth that has been bleached by using the walking bleach technique and sealed with a composite restoration may subsequently become discolored. In this instance, the alternative treatment option should be an attempt to bleach the tooth externally with one of the external bleaching techniques (see next section).

Vital Bleaching Procedures

Generally, the indications for the different vital bleaching techniques are similar, with patient preference, cost, compliance, and difficulty in the removal of certain discolorations dictating the choice of treatment or combination of treatments. Indications for vital bleaching include teeth intrinsically discolored because of aging, trauma, or certain medications. External vital bleaching techniques are alternative treatment options for a failed, nonvital, walking bleach procedure. Vital bleaching also is often indicated before and after restorative treatments to harmonize the shades of the restorative materials with those of natural teeth.

Teeth exhibiting yellow or orange intrinsic discoloration seem to respond best to vital bleaching, whereas teeth exhibiting bluish gray discolorations often are considerably more difficult to treat in this manner. Other indications for external bleaching include teeth that have been darkened by trauma but are still vital or teeth that have a poor endodontic prognosis because of the absence of a radiographically visible canal (i.e., calcific metamorphosis). Brown fluorosis stains also are often responsive to treatment, but white fluorosis stains may not be resolved effectively (although they can be made less obvious if the surrounding tooth structure can be significantly whitened).

Vital bleaching techniques include an in-office technique referred to as *power bleaching* and an out-of-office alternative that is a “dentist-prescribed, home-applied” technique (i.e., nightguard vital bleaching, or simply “at-home bleaching”).^{25,26} These techniques may be used separately or in combination with one another. (Details are provided in subsequent sections.) Some over-the-counter bleaching materials, particularly products involving a trayless strip delivery system, also are effective for whitening teeth, but these are not discussed in this chapter.²⁷

Overall, vital bleaching has been proven to be safe and effective when performed by, or under the supervision of, a dentist. With short-term treatment, no appreciable effect has been observed on existing restorative materials, either in loss of material integrity or in color change, with one exception:

Polymethyl methacrylate restorations exhibit a yellow-orange discoloration on exposure to carbamide peroxide. For this reason, temporary crowns should be made from bis-acryl materials, rather than polymethyl methacrylate crown and bridge resin, if exposure to carbamide peroxide is anticipated.

Because hydrogen peroxide has such a low molecular weight, it easily passes through enamel and dentin. This characteristic is thought to account for the mild tooth sensitivity occasionally experienced during treatment. This effect is transient, however, and no long-term harm to the pulp has been reported.

Often, the dentist has to decide whether to use an in-office bleaching technique or prescribe a home-applied technique. The advantages of the in-office vital bleaching technique are that (although it uses very caustic chemicals) it is totally under the dentist's control, soft tissue is generally protected from the process, and the technique has the potential for bleaching teeth more rapidly. Disadvantages primarily relate to the cost, the unpredictable outcome, and the unknown duration of the treatment. The features that warrant concern and caution include the potential for soft tissue damage to both patient and provider, discomfort caused by the rubber dam or other isolation devices, and the potential for post-treatment sensitivity. The advantages of the dentist-prescribed, home-applied technique are the use of a lower concentration of peroxide (generally 10%–15% carbamide peroxide), ease of application, minimal side effects, and lower cost because of the reduced chair time required for treatment. The disadvantages are reliance on patient compliance, longer treatment time, and the (unknown) potential for soft tissue changes with excessively extended use.

In-Office Vital Bleaching Technique

In-office vital bleaching requires an excellent rubber dam technique and careful patient management. Vaseline or cocoa butter may be placed on the patient's lips and gingival tissue before application of the rubber dam to help protect these soft tissues from any inadvertent exposure to the bleaching agent. Anterior teeth (and sometimes the first premolars) are isolated with a heavy rubber dam to provide maximum retraction of tissue and an optimal seal around teeth. A good seal of the dam is ensured by ligation of the dam with waxed dental tape or the use of a sealing putty or varnish. Light-cured, resin-based "paint-on" rubber dam isolation media are available for use with in-office bleaching materials but cannot provide the same degree of protection and isolation as a conventionally applied rubber dam. Etching of teeth with 37% phosphoric acid, once considered a required part of this technique, is unnecessary.²⁸

Numerous commercially available bleaching agents are available for in-office bleaching procedures. Most consist of paste or gel compositions that most commonly contain 30% to 35% hydrogen peroxide. Other additives, such as metallic ion-producing materials or alkalizing agents that can speed up the oxidation reaction, also are commonly found in these commercially available whitening products. The dentist places the hydrogen peroxide-containing paste or gel on teeth. The patient is instructed to report any sensations of burning of the lips or gingiva that would indicate a leaking dam and the need to terminate treatment.

Most of the credible research indicates that the addition of light during the bleaching procedure does not improve the whitening result beyond what the bleach alone can achieve.²⁹ Use of a light to generate heat may accelerate the oxidation reaction of the hydrogen peroxide and expedite treatment through a thermocatalytic effect. PAC lights and high-output quartz halogen lights have been commonly used for this purpose. Use of lights to heat the bleaching agent, however, causes a greater level of tooth dehydration. This effect not only can increase tooth sensitivity but also results in an immediate apparent whitening of the tooth owing to dehydration that makes the actual whitening result more difficult to assess. Use of carbon dioxide laser to heat the bleaching mixture and accelerate the bleaching treatment has not been recommended, according to a report of the American Dental Association (ADA) because of the potential for hard or soft tissue damage.³⁰ On completion of the treatment, the dentist rinses the patient's teeth, removes the rubber dam or isolation medium, and cautions the patient about postoperative sensitivity. A nonsteroidal analgesic and anti-inflammatory drug may be administered if sensitivity is anticipated.

Contrary to the claims of some manufacturers, optimal whitening typically requires more than one bleaching treatment.³¹ Bleaching treatments generally are rendered weekly for two to six treatments, with each treatment lasting 30 to 45 minutes. Patients may experience transient tooth sensitivity between appointments, but no long-term adverse effects of bleaching teeth with otherwise healthy pulps have been reported in the literature. Because the enamel is not acid-etched, it is not necessary to polish the teeth after they have been bleached, and it is not essential to provide any fluoride treatment.

Dentist-Prescribed, Home-Applied Technique

The dentist-prescribed, home-applied technique (i.e., night-guard vital bleaching) is much less labor intensive and requires substantially less in-office time. An impression of the arch to be treated is made and poured in cast stone. It should be ensured that the impression is free of bubbles on or around teeth by wiping the impression material onto teeth and the adjacent gingival areas before inserting the impression. After appropriate infection control procedures, the dentist rinses the impression vigorously and pours with cast stone. Incomplete rinsing of the impression may cause a softened surface on the stone, which may result in a nightguard (bleaching tray) that is slightly too small and that may irritate tissue. The dentist trims the cast around the periphery to eliminate the vestibule and thin out the base of the cast palatally (until a hole is produced). Generally, the cast must be lifted from the table of the cast-trimming machine to remove the vestibule successfully without damaging teeth. The dentist allows the cast to dry and blocks out any significant undercuts by using a block-out material (e.g., putty, clay, light-activated spacer material).

The nightguard is formed on the cast with the use of a heated vacuum-forming machine. After the machine has warmed up for 10 minutes, a sheet of 0.020- to 0.040-inch (0.75- to 1.5-mm) soft vinyl nightguard material is inserted and allowed to be softened by heat until the material sags approximately by 1 inch. The top portion of the machine is closed slowly and gently, and the vacuum is allowed to

form the heat-softened material around the cast. After sufficient time has been allowed for adaptation of the material, the dentist turns off the machine and allows the material to cool.

Next, the dentist uses scissors or a No. 11 surgical blade in a Bard-Parker handle to trim in a smooth, straight cut about 3 to 5 mm from the most apical portion of the gingival crest of teeth (facially and lingually). This excess material is removed first. The horseshoe-shaped nightguard is removed from the cast. The dentist trims the facial edges of the nightguard in a scalloped design, following the outline of the free gingival crest and using sharp, curved scissors. Scalloping of the lingual surface is optional because the bleaching material is applied primarily to the facial aspects of teeth. Alternatively (on the lingual aspect), the nightguard may be trimmed apically to within 2 mm of the free gingival crest in a smooth, horseshoe-shaped configuration. This scalloped design is preferred because it allows the tray to cover only teeth and prevents entrapment of the bleaching material between gingival tissue and the nightguard. The nightguard is completed and is ready for delivery to the patient (Fig. 12-25).

The dentist inserts the nightguard into the patient's mouth and evaluates it for adaptation, rough edges, or blanching of tissue. A properly fitting nightguard is shown in Figure 12-26. Further shortening (i.e., trimming) may be indicated in problem areas. The dentist evaluates the occlusion on the nightguard with the patient in maximum intercuspation. If the patient is unable to obtain a comfortable occlusion because of premature posterior tooth contacts, the nightguard is trimmed to exclude coverage of the terminal posterior teeth, as needed (to allow optimal tooth contact in maximum intercuspation). In addition, if no lingual scalloping is done, the edges of the guard on the palate should terminate in grooves or valleys, where possible, rather than on the heights of soft tissue contours (e.g., in the area of the incisive papilla).

A 10% to 15% carbamide peroxide bleaching material generally is recommended for this bleaching technique.



Fig. 12-25 Vacuum-formed, clear plastic nightguard used for vital bleaching (i.e., scalloped version).

Commercial bleaching products are available as clear gels and white pastes. Carbamide peroxide degrades into 3% hydrogen peroxide (active ingredient) and 7% urea. Bleaching materials containing carbopol are recommended because carbopol thickens the bleaching solution and extends the oxidation process. On the basis of numerous research studies, carbamide peroxide bleaching materials seem to be safe and effective when administered by or under the supervision of a dentist.²²

The patient is instructed in the application of the bleaching gel or paste into the nightguard. A thin bead of material is extruded into the nightguard along the facial aspects corresponding to the area of each tooth to be bleached. Usually, only the anterior six to eight teeth are bleached. The clinician should review proper insertion of the nightguard with the patient. After inserting the nightguard, excess material is wiped from the soft tissue along the edge with a soft-bristled toothbrush. No excess material should be allowed to remain on soft tissue because of the potential for gingival irritation. The patient should be informed not to drink liquids or rinse during treatment and to remove the nightguard for meals and oral hygiene.

Although no single treatment regimen is best for all patients, most patients prefer an overnight treatment approach because of the convenience. If the nightguard is worn at night, a single application of bleaching material at bedtime is indicated. In the morning, the patient should remove the nightguard, clean it under running water with a toothbrush, and store it in the container provided. Total treatment time using an overnight approach is usually 1 to 2 weeks. If patients cannot tolerate overnight bleaching, the bleaching time and frequency can be adjusted to accommodate the patient's comfort level. In addition, in these cases, tolerance to the nightguard and bleaching material generally are improved if the patient gradually increases the wearing time each day.

If either of the two primary adverse effects occurs (i.e., sensitive teeth or irritated gingiva), the patient should reduce or discontinue treatment immediately and contact the dentist so that the cause of the problem can be determined and the treatment approach modified. The dentist may prescribe desensitizing agents to help alleviate sensitivity associated with bleaching.

It is recommended that only one arch be bleached at a time, beginning with the maxillary arch. Bleaching the maxillary arch first allows the untreated mandibular arch to serve as a constant standard for comparison. Restricting the bleaching to one arch at a time reduces the potential for occlusal problems that could occur if the thicknesses of two mouthguards were interposed simultaneously. Figure 12-27 illustrates a typical case before and after treatment with nightguard vital bleaching.

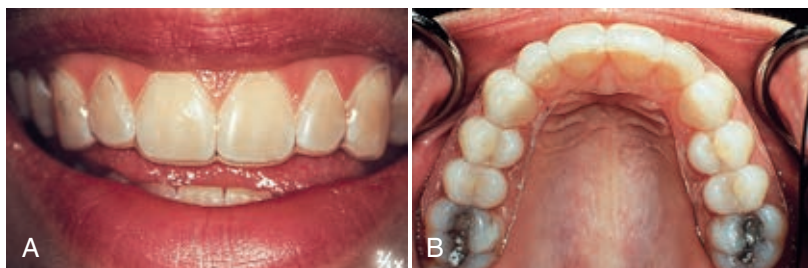


Fig. 12-26 Nightguard for vital bleaching. **A** and **B**, Clear plastic nightguard properly seated and positioned in the mouth (scalloped on facial, unscalloped on lingual).

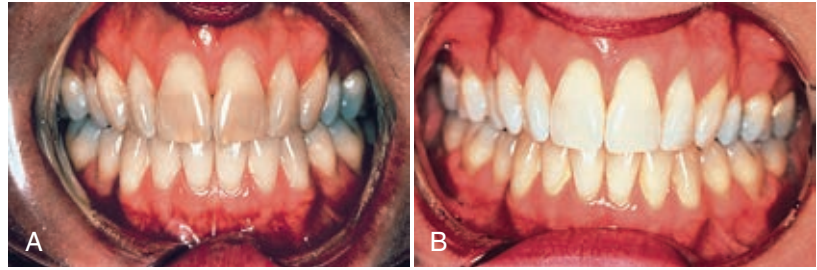


Fig. 12-27 Nightguard vital bleaching. **A**, Before bleaching treatment. **B**, After treatment.

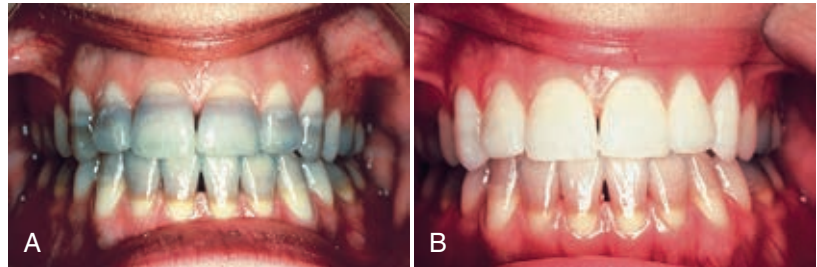


Fig. 12-28 Bleaching tetracycline-stained teeth. **A**, Before nonvital bleaching. **B**, After treatment. (Courtesy of Dr. Wayne Mohorn.)

Tetracycline-stained teeth typically are much more resistant to bleaching. Teeth stained with tetracycline require prolonged treatment durations of several months before any results are observed. Often, tetracycline-stained teeth are unresponsive to the procedure, especially if the stains are blue-gray in color. Tetracycline-stained teeth may approach, but never seem to achieve, the appearance of normal teeth. A single tetracycline-stained tooth with previous endodontic therapy or a different pulp size may respond differently from other teeth in the arch to the bleaching technique.

Because bleaching tetracycline-stained teeth is difficult, some clinicians advocate intentional endodontic therapy along with the use of an intracoronal nonvital bleaching technique to overcome this problem (Fig. 12-28). Although the esthetic result appears much better than that obtained from external bleaching, this approach involves all the inherent risks otherwise associated with root canal treatment. External bleaching techniques offer a safer alternative, although they may not be as rapid or effective. Veneers or full crowns are alternative esthetic treatment methods for difficult tetracycline-stained teeth but involve irreversible restorative techniques (see the section on Indirect Veneer Techniques). No one bleaching technique is effective in all cases, and all successes are not equal. Often, with vital bleaching, a combination of the in-office technique and the dentist-prescribed, home-applied technique has better results than either technique used alone.

Microabrasion and Macroabrasion

Microabrasion and *macroabrasion* represent conservative alternatives for the reduction or elimination of superficial discolorations. As the terms imply, the stained areas or defects are abraded away. These techniques result in the physical removal of the tooth structure and are indicated only for stains or enamel defects that do not extend beyond a few tenths of a millimeter in depth. If the defect or discoloration remains

even after treatment with microabrasion or macroabrasion, a restorative alternative is indicated.

Microabrasion

In 1984, McCloskey reported the use of 18% hydrochloric acid swabbed on teeth for the removal of superficial fluorosis stains.³² Subsequently, in 1986, Croll and Cavanaugh modified the technique to include the use of pumice with hydrochloric acid to form a paste applied with a tongue blade.³³ This technique is called *microabrasion* and involves the surface dissolution of the enamel by acid along with the abrasiveness of the pumice to remove superficial stains or defects. Since that time, Croll further modified the technique, reducing the concentration of the acid to approximately 11% and increasing the abrasiveness of the paste using silicon carbide particles (in a water-soluble gel paste) instead of pumice.³⁴ This product, marketed as Prema compound (Premier Dental Products Co., Plymouth Meeting, PA) or Opalustre (Ultradent Products, Inc., South Jordan, UT), represents an improved and safer means for the removal of superficial stains or defects. This technique involves the physical removal of tooth structure and does not remove stains or defects through any bleaching phenomena.

Before treatment, the clinician should evaluate the nature and extent of the enamel defect or stain and differentiate between nonhereditary developmental dysmineralization (i.e., abnormal mineralization) defects (e.g., white or light brown fluorotic enamel and the idiopathic white or light brown spot) versus incipient carious lesions. Incipient carious lesions usually are located near the gingival margin. These lesions have a smooth surface and appear opaque or chalky white when dried but are less visible when hydrated.

Incipient caries is reversible if treated immediately. Changing the oral environment through oral hygiene practices and dietary adjustments allows remineralization to occur. If the caries lesion has progressed to have a slightly roughened surface, however, microabrasion coupled with a

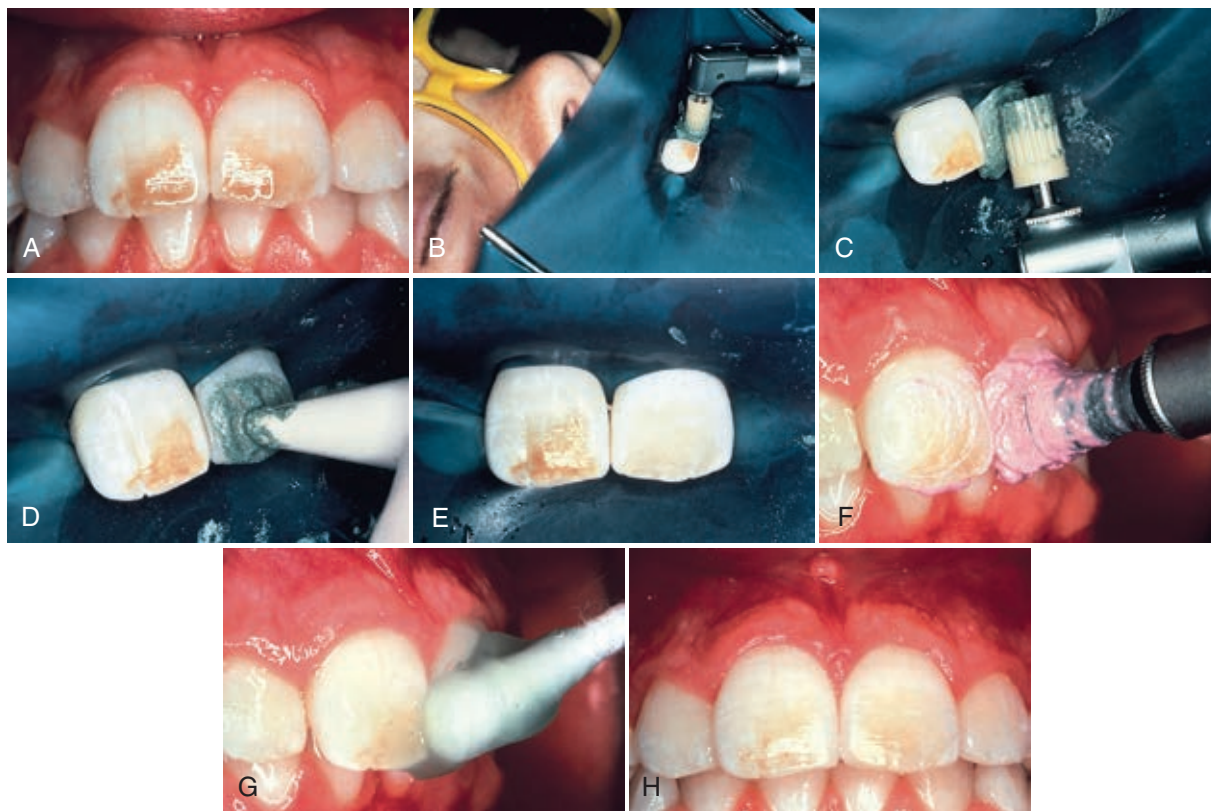


Fig. 12-29 Microabrasion. **A**, Young patient with unesthetic fluorosis stains on central incisors. **B** and **C**, Prema compound applied with special rubber cup with fluted edges. Protective glasses and rubber dam are needed for the safety of the patient. **D**, Hand applicator for applying Prema compound. **E**, Stain removed from the left central incisor after microabrasion. **F**, Treated enamel surfaces polished with prophylactic paste. **G**, Topical fluoride applied to treated enamel surfaces. **H**, Final esthetic result. (Courtesy of Dr. Ted Croll.)

remineralization program is an initial option. If this approach is unsuccessful, it can be followed by a restoration. Cavitation of the enamel surface is an indication for restorative intervention. As the location of smooth-surface enamel caries nears the cemento-enamel junction (CEJ), then enamel is too thin to permit microabrasion or macroabrasion as a treatment option.

A developmental discolored spot (opaque white or light brown) is the result of an unknown, local traumatic event during amelogenesis and is termed *idiopathic*. Its surface is intact, smooth, and hard. It usually is located in the incisal (occlusal) half of enamel, which contributes to the unsightly appearance. The patient (or the patient's parents in the case of a child) must be informed that an accurate prognosis for microabrasion cannot be given but that microabrasion will be applied first. If microabrasion is unsuccessful because of the depth of the defect exceeding 0.2 to 0.3 mm, the tooth will be restored with a tooth-colored restoration. Surface discolorations resulting from fluorosis also can be removed by microabrasion if the discoloration is within the 0.2- to 0.3-mm removal depth limit.

Figure 12-29, **A**, shows a young patient with fluorosis stains on teeth No. 8 and No. 9. A rubber dam is placed to isolate the teeth to be treated and to protect the gingival tissues from the acid in the Prema paste or compound (Premier Dental Products). Protective glasses should be worn by the patient to shield the eyes from any spatter. The Prema paste is applied to the defective area of the tooth with a special rubber cup that has fluted edges (see Fig. 12-29, **B** and **C**). The abrasive

compound can be applied with either the side or the end of the rubber cup. A 10× gear reduction, low-speed handpiece (similar to that used for placing pins) is recommended for the application of the Prema compound to reduce the possibility of removing too much tooth structure and to prevent spatter. Moderately firm pressure is used in applying the compound.

For small, localized, idiopathic white or light brown areas, a hand application device also is available for use with the Prema compound (see Fig. 12-29, **D**). Periodically, the paste is rinsed away to assess the extent of defect removal. The facial surface also is viewed with a mirror from the incisal aspect to determine how much tooth structure has been removed. Care must be taken not to remove too much tooth structure. The procedure is continued until the defect is removed or until it is deemed imprudent to continue further (see Fig. 12-29, **E**). The treated areas are polished with a fluoride-containing Prophy paste to restore surface luster (see Fig. 12-29, **F**). Immediately after treatment, a topical fluoride is applied to teeth to enhance remineralization (see Fig. 12-29, **G**). Results are shown in Figure 12-29, **H**.

Macroabrasion

An alternative technique for the removal of localized, superficial white spots (not subject to conservative, remineralization therapy) and other surface stains or defects is called *macroabrasion*. Macroabrasion simply uses a 12-fluted composite finishing bur or a fine grit finishing diamond in a

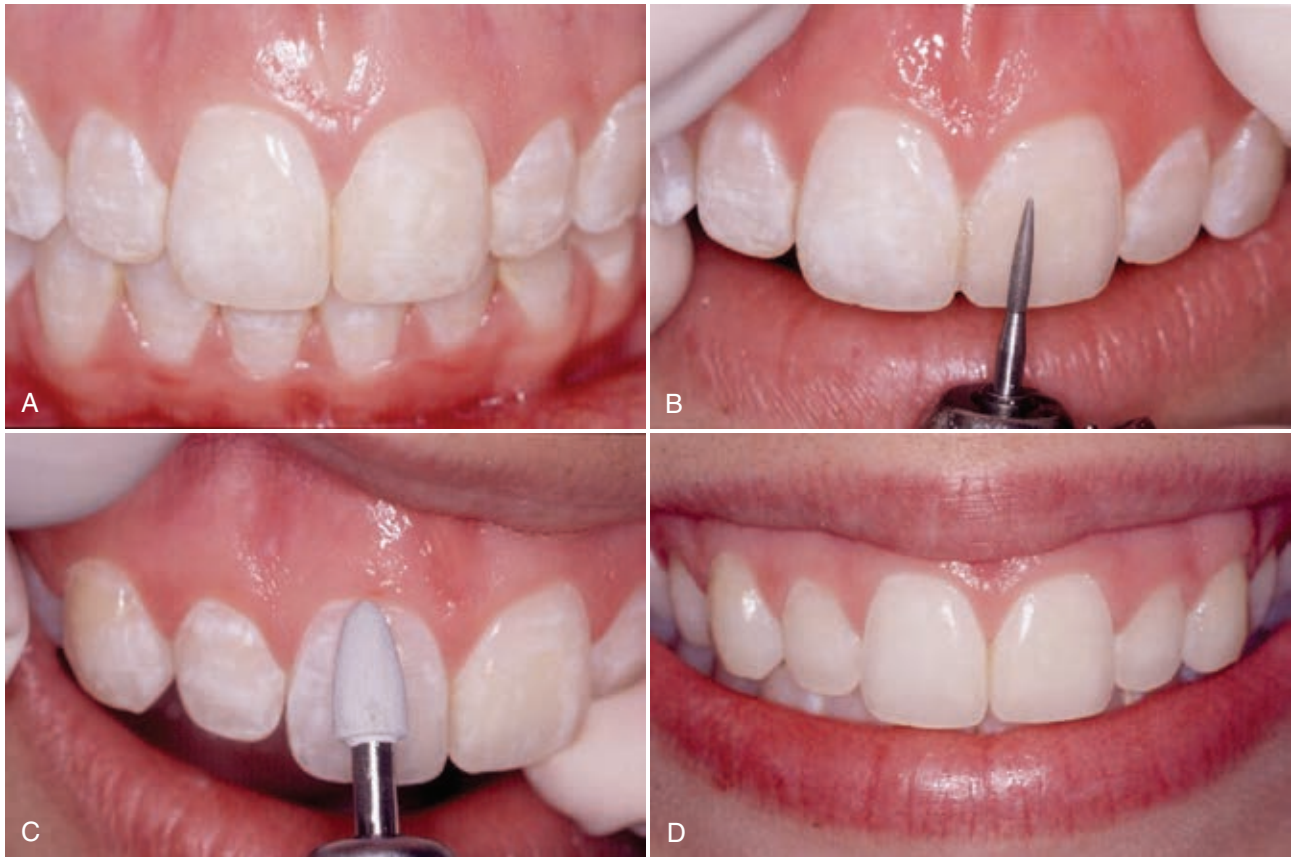


Fig. 12-30 Macroabrasion. **A**, Outer surfaces of maxillary anterior teeth are unesthetic because of superficial enamel defects. **B** and **C**, Removal of discoloration by abrasive surfacing and polishing procedures. **D**, Completed treatment revealing conservative esthetic outcome.

high-speed handpiece to remove the defect (Fig. 12-30, *A* and *B*). Care must be taken to use light, intermittent pressure and to monitor the removal of tooth structure carefully to avoid irreversible damage to the tooth. Air-water spray is recommended, not only as a coolant but also to maintain the tooth in a hydrated state to facilitate the assessment of defect removal. Teeth that have white spot defects are particularly susceptible to dehydration resulting in other apparent white spots that are not normally seen when the tooth is hydrated. Dehydration exaggerates the appearance of white spots and makes defect removal difficult to assess. After removal of the defect or on termination of any further removal of tooth structure, a 30-fluted, finishing bur is used to remove any facets or striations created by the previous instruments. Final polishing is accomplished with an abrasive rubber point (see Fig. 12-30, *C*). The results are shown in Figure 12-30, *D*.

Comparable results can be achieved with microabrasion and macroabrasion. Both treatments have advantages as well as disadvantages. Microabrasion has the advantage of ensuring better control of the removal of tooth structure. High-speed instrumentation used in macroabrasion is technique sensitive and can have catastrophic results if the clinician fails to use extreme caution. Macroabrasion is considerably faster and does not require the use of a rubber dam or special instrumentation. Defect removal also is easier with macroabrasion compared with microabrasion if an air-water spray is used during treatment to maintain hydration of teeth. Nonetheless, microabrasion is recommended over macroabrasion for the

treatment of superficial defects in children because of better operator control and superior patient acceptance. To accelerate the process, a combination of macroabrasion and microabrasion also may be considered. Gross removal of the defect is accomplished with macroabrasion, followed by final treatment with microabrasion.

Veneers

A veneer is a layer of tooth-colored material that is applied to a tooth to restore localized or generalized defects and intrinsic discolorations (see Figs. 12-7, 12-33, 12-34, 12-35, and 12-41). Typically, veneers are made of directly applied composite, processed composite, porcelain, or pressed ceramic materials. Common indications for veneers include teeth with facial surfaces that are malformed, discolored, abraded, or eroded or have faulty restorations (Fig. 12-31).

Two types of esthetic veneers exist: (1) partial veneers and (2) full veneers (Fig. 12-32). Partial veneers are indicated for the restoration of localized defects or areas of intrinsic discoloration (Fig. 12-33; see also Fig. 12-1). Full veneers are indicated for the restoration of generalized defects or areas of intrinsic staining involving most of the facial surface of the tooth (see Figs. 12-7, 12-35, 12-36, 12-37, and 12-41). Several important factors, including patient age, occlusion, tissue health, position and alignment of teeth, and oral hygiene, must be evaluated before pursuing full veneers as a treatment



Fig. 12-31 Clinical examples of indications for treatment with veneers include teeth affected by tetracycline drug staining (A), fluorosis or enamel hypoplasia (B), acid-induced erosion (e.g., lemon-sucking habit) (C), and defective or improperly done existing veneers (note significant gingival overhang with associated purulent exudate) (D).

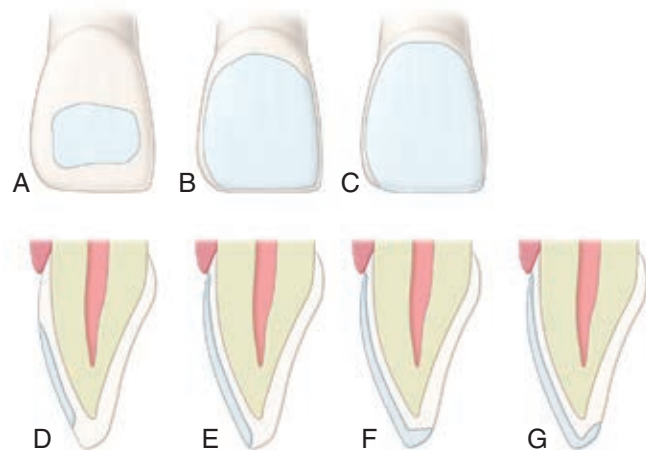


Fig. 12-32 Four types of veneers. **A**, Facial view of partial veneer that does not extend subgingivally or involve the incisal angle. **B**, Full veneer with window preparation design that extends to the gingival crest and terminates at the facio-incisal angle. **C**, Full veneer with either a butt-joint incisal preparation design or an incisal-lapping preparation design extending subgingivally and including all of incisal surface. (Subgingival extension is indicated only for preparation of darkly stained teeth and is not considered routine.) **D–G**, Cross-sections of the four types of veneers: **D**, Partial veneer; **E**, Full veneer with window preparation design; **F**, Full veneer with butt-joint incisal preparation design; **G**, Full veneer with incisal-lapping incisal preparation design.

option. If full veneers are done, care must be taken to provide proper physiologic contours, particularly in the gingival area, to ensure good gingival health. An example of poorly contoured veneers is shown in [Figure 12-31, D](#); severe gingival irritation exists around the over-contoured veneers; a purulent exudate is evident on probing the margins with an explorer.

Full veneers can be accomplished by the direct or indirect technique. When only a few teeth are involved or when the entire facial surface is not faulty (i.e., partial veneers), directly applied composite veneers can be completed chairside in one appointment for the patient. Placing direct composite

full veneers is time consuming and labor intensive. For cases involving young children or a single discolored tooth, or when the patient's time or money is limited, precluding a laboratory-fabricated veneer, the direct technique is a viable option. Indirect veneers require two appointments but typically offer three advantages over directly placed full veneers:

1. Indirectly fabricated veneers are much less sensitive to operator technique. Considerable artistic expertise and attention to detail are required to consistently achieve esthetically pleasing and physiologically sound direct veneers. Indirect veneers are made by a laboratory technician and are typically more esthetic.
2. If multiple teeth are to be veneered, indirect veneers usually can be placed much more expeditiously.
3. Indirect veneers typically last much longer than do direct veneers, especially if they are made of porcelain or pressed ceramic.

Some controversy exists regarding the extent of tooth preparation that is necessary and the amount of coverage for both direct and indirectly fabricated veneers (see [Fig. 12-32](#)). Some operators prefer to etch the existing enamel and apply the veneer (direct or indirect type) to the entire existing facial surface without any tooth preparation. The perceived advantage of these “no prep” veneers is that little or no tooth structure is removed. Also, in the event of failure or if the patient does not like the veneer, it supposedly can be removed (being reversible), although in actuality, it is never easy to remove any bonded veneer without concomitant removal of some tooth structure (see also section on Indirect Veneer Techniques, No-Prep Veneers).

Several significant problems exist, however, with this approach. First, to achieve an esthetic result, if the tooth is otherwise of normal contour, the facial surface of such a restoration will be over-contoured, appearing and feeling unnatural. This observation is true for both direct and indirect veneers. An over-contoured veneer frequently results in gingival irritation with accompanying hyperemia and bleeding caused by bulbous and impinging gingival contours. Second,



Fig. 12-33 Direct partial veneers. **A**, Patient with over-contoured direct full veneers. **B**, After removal of old veneer, localized white spots are evident. **C**, Models illustrate fault (x) and cavity preparation (y). The chamfered margins are irregular in outline. **D**, Intra-enamel preparations for partial veneer restorations. **E**, Conservative esthetic result of completed partial veneers.

with regard to direct veneers, the veneer is more likely to be dislodged when no tooth structure is removed before the etching and bonding procedures are done. If the veneer is lost, it can be replaced. The patient may live in constant fear, however, that it will happen again, possibly causing embarrassment.

The reversibility of no-prep veneers may seem desirable and appealing to patients from a psychological standpoint; however, few patients who elect to have veneers wish to return to the original condition. In addition, removing full veneers with no damage to the underlying unprepared tooth, as noted earlier, is exceedingly difficult, if not impossible. To achieve esthetically pleasing and physiologically sound results consistently, an intra-enamel preparation is usually indicated. The only exception is in cases in which the facial aspect of the tooth is significantly under-contoured because of severe abrasion or erosion. In these cases, mere roughening of the involved enamel and defining of the peripheral margins are indicated.

Intra-enamel preparation (or the roughening of the surface in under-contoured areas) before placing a veneer is strongly recommended for the following reasons:

1. To provide space for bonding and veneering materials for maximal esthetics without over-contouring
2. To remove the outer, fluoride-rich layer of enamel that may be more resistant to acid-etching
3. To create a rough surface for improved bonding
4. To establish a definite finish line

Establishing an intra-enamel preparation with a definite finish line is particularly important when placing indirectly fabricated veneers. Accurate positioning and seating of an indirectly made veneer are enhanced significantly if an intra-enamel preparation is present.

Another controversy involves the location of the gingival margin of the veneer (see Fig. 12-32). Should it terminate short of the free gingival crest at the level of the gingival crest or apical of the gingival crest? The answer depends on the

individual situation. If the defect or discoloration does not extend subgingivally, the margin of the veneer should not extend subgingivally. The position of the gingival margin of any veneer is dictated by the extent of the defects or discoloration and the amount of tooth structure that is visible with maximum smiling. If a patient exhibits a high smile line that exposes the entire facial surface of the tooth and if defects like fluorosis stains are generalized, then the margin of the veneer must be positioned at the level of the crest of tissue to optimize esthetics. However, the only logical reason for extending the margin subgingivally is if the gingival area is carious or defective, warranting restoration, or if it involves significantly dark discoloration that presents a difficult esthetic problem. No restorative material is as good as normal tooth structure, and the gingival tissue is never as healthy when it is in contact with an artificial material.

Three basic preparation designs exist for full veneers: (1) a window preparation; (2) a butt-joint incisal preparation, and (3) an incisal-lapping preparation (see Fig. 12-32). A window preparation is recommended for most direct composite veneers. It is also frequently used in cases of indirectly fabricated veneers where the outline form of the canine is intact and the patient is canine guided. This intra-enamel preparation design preserves the functional lingual and incisal surfaces of maxillary anterior teeth, protecting the veneers from significant occlusal stress. This quality is of particular importance with direct composite veneers.

A window preparation design also is recommended for indirectly fabricated porcelain veneers in patients who exhibit a canine-guided pattern of lateral guidance and in whom the maxillary canines are of normal contour with little incisal wear or notching. By using a window preparation, the functional surfaces are better preserved in enamel (see Figs. 12-32, E, and 12-41, I). This design reduces the potential for accelerated wear of the opposing tooth that could result if the functional path involved porcelain on the lingual and incisal surfaces, as with incisal butt-joint or incisal-lapping designs.

For most indirectly fabricated porcelain veneers, either a butt-joint incisal design or an incisal-lapping approach is used. A butt-joint incisal design is used routinely in cases where no defects exist along the lingual aspect of the incisal edge. It is the simplest design and is used to easily provide adequate reduction of the tooth to accommodate the needed strength of the porcelain veneer in this area of the preparation (see Figure 12-32, F). An incisal-lapping preparation is indicated when the tooth being veneered needs lengthening or when an incisal defect warrants restoration. The extent of the lapping onto the lingual surface is generally dictated by the extent of the lingual incisal defect or by the amount of faciolingual resistance form desired for reinforcement of the incisal edge (see Figs. 12-32, G, and 12-40).

The preparation and restoration of a tooth with a veneer should be carried out in a manner that provides optimal function, esthetics, retention, physiologic contours, and longevity. All of these objectives should be accomplished without compromising the strength of the remaining tooth structure. If the veneer becomes chipped, discolored, or worn, it usually can be repaired or replaced.

Darkly stained teeth, especially teeth discolored by tetracycline, are much more difficult to veneer with full veneers compared with teeth with generalized defects but that have normal underlying coloration (see Fig. 12-44). The difficulty is compounded further when the cervical areas are badly discolored. Usually, only the six maxillary anterior teeth require correction because they are the most noticeable when a person smiles or talks. The maxillary first premolars (and, to a lesser extent, the second premolars) also are included, however, if they, too, are noticeable on smiling.

Discolored mandibular anterior teeth are rarely indicated for veneers because the facio-incisal portions are thin and usually subject to biting forces and attrition. Veneering mandibular teeth is discouraged if the teeth are in normal occlusal contact because it is exceedingly difficult to achieve adequate reduction of the enamel to compensate for the thickness of the veneering material. Also, if porcelain veneers are placed on mandibular teeth, the veneers may accelerate the wear of opposing maxillary teeth because of the abrasive nature of the porcelain. In most cases, the lower lip hides these teeth, and esthetics is not a significant problem. Most patients are satisfied with the conservative approach of veneering only maxillary anterior teeth.

Direct Veneer Technique

Direct Partial Veneers

Small localized intrinsic discolorations or defects that are surrounded by healthy enamel are ideally treated with direct partial veneers (see Fig. 12-1, B and C). Often, practitioners place full veneers when only partial veneers are indicated. The four anterior teeth in Figure 12-33, A, illustrate the clinical technique for placing partial veneers. These defects can be restored in one appointment with a light-cured composite. Preliminary steps include cleaning, shade selection, and isolation with cotton rolls or rubber dam. Anesthesia usually is not required unless the defect is deep, extending into dentin.

Figure 12-33, A, shows four anterior teeth that had previously received direct composite veneers with no enamel preparation for the restoration of developmental white spot lesions. However, even after veneering, the white spots still show

through the veneers. On removal of the defective veneers, the localized white spots are evident (see Fig. 12-33, B). Models illustrating proper preparation are shown in Figure 12-33, C. The outline form is dictated solely by the extent of the defect and should include all discolored areas. The clinician should use a coarse, elliptical or round diamond instrument with air-water coolant to remove the defect. The use of water-air spray is also imperative so that the tooth can be maintained in a hydrated state. If dehydration is allowed to occur, it can cause the appearance of other white spots which are artifacts and which will make defect assessment much more difficult (see Fig. 12-33, D). After preparation, etching, and restoration of the defective areas (as described in the following paragraph), the finished partial veneers are seen (see Fig. 12-33, E).

Usually, it is desirable to remove all of the discolored enamel in a pulpal direction. If the entire defect or stain is removed, a microfilled composite is recommended for restoring the preparation. Microfills are excellent “enamel replacement” materials because of their optical properties. If the tooth has been maintained in a hydrated state, the microfilled composite can be positioned on a trial basis to assess the accuracy of the shade prior to final restoration. Nanofilled composites also are excellent material choices for this technique. If a residual lightly stained area or white spot remains in enamel, however, an intrinsically less translucent composite can be used, rather than extending the preparation into dentin to eliminate the defect. Most composites filled primarily with radiopaque fillers (e.g., barium glass) are more optically opaque with intrinsic masking qualities (in addition to being radiopaque). Use of these types of composites for the restoration of preparations with light, residual stains is most effective and conserves the tooth structure. In this example, all restorations are of a light-cured microfilled composite.

Direct Full Veneers

Extensive enamel hypoplasia involving all maxillary anterior teeth was treated by placing direct full veneers in this case (Fig. 12-34, A). A diastema also was present between the central incisors. The patient desired to have the hypoplasia and the diastema corrected; examination indicated a good prognosis. A direct technique was used with a light-cured microfilled composite. Placing direct full composite veneers is very time consuming. Although all six teeth can be restored at the same appointment, it may be less traumatic for the patient and the dentist if the veneers are placed in two appointments. In this example, the central incisors were completed during the first appointment, and the lateral incisors and canines were completed during the second appointment.

After the teeth to receive the veneers are cleaned and a shade is selected, the area is isolated with cotton rolls and retraction cords. Both central incisors are prepared with a coarse, rounded-end diamond instrument. The window preparation typically is made to a depth roughly equivalent to half the thickness of the facial enamel, ranging from approximately 0.5 to 0.75 mm midfacially and tapering down to a depth of about 0.3 to 0.5 mm along the gingival margin, depending on the thickness of enamel (see Fig. 12-32). A well-defined chamfer at the level of the gingival crest provides a definite preparation margin for subsequent finishing procedures. The margins are not extended subgingivally because these areas are not defective. The preparation for all veneer types (both direct and

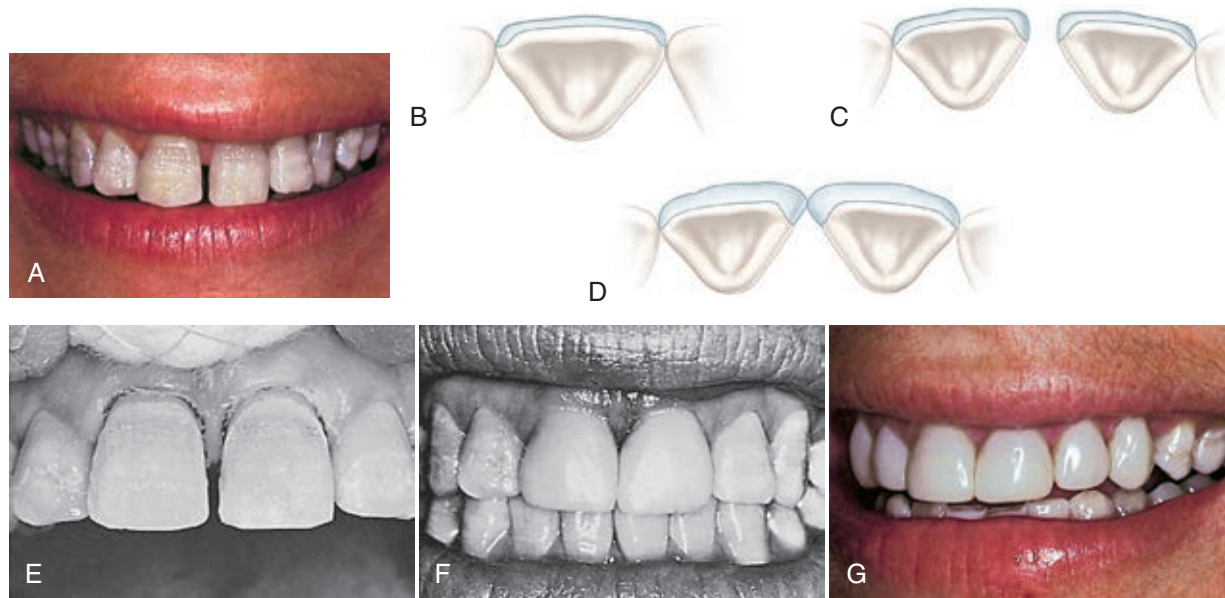


Fig. 12-34 Direct full veneers using light-cured composite. **A**, Enamel hypoplasia of maxillary anterior teeth. **B**, Typical preparation of facial surface for full veneer. **C**, The preparation is extended onto the mesial surface to allow closure of diastema. **D**, Full veneers restore proximal contact. **E**, Etched preparations of central incisors. **F**, Veneers completed on maxillary central incisors. **G**, Treatment completed with placement of full veneers on remaining maxillary anterior teeth.

indirect) normally is terminated just facial to the proximal contact except in the case of a diastema (see Fig. 12-34, *B*). When interdental spaces exist, the preparations must be extended from the facial surfaces onto the mesial surfaces, terminating at the mesiolingual line angles (see Fig. 12-34, *C* and *D*). This lingual extension of the preparation allows for proper re-establishment of the entire proximal contour of the tooth in the final restoration. The incisal edges were not included in the preparations in this example because no discoloration was present. In addition, preservation of the incisal edges better protects the veneers from heavy functional forces, as noted earlier for window preparations.

The teeth to be treated should be restored one at a time. After the etching, rinsing, and drying procedures (see Fig. 12-34, *E*), the dentist applies and polymerizes the resin-bonding agent. The dentist places the composite on the tooth in increments, especially along the gingival margin, to reduce the effects of polymerization shrinkage. The composite is placed in slight excess to allow some freedom in contouring. It is helpful to inspect the facial surface from an incisal view with a mirror to evaluate the contour before polymerization. After the first veneer is finished, the second tooth is restored in a similar manner (see Fig. 12-34, *F*). In this case, the remaining four anterior teeth are restored with direct composite veneers (see Fig. 12-34, *G*) at the second appointment. Chapter 9 describes the procedures used to insert and finish composite restorations. Another excellent example of direct composite veneers is seen in Figure 12-35.

Indirect Veneer Techniques

Many dentists find that the preparation, placement, and finishing of several direct veneers at one time is too difficult, fatiguing, and time consuming. Some patients become uncomfortable and restless during long appointments. In addition,

veneer shades and contours can be better controlled when made outside of the mouth on a cast. For these reasons, indirect veneer techniques are usually preferable. Indirect veneers are primarily made of (1) processed composite, (2) feldspathic porcelain, and (3) cast or pressed ceramic. Because of superior strength, durability, and conservation of the tooth structure, feldspathic porcelain bonded to intra-enamel preparations has historically been the preferred approach for indirect veneering techniques used by dentists. Some pressed ceramic veneering materials offer comparable esthetic qualities but may require a deeper tooth preparation that is often located in dentin. Studies show that bond strengths to dentin decline over time and that porcelain veneers placed in intra-enamel preparations offer the best long-term results.³⁵⁻³⁸ However, newer, currently available pressed or castable ceramics are capable of being fabricated to much thinner dimensions, making them viable options for indirect fabrication as well.

Although two appointments are required for indirect veneers, chair time is reduced because much of the work has been done in the laboratory. Excellent results can be obtained when proper clinical evaluation and careful operating procedures are followed. Indirect veneers are attached to the enamel by acid etching and bonding with light-cured resin cement.

No-Prep Veneers

As noted earlier (see the section titled Veneers), one approach being used for indirect veneers is to place them on teeth with no tooth preparation. Although this “no prep” approach may at first appear desirable, it can later cause problems if proper case selection is not done. No-prep veneers are best used when teeth are inherently under-contoured, when interdental spaces or open incisal embrasures are present, or when both conditions exist. Examples of successful no-prep veneers following these guidelines are seen in Figures 12-36 and 12-37.



Fig. 12-35 Direct full veneers using light-cured composite for defective veneers. **A**, Defective composite veneers with marginal staining. **B**, Conservative intra-enamel preparation. **C**, New direct composite veneers on maxillary anterior teeth (Courtesy Dr. Robert Margeas).



Fig. 12-36 No-prep veneers placed on maxillary anterior teeth. **A**, Before treatment. **B**, Immediately after placement of the no-prep veneers. (Courtesy of Dr. Patricia Pereira.)

However, no-prep veneers can be problematic. First, no-prep veneers are inherently made thinner and, consequently, are more prone to fracture, especially during the try-in phase. Second, for indirect no-prep veneers, interproximal areas are difficult to access for proper finishing. And third, as noted earlier, if case selection is not done properly and the teeth are already of normal contour, the resulting veneers inevitably will be over-contoured. Veneers that are over-contoured are not generally esthetic and often can result in impingement of gingival tissue, as noted earlier (see Fig.

12-31, *D*). For these reasons, it is advisable, in most cases, to use a conservative, intra-enamel preparation for the use of indirect veneers, as noted below.

Etched Porcelain Veneers

The preferred type of indirect veneer is the etched porcelain (i.e., feldspathic) veneer. Porcelain veneers etched with hydrofluoric acid are capable of achieving high bond strengths to the etched enamel via a resin-bonding medium.³⁹⁻⁴¹ This

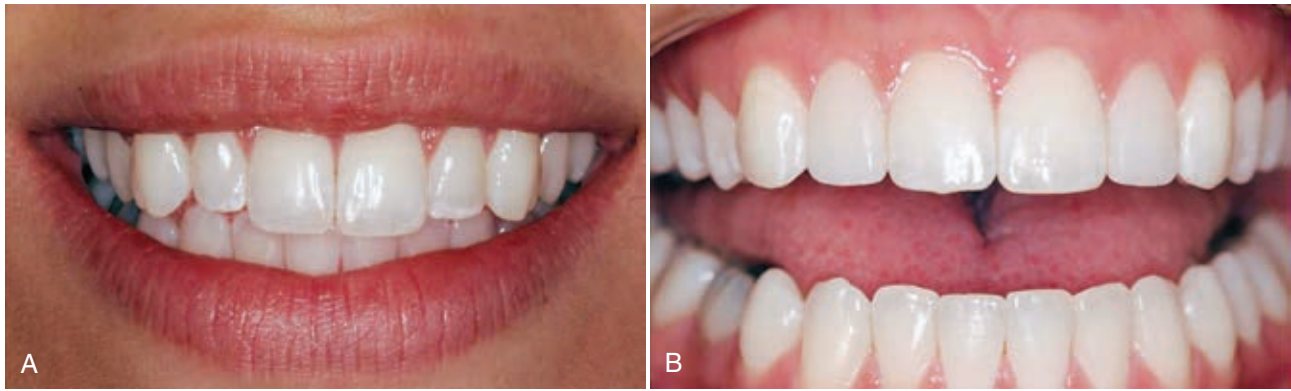


Fig. 12-37 No-prep veneers placed to restore undersized maxillary lateral incisors. **A**, Before treatment. **B**, After placement of the no-prep veneers. (Courtesy of Dr. Gary Radz.)

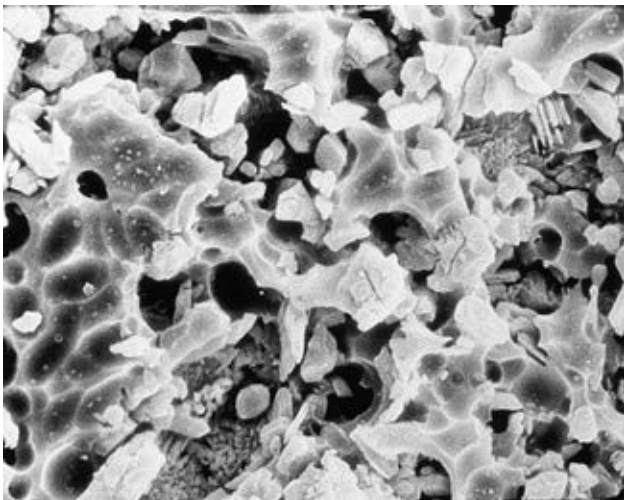


Fig. 12-38 Scanning electron micrograph ($\times 31,000$) of feldspathic porcelain etched with hydrofluoric acid. (Courtesy of Dr. Steven Bayne.)

porcelain etching pattern is shown in [Figure 12-38](#). In addition to the high bond strengths, etched porcelain veneers are highly esthetic, stain resistant, and periodontally compatible. The incidence of cohesive fracture for etched porcelain veneers is also very low.³⁶ However, as noted earlier, the key to the long-term success with etched porcelain veneers is the use of a *conservative intra-enamel preparation*. Preparations into dentin should be avoided because virtually all problems associated with etched porcelain veneers (debonding, accelerated marginal staining, tooth sensitivity, etc.) occur when excessive amounts of dentin are exposed in the veneer preparation.

TOOTH PREPARATION

Because the most important consideration in determining the success of etched porcelain veneers is tooth preparation, a systematic approach will be presented first, using a dentiform series, prior to reviewing the associated clinical procedures ([Fig. 12-39](#)). A veneer design using a butt-joint incisal edge will be illustrated first. The tooth used to illustrate the preparation sequence has intentionally been colored blue to allow better visualization of the involved steps. However, it is not recommended that this tooth marking be done clinically.

The veneer preparation is made with a tapered, rounded-end diamond instrument. It is critical that the tip diameter of the diamond be measured because the diamond will serve as the measuring tool in gauging proper reduction depth. A diamond with a tip diameter of 1.0 to 1.2 mm is recommended. The tip diameter of the diamond used in this series is 1.2 mm.

The first step in the veneer preparation is establishing the peripheral outline form. Position the diamond to half its depth (approximately 0.6 mm in this example) just facial to the proximal contact on either proximal surface, and then extend the bur, while maintaining its occluso-gingival orientation, around the gingival area and then back up the opposite proximal area, again keeping the diamond positioned just facial to the proximal contact area (see [Fig. 12-39, A and B](#)). In this example, a supragingival marginal position was maintained. Recall that clinically, the position of the gingival margin is determined by lip position (and the resulting display of teeth) and the gingival extent of the facial discoloration or defect being treated, as noted previously. If possible, a supragingival margin position is always considered desirable because it minimizes the potential for an adverse gingival response.

Facial reduction is achieved by first identifying and then reducing three separate facial zones: the incisal third, the middle third, and the gingival third (see [Fig. 12-39, C](#)), in that order. To prepare the incisal zone of facial reduction, the diamond first is aligned parallel with the facial surface of the incisal third of the tooth. The diamond is then moved mesiodistally from line angle to line angle until the desired depth of approximately 0.6 mm is attained. Again, the tip of the diamond is used to gauge this reduction. Reduction depth can be verified by viewing the tip of the diamond in proximity to the unprepared tooth structure gingival to this reduced area when viewed from the proximal, facial, and incisal aspects (see [Fig. 12-39, D and E](#)). Care also must be taken to round the mesial and distal facial line angles during this reduction sequence to ensure uniform facial reduction.

The middle third is reduced in a similar manner. By carefully watching the striations being created by the diamond mesiodistally during the reduction of the middle third, it is easy to see when the level of the previous incisal third reduction is reached (see [Fig. 12-39, F](#)). When a similar reduction level has been reached, the striations in the middle one third will then extend into the area previously reduced in the incisal

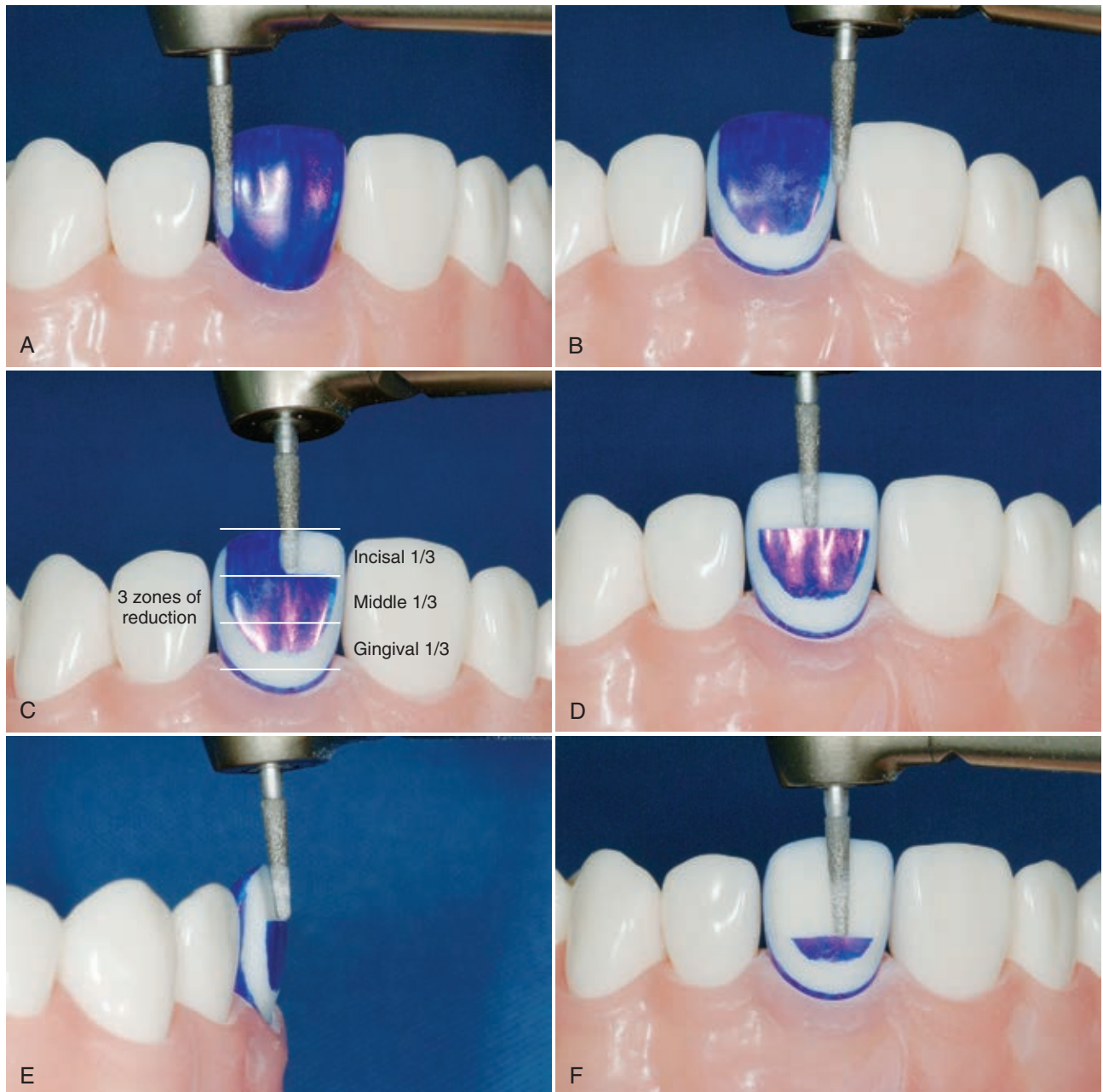


Fig. 12-39 Intra-enamel preparation for an etched porcelain veneer with a butt-joint incisal edge design. **A** and **B**, The peripheral outline form is first established using a rounded-end diamond instrument. **C–H**, Facial reduction is achieved by first identifying and then reducing three separate facial zones: the incisal third, the middle third, and the gingival third (see Fig. 12-39, **C**), in that order.

third. Stop immediately. *Do not go deeper.* Again, a reduction depth of approximately 0.6 mm is desirable. Moreover, the reduction depth again can be verified by viewing the tip of the diamond in proximity to the unprepared tooth structure gingival to this reduced area when viewed from the proximal, facial, and incisal aspects. Care also must be taken to round the mesial and distal facial line angles during this reduction sequence to ensure uniform facial reduction.

Reduction of the gingival one third is straightforward and simply involves removal of the remaining “island” of unprepared tooth structure to a level consistent with the surrounding previously prepared tooth structure (see Fig. 12-39, **G** and **H**).

Incisal reduction is made by orienting the diamond perpendicular to the incisal edge and then reducing the incisal edge to attain a *minimum* reduction of 1 mm or, more desirably, 1.5 mm (see Fig. 12-39, **I**). Clinically, this reduction in depth will be gauged using an incisal reduction index. In this dentiform example, a minimum 1-mm incisal reduction depth was generated. Finally, round the facio-incisal line angle with the side of the diamond to reduce internal stresses in the porcelain veneer. The final intra-enamel preparation for an etched porcelain veneer using a butt-joint incisal edge design is seen in Figure 12-39, **J**.

Frequently, an incisal lapping preparation is preferred. If the patient has worn or defective areas on the lingual aspect

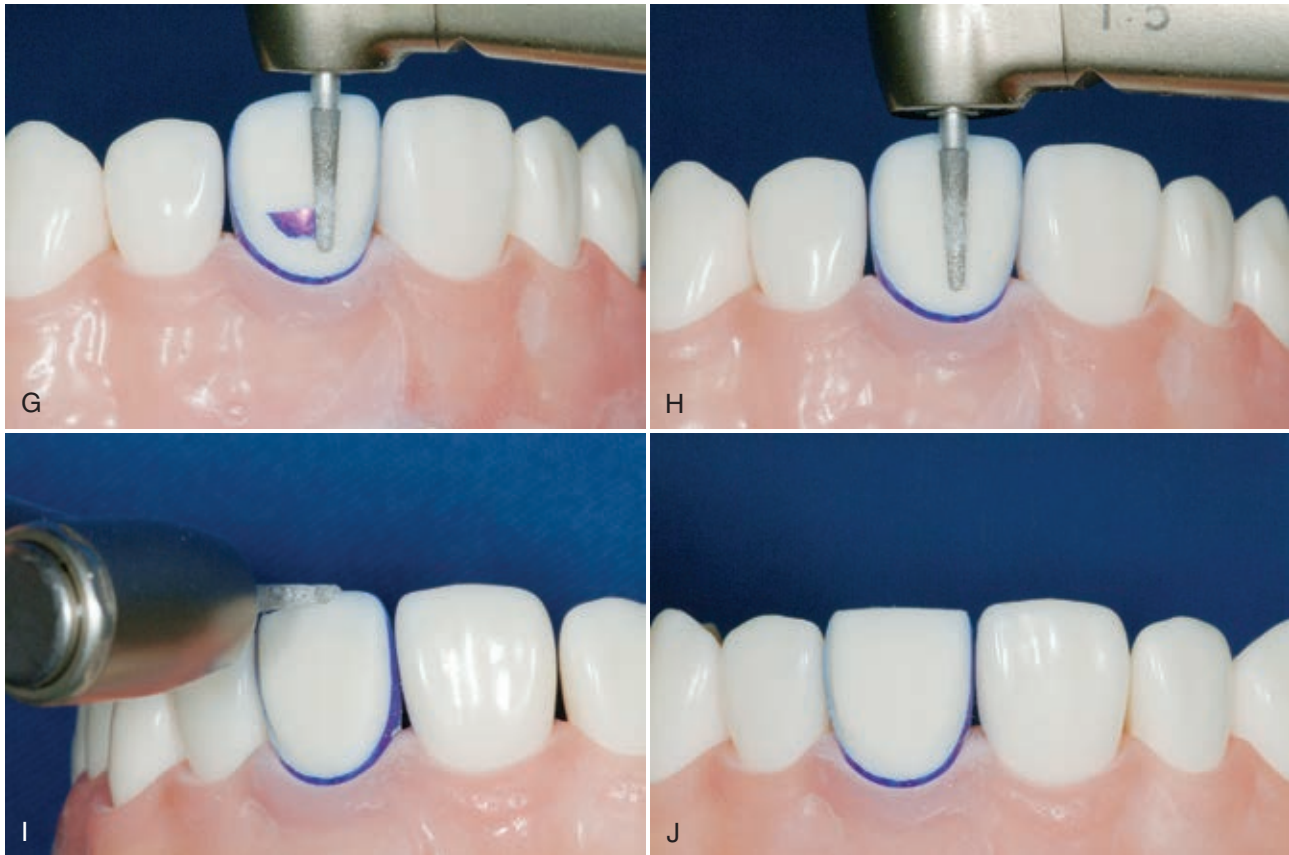


Fig. 12-39, cont'd I, Incisal reduction is attained. J, The completed intra-enamel preparation for an etched porcelain veneer with a butt-joint incisal edge.

of the incisal edge, this design is indicated. Some operators also prefer this design because of enhanced adaptation of the veneer to the lingual preparation margin attributable to a “lap sliding” fit.

The preparation steps for the incisal lapping preparation are identical to those for the butt-joint design, including the steps for incisal reduction. However, additional steps are required to attain the incisal lapping feature. The first step in achieving this preparation design is to notch the mesial and distal incisal angles. The tip of the same diamond instrument used for the earlier steps of the veneer preparation is used to establish these notches. Using the diamond, extend the notches completely through the incisal angles faciolingually to a depth incisogingivally consistent with the desired amount of lapping of the lingual surface (Fig. 12-40, A). For example, if a 0.5-mm lap of the lingual surface is desired, as in this example, the notches are prepared to a depth of 0.5 mm each accordingly (see Fig. 12-40, B).

Once the incisal notches have been generated incisogingivally to a depth consistent with the desired amount of lingual lapping, the preparation of the lingual lap is made. Position the diamond into the tooth to a depth of approximately 0.6 mm (less if remaining faciolingual thickness of the incisal edge enamel is compromised) and extend the preparation across the lingual surface from notch to notch (see Fig. 12-40, C). The resulting sharp incisal angles must then be rounded to finish the incisal lapping portion of the preparation. Care must be taken to include any desired lingual defect. The

gingival extent of the incisal lap is determined by the extent of any lingual defect. The final lapping portion of the preparation is seen in Figure 12-40, D. The facial view of the completed incisal lapping preparation with a lingual lap of 0.5 mm is seen in Figure 12-40, E.

CLINICAL PROCEDURES

The case of a patient with generalized fluorosis is used to illustrate the clinical procedures involved (Fig. 12-41, A). A consult appointment is always recommended prior to initiating the veneer procedures. At this appointment, the actual procedures are discussed in detail, appropriate consents are obtained, and any needed records are generated, including shade selection, intraoral photographs, and impressions for diagnostic models and occlusal records. Laboratory communications are greatly enhanced through the inclusion of digital photographs. An excellent series of baseline photographs, including some with shade tabs positioned in the photographic field to document the preoperative shapes and shades of the involved teeth, should be made.

Although intra-enamel preparations will be used, it is always recommended that patients be anesthetized during the appointment for tooth preparation to ensure maximum comfort for the patient and the dentist. Once the anesthetic is administered, preoperative records such as an incisal reduction index and those needed to facilitate temporization are made. An incisal reduction index is always recommended to accurately gauge the amount of incisal reduction during the



Fig. 12-40 Intra-enamel preparation steps for an etched porcelain veneer with an incisal-lapping design. **A** and **B**, Incisal notches. **C**, Preparing the lingual lapping portion of the prep. **D** and **E**, The completed intra-enamel preparation viewed from the lingual and facial aspects for an etched porcelain veneer with an incisal-lapping design.

preparation of teeth for etched porcelain veneers (Fig. 12-42; see also Fig. 12-41, *B* through *H*). An incisal reduction index is made by recording the lingual and incisal contours of the anterior teeth to be prepared or the contours generated in a diagnostic wax-up. Typically, a fast setting silicone or polyvinyl siloxane elastomeric material is used to generate this record. If a diagnostic model has been made in which the incisal edge positions of the final veneers will be different from the current teeth, the incisal reduction index should be made using the diagnostic model (see Fig. 12-42, *A* and *B*). As in this case, if no change in the incisal edge positions of the involved teeth is desired, the reduction index can be made directly in the patient's mouth by recording the existing contours of the

involved teeth. Once the facial excess has been trimmed away with a No. 12 surgical blade in a Bard-Parker handle, the incisal reduction index should be tried in the mouth to verify the accuracy of the index (see Fig. 12-41, *B*).

The patient in this case has a high smile line and generalized defects that involve the entire facial surfaces of anterior teeth. Therefore, a small diameter gingival retraction cord is placed in anticipation of veneer margins that will be placed at the level of the free gingival margins (see Fig. 12-41, *C*).

Incisal lapping preparations for porcelain veneers are made on the maxillary central and lateral incisors consistent with the systematic step-by-step preparation procedures described earlier. The intra-enamel preparations are made with a tapered,



Fig. 12-41 Etched porcelain veneers using an intra-enamel preparation. **A**, A patient with severe dental fluorosis. **B**, An incisal reduction index is made intraorally, since no significant change in incisal edge position is desired. **C**, Retraction cord is placed. **D**, The outline form is first established. **E-G**, Facial reduction is attained by using three zones of facial reduction. **H**, Incisal reduction is verified using the incisal reduction index.

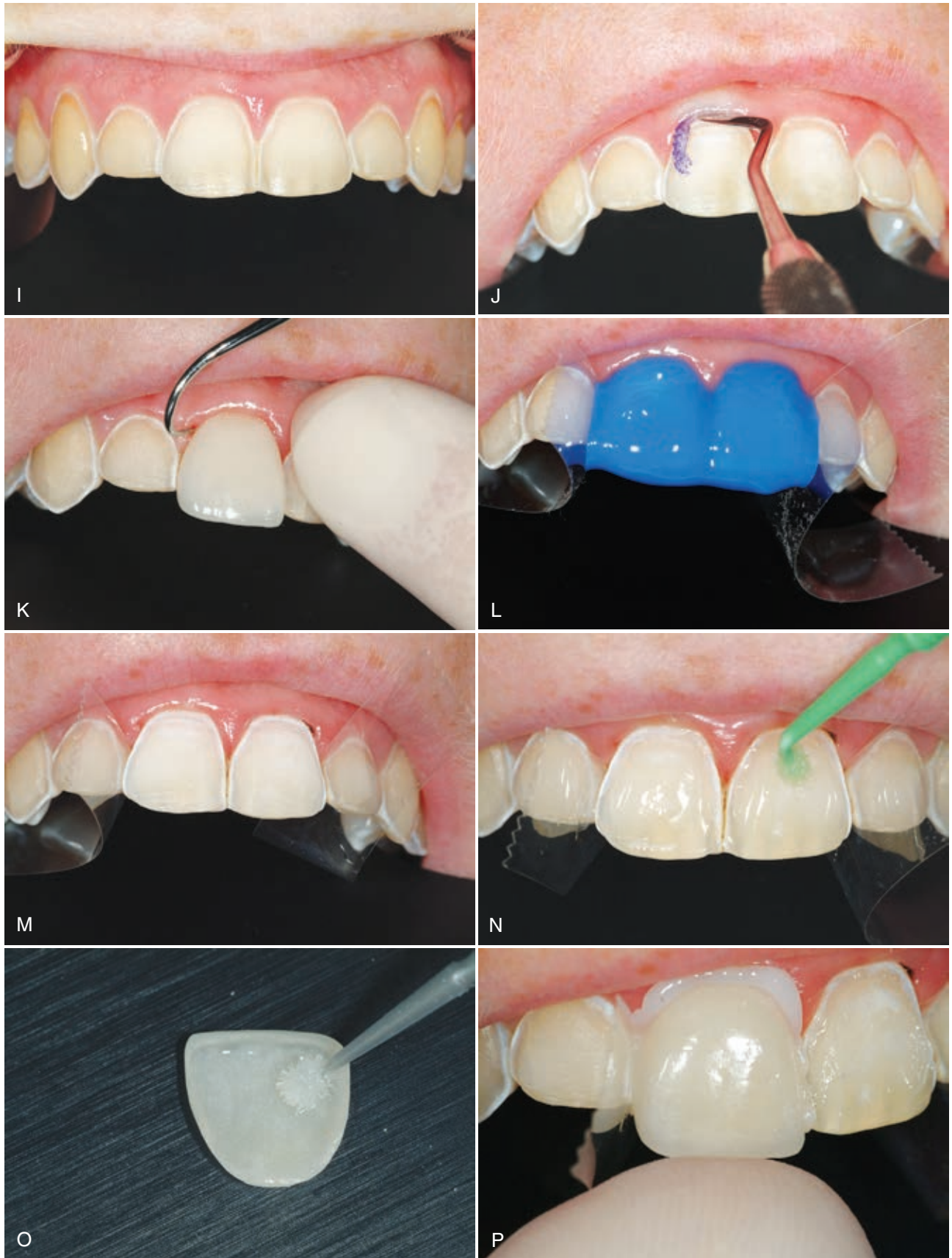


Fig. 12-41, cont'd **I**, Finished preparations for intra-enamel preparations. Note the window preparations on canines and premolars. **J**, Retraction cord is placed for isolation. **K**, The fit of the veneer is assessed. **L** and **M**, Etching of the prepared maxillary central incisors. **N** and **O**, Adhesive is applied to the etched enamel and the tooth side of the porcelain veneer. **P**, The veneer is loaded with resin cement and seated on the tooth.



Fig. 12-41, cont'd **Q**, Excess cement is removed with a microbrush. **R**, Excess cement is removed interproximally through removal of polyester strip. **S**, Resin cement cured with intense curing light. **T**, No. 12 surgical blade in a Bard-Parker handle is used for removing excess cured resin cement. **U** and **V**, Diamond instruments used to “dress” marginal areas. **W** and **X**, 30-fluted carbide burs and diamond impregnated polishing instruments used to finish and polish veneer margins.



Fig. 12-41, cont'd Y and Z, Finished etched porcelain veneers as viewed from the lingual and facial aspects.



Fig. 12-42 Incisal reduction index made from a diagnostic model. A and B, A fast-set elastomeric material is used to record the lingual and incisal contours of the diagnostic model. C, Incisal reduction index is used to verify proper incisal preparation of teeth. D, Finished etched porcelain veneers.

rounded-end diamond instrument to a depth of approximately 0.5 to 0.75 mm midfacially, diminishing to a depth of 0.3 to 0.5 mm along the gingival margins, depending on enamel thickness. The outline form is first established as noted earlier (see Fig. 12-41, D). Facial reduction is attained by using three zones of facial reduction as previously described (see Fig. 12-41, E through G). Veneer interproximal margins should extend into the facial and gingival embrasures, without engaging an undercut, and yet should be located just facial to the proximal contacts.

Since this patient is young with beautifully shaped canines and also exhibits a canine-guided occlusion, a window type of preparation design was employed when preparing the maxillary canines. By restricting the window prep veneers to the facial surface entirely, functional contact will be maintained solely on tooth structure, thereby preventing accelerated wear of opposing teeth. Adequate incisal reduction is verified using the incisal reduction index as noted earlier (see Fig. 12-41, H). The finished preparations are shown in Figure 12-41, I.

After the preparations are completed, an elastomeric impression is made and appropriate occlusal records generated. Digital photos of the prepared teeth (with and without appropriate shade tabs in the photographic field) also are recommended. In most cases, temporaries are fabricated for the prepared teeth, as described in the subsequent section on temporization (see Veneer Temporization). If a diagnostic wax-up was generated, veneer temporaries are necessary to assess the tooth contours generated in the wax-up intraorally. If no diagnostic wax-up was needed, occasionally, temporary restorations are not required, if the patient consents, because the preparations are shallow and involve only enamel. In these cases, the patient should be instructed to avoid biting hard foods, objects, keep the areas clean with a soft bristled brush, and expect the possibility of some mild sensitivity to hot and cold. It should be noted that the vast majority of veneer cases will warrant temporization.

After they have been fabricated in the laboratory, the porcelain veneers are returned to the dentist for cementation at the second appointment. The completed veneers must be inspected for cracks, overextended margins, and adequate internal etching (as evidenced by a frosted appearance). Marginal areas, in particular, should be inspected for proper etching so that an adequate seal occurs in these areas. Overextended marginal areas interproximally may preclude full seating of adjacent veneers. These areas can be trimmed carefully with a micron-finishing diamond instrument or flexible abrasive disk. Unless severe or inaccessible, most minor overextensions should be trimmed only after bonding the veneer to the tooth because of the risk of fracturing the porcelain.

After the prepared teeth are cleaned with a pumice slurry, rinsed, and dried, isolation is accomplished with a lip retractor (optional) and cotton rolls. A 2 × 2 inch cotton gauze is placed across the back of the patient's mouth to protect against aspiration or swallowing of an inadvertently dropped veneer. If the veneer margins closely approximate the gingiva, a small diameter retraction cord should be placed in the gingival crevice during try-in and cementation to prevent inadvertent contamination of the bonds from crevicular fluids (see Fig. 12-41, J).

The fit of each veneer is evaluated on the respective individual tooth and adjusted if necessary. A No. 2 explorer should be used to assess marginal fit (see Fig. 12-41, K). All of the veneers should be tried in place not only individually but also in adjacent pairs to ensure the fit of adjacent seated veneers. Veneers should be tried in place only on clean, dry teeth to eliminate any potential for contamination. If accidental contamination occurs, the veneer should be cleaned thoroughly with alcohol or acid etchant, rinsed, and dried before bonding.

Prior to cementation, a silane agent can optionally be applied to the internal surfaces of the veneers. The silane acts as a coupling agent, forming a chemical bond between the porcelain and the resin that increases bond strength of the resin to the porcelain.⁴² It also improves the wettability of the porcelain. The primary source of retention with porcelain veneers still remains the etched porcelain surface itself. Only a modest increase in bond strength results from silanation of the porcelain; however, it is recommended because it also may reduce marginal leakage and discoloration.

A light-cured resin cement is recommended for bonding the veneer to the tooth because light-cured resins are more color stable and provide additional working time over the

self-cured or dual-cured versions. Shade selection of the bonding medium is determined after the fit of the individual veneers has been evaluated and confirmed. Water can be used as an optical medium for try-in to assess the appearance of the veneers. With this technique, water is placed in a single central incisor veneer (or both central incisor veneers), placed on clean, dry teeth, and the appearance assessed. If the veneers are deemed acceptable in appearance, an untinted shade of the bonding resin is indicated. For the vast majority of etched porcelain veneers, an untinted shade of the bonding resin is recommended. Because etched porcelain veneers can be fabricated with inherent color gradients, characterizations and even additional opaques when further masking of stains is needed, it is unusual that alternative shades or opaque resin bonding media are needed. Nonetheless, alternative shades or opaque versions of resin bonding cements are sometimes preferred by some dentists.

If alternative shades of resin cements are needed, shade selection is made by first placing a uniform layer of a selected shade of resin cement, approximately 0.5 mm in thickness, on the tooth side of a single veneer. Typically, a central incisor veneer is used to facilitate shade determination of the cement. The operatory light is turned away during shade assessment to prevent premature and inadvertent curing of the resin cement. The veneer is seated on a clean, dry, unetched tooth; the excess resin cement is removed with a brush; and the overall shade of the veneer is evaluated. After try-in, the veneer is removed quickly and stored in a container that is impervious to light to prevent curing of the cement. If the shade of the cement is determined to be appropriate, more of the same shade is added to the veneer just before bonding. If a different shade is deemed necessary, the existing shade is wiped from the inner aspect of the veneer with a disposable microbrush, and a new shade of resin cement is placed in the veneer. In the meantime, the assistant can remove residual cement of the previous shade from the tooth with a cotton pellet or brush. The veneer loaded with the new shade of cement is reseated and evaluated, as previously described.

Water-soluble try-in pastes that correspond to the same shades of resin cements also are available with many veneer bonding kits. These try-in pastes allow shade assessment without the risk of inadvertent premature curing of the cement because the try-in pastes are not capable of setting. However, after the try-in process with these try-in pastes, the veneers must be thoroughly cleaned, according to the manufacturer's instructions, to ensure that optimal bonding occurs. A light-cured resin cement of the same shade is used for final cementation.

The inherent shade of the veneer, characterization, and internal opaquing must be accomplished primarily during the fabrication of the veneer itself in the laboratory. Some additional masking can be accomplished chairside using an opaque resin-bonding medium at the time of bonding. However, excess use of opaque bonding resins also can reduce the "esthetic vitality" of the veneer, resulting in a poor esthetic outcome. Also, the overall shade of the veneer can be modified only slightly by the shade of cement selected. Significant changes in shading or masking ability cannot be accomplished chairside.

Prior to cementation of the veneers, the retraction cords are evaluated to ensure that they are tucked adequately into the gingival crevice. The tooth used for try-in to assess the shade

of the resin bonding medium should be cleaned again with a slurry of pumice to remove any residual resin or try-in paste that may preclude proper acid etching of the enamel.

A technique recommended for applying the veneers one at a time is presented here. Polyester strips are placed interproximally to prevent inadvertent bonding to the adjacent tooth, followed by etching, rinsing, and drying procedures. It is recommended that the two central incisors be etched and their veneers bonded first because of their critical importance esthetically. Etch the teeth to be bonded with a 35% to 37% phosphoric acid gel (see Fig. 12-41, *L*). Following etching, rinsing, and drying, the preparations should exhibit a frosted appearance as evidence of an appropriately etched enamel surface (see Fig. 12-41, *M*). An adhesive is applied to the etched enamel and the tooth side of the silane-primed porcelain veneer (see Fig. 12-41, *N* and *O*). Next, a thin layer (0.5 mm) of the selected shade of light-cured resin cement is placed on the tooth side of the veneer, taking care not to entrap air. The first veneer is placed on the tooth and vibrated (carefully and lightly) into position with a blunt instrument or light finger pressure (see Fig. 12-41, *P*). The margins of the veneer are examined with a No. 2 explorer to verify accurate seating. Next, the excess resin cement is removed with a disposable microbrush, always directing the microbrush in a gingival direction to prevent displacement of the veneer (see Fig. 12-41, *Q*). The second veneer is placed and cleaned of excess cement in like manner. If a veneer cement with thick viscosity is used, the polyester strips can be carefully removed to facilitate removal of interproximal resin prior to curing (see Fig. 12-41, *R*). However, the resin cement should be cured only after visual inspection reveals no excess resin remains in these critical interproximal areas.

Veneer margins are evaluated again before the veneer is exposed to the curing light. To ensure complete polymerization, the veneer should be cured for a minimum of 20 to 40 seconds each from the facial and lingual directions with a high-intensity blue LED (light-emitting diode) light (see Fig. 12-41, *S*). A light stream of air can be directed on the tooth during the curing sequence to prevent overheating from the curing light. After positioning and bonding of the first two veneers on the central incisors, the remaining veneers can be positioned carefully and bonded in like manner. Following proper positioning and bonding of all the veneers, any residual resin cement can be removed. A No. 12 surgical blade in a Bard-Parker handle is ideal for removing excess cured resin cement remaining around the margins (see Fig. 12-41, *T*). Care must be exercised to ensure that the surgical blade is used only with a secure finger rest and using short shaving strokes, always directed parallel to the veneer margins. Removal of the

retraction cord at this time facilitates access and visibility to the subgingival areas. If the marginal fit of the porcelain veneers is deemed acceptable and a favorable emergence profile exists, only removal of the excess cement is required.

If the porcelain margins are overextended beyond the cavo-surface angles, an overhang is present, or the marginal areas are too bulbous, recontouring of these areas is required (especially along the gingival margins) to ensure proper physiologic contours and gingival health. A flame-shaped fine diamond instrument is used to carefully recontour and “dress” these areas (see Fig. 12-41, *U*). Marginal areas should be confluent with the surrounding unprepared tooth surfaces when assessed with a No. 2 explorer. The lingual areas are always finished with an oval-shaped fine diamond instrument (see Fig. 12-41, *V*). Because the use of a diamond instrument breaks the glazed surface, a series of appropriate instruments is used to restore a smooth surface texture. First, a rounded end or bullet-shaped (or oval for lingual surfaces), 30-fluted carbide finishing bur (Midwest No. 9803 or Brasseler No. 7801) is used to plane the porcelain surface and to remove the striations created by the diamond instruments (see Fig. 12-41, *W*). Studies show that the best results occur if the diamond instruments are used with air and water coolant, whereas the 30-fluted bur should be used dry.⁴³ Second, the porcelain is smoothed and polished with a series of abrasive rubber, porcelain polishing cups, and points (Dialite Porcelain Polishing Kit; Brasseler USA, Savannah, GA) (see Fig. 12-41, *X*). Final surface luster is imparted by using a porcelain-polishing paste, applied with either a rubber Prophyl cup or a felt wheel. This step is optional if a suitable polish has been attained with the polishing points and cups. The completed veneers are shown from incisal and facial views in Figure 12-41, *Y* and *Z*.

Etched porcelain veneers also can be used effectively to restore malformed anterior teeth conservatively. Malformed lateral incisors are shown in Figure 12-43, *A*. Incisal, lapping preparations that are extended well onto the lingual surface are used (see Fig. 12-43, *B*). The resulting restorations are virtually comparable with “three-quarter crowns” in porcelain. The final esthetic results are shown in Figure 12-43, *C*.

Darkly discolored teeth are more difficult to treat with porcelain veneers. Several modifications in the veneering technique can be used to enhance the final esthetic result. First, opaque porcelain can be incorporated during the fabrication of the veneers to achieve more inherent masking. If the veneers are not inherently opaque, little chance exists for adequate masking of a darkly stained tooth. Typically, 5% to 15% opaque porcelain is required to achieve optimal masking. Exceeding 15% opaque porcelain dramatically reduces light penetration and results in a significant loss of esthetic vitality;



Fig. 12-43 Treatment of malformed teeth with porcelain veneers. **A**, Malformed lateral incisors. **B**, An incisal-lapping preparation similar to a three-quarters crown in enamel is used. **C**, Final esthetic results.

the esthetic vitality or the realistic appearance of teeth depends on light penetration (see the section on Artistic Elements, Translucency). Second, a slightly deeper tooth preparation can be used to allow greater veneer thickness. The preparation should always be restricted to enamel, however, to ensure optimal bonding of the veneer to the tooth. Even with improved dentin-bonding agents, the bonds to dentin are less predictable or durable than the bonds to enamel because of the high variability and dynamic nature of dentin. Bonds to etched enamel are highly predictable and very durable.

Third, the laboratory can be instructed to use several coats of a die-spacing medium on the laboratory model to allow a slightly greater thickness of the resin-bonding medium. The die-spacing medium must not be extended closer than 1 mm to the margins to ensure adequate positioning of the veneer to the preparation during try-in and bonding and to provide for a slight internal space. A typical case of darkly discolored teeth showing prepared teeth and postoperative result is shown in Figure 12-44.

Patients who have darkly stained teeth always should be informed that although porcelain (or composite) veneers can result in improved esthetics, they may not entirely eliminate or mask extremely dark stains. Because of the limited thickness of the veneers and the absolute necessity of incorporating intrinsic opacity, the realistic translucency or esthetic vitality of veneered teeth may never be comparable with that of natural, unaffected teeth (see Fig. 12-9). Full porcelain coverage with all-ceramic crowns may be indicated in some

patients with severe discoloration because of the crown's greater capacity to restore esthetic vitality. Nonetheless, porcelain veneers are a viable option, in most cases, for patients who desire esthetic improvement without significant tooth reduction.

Pressed Ceramic Veneers

Another esthetic alternative for veneering teeth is the use of pressed ceramics (e.g., IPS Empress or e.max [Ivoclar Vivadent]). In contrast to etched porcelain veneers that are fabricated by stacking and firing feldspathic porcelain, pressed ceramic veneers are literally cast using a lost wax technique. Excellent esthetics is possible using pressed ceramic materials for most cases involving mild to moderate discoloration. Because of the more translucent nature of pressed ceramic veneers, however, dark discolorations are best treated with etched porcelain veneers. The clinical technique for placing pressed ceramic veneers (e.g., IPS Empress) is not markedly different from that for feldspathic porcelain veneers, other than the need for a slightly greater tooth reduction depth.

The procedures for tooth preparation, try-in, and bonding of pressed veneers are the same as for etched porcelain veneers except that the marginal fit is superior. For that reason, often little marginal finishing is necessary. Only the excess bonding medium needs to be removed. A typical case involving pressed ceramic veneers, with before and after treatment views, is shown in Figure 12-45.

Fig. 12-44 Darkly stained teeth treated with porcelain veneers. **A**, Tetracycline-stained teeth seen after preparation for porcelain veneers. **B**, After view of completed veneers.

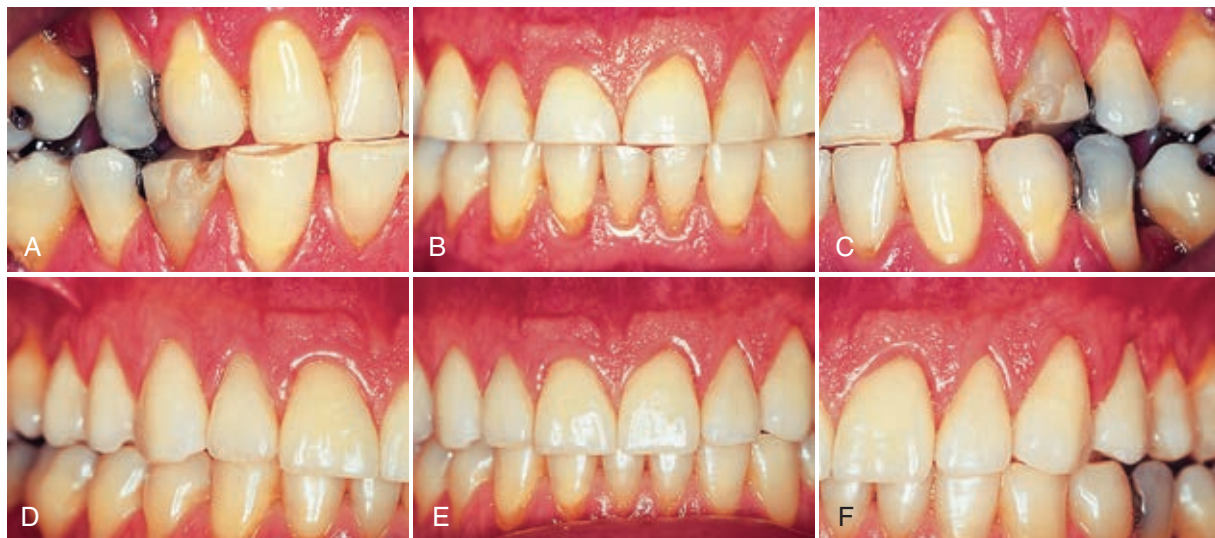


Fig. 12-45 Pressed ceramic veneers (IPS Empress). **A-C**, Before treatment, facial views. **D-F**, Esthetic result after completed veneers. (Courtesy of Dr. Luiz N. Baratieri.)

Veneers Temporization

Because intra-enamel preparations for etched porcelain veneers are by design very conservative, the resulting temporaries are inherently thin. Furthermore, they cannot be bonded in a similar manner to conventional temporaries for crowns, for example, because of the lack of inherent retention form. Moreover, since they are very thin, they cannot be made in the mouth and removed for trimming and subsequent cementing because of the high probability of fracture. Therefore, veneers temporaries must be made and placed simultaneously intraorally.

Figure 12-46 illustrates a typical case involving the fabrication of temporaries for etched porcelain veneers for maxillary

anterior teeth. A clear polyvinyl siloxane material is used to make the preoperative impression from which the temporaries will be made. If no diagnostic model is needed and the existing contours of the teeth are to be replicated, the impression for the temporaries is made directly in the mouth. However, as in this case, if a diagnostic wax-up was generated (see Fig. 12-46, *A and B*), the clear polyvinyl siloxane impression is made from this diagnostic model. Making the temporary from this diagnostic wax-up enables the clinician to see the contours of the wax-up manifested intraorally in the resulting temporaries. As seen in Figure 12-46, *C*, the impression itself is removed from the outer tray (no tray adhesive is used) and set aside for future use.



Fig. 12-46 Temporization for etched porcelain veneers. **A and B**, Diagnostic models in anticipation of etched porcelain veneers. **C**, Clear polyvinyl siloxane (PVS) impression made from diagnostic model. **D–F**, Spot-etched areas for retention of temporary veneers.



Fig. 12-46, cont'd **G** and **H**, Clear PVS impression is quickly loaded with bis-acryl temporary material, and positioned in the mouth. **I** and **J**, Impression is removed, and No. 12 blade in a Bard-Parker surgical handle is used to remove excess material. **K**, Glazing agent placed and cured. **L** and **M**, Final facial and lingual views of veneer temporaries.

Following the preparation and impression of the teeth for porcelain veneers, the teeth to be temporized are “spot-etched” with 35% to 37% phosphoric acid. Only a 2-mm circle of enamel should be etched on the facial surface of each tooth to be veneered (see Fig. 12-46, *D* and *E*). Because of the low viscosity of the bis-acryl temporary material, no bonding agent is required for bonding. The bis-acryl material will infiltrate the etched areas for micromechanical bonding. These “spot-etched” areas will be the only areas to which the veneer temporaries will be bonded. If the entire tooth were etched, the veneer temporaries could not be readily removed. After “spot etching,” only small etched circles evidenced by a frosted

appearance should be present on the surface of each prepared tooth (see Fig. 12-46, *F*).

The etched teeth must be kept clean and dry at this point. The clear polyvinyl siloxane impression is quickly loaded with a self-curing bis-acryl temporary material and thereafter is immediately positioned in the mouth (see Fig. 12-46, *G* and *H*). Once seated, finger pressure is applied to the peripheral areas of the flexible impression (since no outer hard tray is present) to express the excess material and “thin out” the resulting resin “flash.”

When the bis-acryl temporary material has set, the clear impression is removed (see Fig. 12-46, *I*). The gross excess



Fig. 12-46, cont'd N and O, At delivery appointment, temporary veneers are removed with Black's spoon, and the spot-etched and bonded areas are relieved with a diamond.

“flash” material facially and lingually is removed with cotton pliers. Thereafter, a No. 12 blade held in a Bard-Parker surgical handle is used to *carefully* trim the excess temporary material around the margins of each tooth (see Fig. 12-46, J). The same No. 12 blade is used to carefully trim excess material in the gingival embrasure areas as well.

A sharp large discoid applied parallel to the lingual margins is used to remove resin “flash” in the lingual concave areas. The temporary veneers are all joined together interproximally, increasing their collective strength and enhancing retention. A light-cured resin glazing agent is applied and cured to generate a smooth surface texture (see Fig. 12-46, K). Final views of the finished temporaries are seen in Figure 12-46, L and M.

Appropriate adjustments can then be made intraorally in the temporaries to optimize occlusion and esthetics. A digital photograph of the final temporaries should be shared with the laboratory as a template for the final veneers. Patients must be instructed that they should not bite anything of any substance because of the weak nature of these veneers. These provisional veneers literally are more to accommodate esthetics and not function during the interim time until delivery of the final veneers.

As demonstrated in a different case, once the patient returns for the final try-in and cementation of the veneers, the temporaries are carefully removed by prying them from each tooth using a Black's spoon (see Fig. 12-46, N). The temporaries can readily be removed, since the only area where they

actually are bonded to the tooth is the very small “spot-etched” 2-mm circle on the facial surface of each prepared tooth. Once the veneer temporaries are removed, the areas that had been “spot-etched” and bonded need to be lightly resurfaced with a flame-shaped diamond to ensure no residual resin bonding agent is present that could preclude proper seating and bonding of the final veneers (see Fig. 12-46, O).

Veneers for Metal Restorations

Esthetic inserts (i.e., partial or full veneers) of a tooth-colored material can be placed on the facial surface of a tooth previously restored with a metal restoration. For new castings, plans are made at the time of tooth preparation and during laboratory development of the wax pattern to incorporate a veneer into the cast restoration. After such a casting has been cemented, the veneer can be inserted, as described in the next section, except that the portion of mechanical retention of the veneer into the casting has been provided in the wax pattern stage.

Veneers for Existing Metal Restorations

Occasionally, the facial portion of an existing metal restoration (amalgam or gold) is judged to be distracting (Fig. 12-47, A). A careful examination, including a radiograph, is required to determine that the existing restoration is sound before an

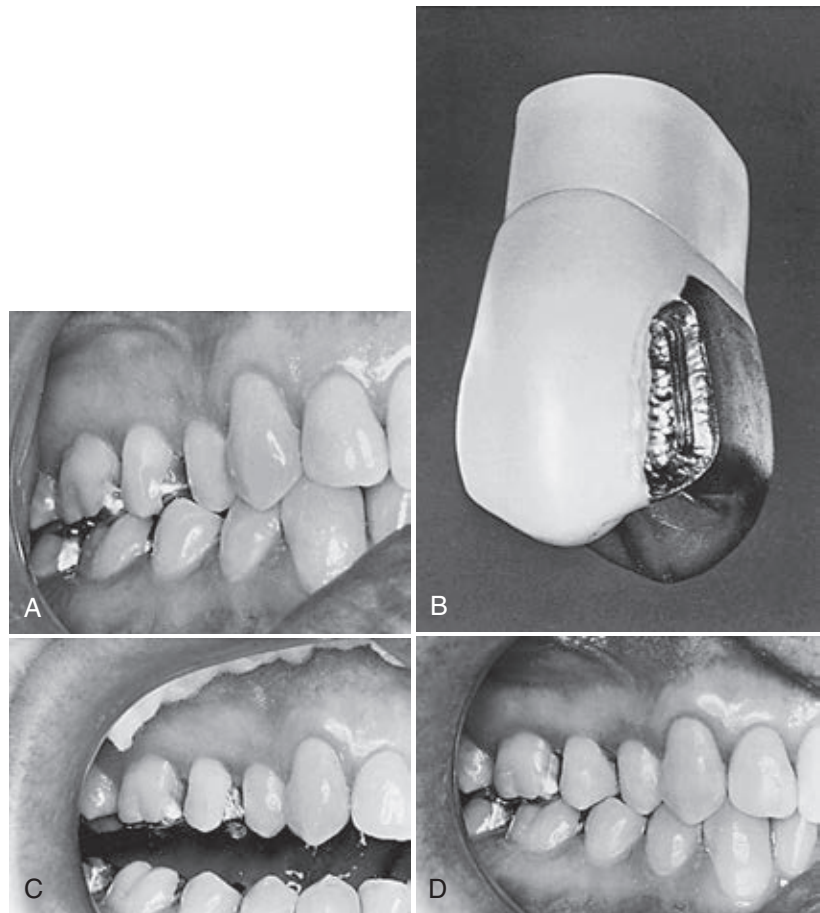


Fig. 12-47 Veneer for existing cast restoration. **A**, Mesiofacial portion of onlay is distracting to patient. **B**, Model of tooth and preparation. Note 90-degree cavosurface angle and retention prepared in gold and the cavosurface bevel in enamel. **C**, Clinical preparation ready for composite resin. **D**, Completed restoration.

esthetic correction is made. The size of the unesthetic area determines the extent of the preparation. Anesthesia is not usually required because the preparation is in metal and enamel. Preliminary procedures consist of cleaning the area with pumice, selecting the shade, and isolating the site with a cotton roll. When the unesthetic metal extends subgingivally, the level of the gingival tissue is marked on the restoration with a sharp explorer, and a retraction cord is placed in the gingival crevice. Rubber dam isolation may be required in some instances.

A No. 2 carbide bur rotating at high speed with an air-water spray is used to remove the metal, starting at a point midway between the gingival and occlusal margins. The preparation is made perpendicular to the surface (a minimum of approximately 1 mm in depth), leaving a butt joint at the cavosurface margins. The 1-mm depth and butt joint should be maintained as the preparation is extended occlusally. All of the metal along the facial enamel is removed, and the preparation is extended into the facial and occlusal embrasures just enough for the veneer to hide the metal. The contact areas on the proximal or occlusal surfaces must not be included in the preparation. To complete the outline form, the preparation is extended gingivally approximately 1 mm past the mark indicating the clinical level of the gingival tissue.

The final preparation should have the same features as those described for veneers in new cast restorations. Mechanical retention is placed in the gingival area with a No. 1/4 carbide bur (using air coolant to enhance vision) 0.25 mm

deep along the gingivoaxial and linguoaxial angles. Retention and esthetics are enhanced by beveling the enamel cavosurface margin (approximately 0.5 mm wide) with a coarse, flame-shaped diamond instrument oriented at 45 degrees to the external tooth surface (see Fig. 12-47, B). After it is etched, rinsed, and dried, the preparation is complete (see Fig. 12-47, C). Adhesive resin liners containing 4-methoxy ethyl trimellitic anhydride (4-META), capable of bonding composite to metal, also may be used but are quite technique sensitive.⁴⁴ Manufacturers' instructions should be followed strictly to ensure optimal results with these materials. The composite material is inserted and finished in the usual manner (see Fig. 12-47, D).

Repairs of Veneers

Failures of esthetic veneers occur because of breakage, discoloration, or wear. Consideration should be given to conservative repairs of veneers if the examination reveals that the remaining tooth and restoration are sound. It is not always necessary to remove all of the old restoration. The material most commonly used for making repairs is light-cured composite.

Veneers on Tooth Structure

Small chipped areas on veneers often can be corrected by recontouring and polishing. When a sizable area is broken, it

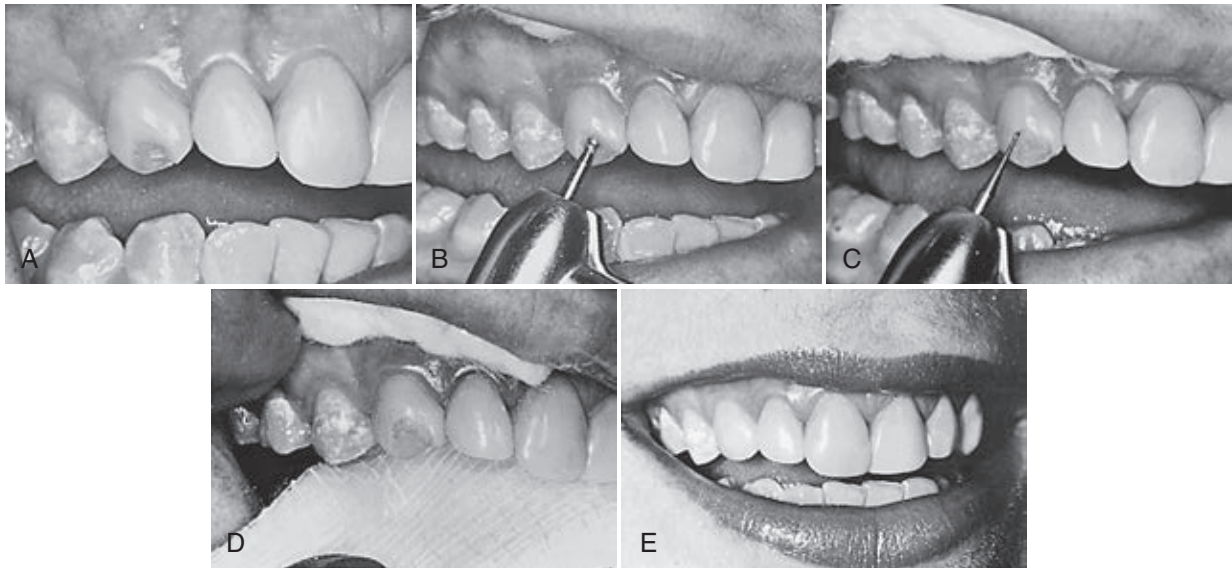


Fig. 12-48 Repairing a direct composite veneer. **A**, Fractured veneer on the maxillary canine. **B**, Preparation with rounded-end diamond instrument. **C**, Undercuts placed in existing veneer with a No. 1/4 bur. **D**, Completed preparation is shown isolated and etched. **E**, Veneer restored to original color and contour.

usually can be repaired if the remaining portion is sound (Fig. 12-48, A). For direct composite veneers, repairs ideally should be made with the same material that was used originally. After cleaning the area and selecting the shade, the operator should roughen the damaged surface of the veneer or tooth or both with a coarse, tapered, rounded-end diamond instrument to form a chamfered cavosurface margin (see Fig. 12-48, B). Roughening with micro-etching (i.e., sandblasting) also is effective. For more positive retention, mechanical locks may be placed in the remaining composite material with a small, round bur (see Fig. 12-48, C). Acid etchant is applied to clean the prepared area and to etch any exposed enamel, which is then rinsed and dried (see Fig. 12-48, D). Next, an adhesive is applied to the preparation (i.e., existing composite and enamel) and polymerized. Composite is added, cured, and finished in the usual manner (see Fig. 12-48, E).

To repair porcelain veneers, a hydrofluoric acid gel, suitable for intraoral use (but only with a rubber dam in place), must be used to etch the fractured porcelain. Hydrofluoric acid gels are available in approximately 10% buffered concentrations that can be used for intraoral porcelain repairs if proper isolation with a rubber dam is used. Although caution still must be taken when using hydrofluoric acid gels intraorally, the lower acid concentration allows for relatively safe intraoral use. Full-strength hydrofluoric acid should *never* be used intraorally for etching porcelain. Isolation of the porcelain veneer to be repaired should always be accomplished with a rubber dam to protect gingival tissue from the irritating effects of the hydrofluoric acid. The manufacturer's instructions must be followed regarding application time for the hydrofluoric acid gel to ensure optimal porcelain etching. A lightly frosted appearance, similar to that of etched enamel, should be seen if the porcelain has been properly etched. A silane coupling agent may be applied to the etched porcelain surface before the adhesive is applied. Composite material is added, cured, and finished in the usual manner. Large fractures are best treated by replacing the entire porcelain veneer.

Acknowledgments

Portions of the section on artistic elements were reprinted with permission from Heymann HO: *The artistry of conservative esthetic dentistry*, *J Am Dent Assoc* 115(12E; special issue):14, 1987.

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Introduction to Amalgam Restorations

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Amalgam

Dental amalgam is a metallic restorative material composed of a mixture of silver–tin–copper alloy and mercury. The unset mixture is pressed (condensed) into a specifically prepared undercut tooth form and contoured to restore the tooth's form and function. When the material hardens, the tooth is functional again, restored with a silver-colored restoration (Fig. 13-1). Dental amalgam is described in detail in Online Chapter 18. In this book, dental amalgam is referred to as *amalgam*. Amalgam has been the primary direct restorative material for more than 150 years in the United States. It has been the subject of intense research and has been found to be safe and beneficial as a direct restorative material.¹⁻³ Many people have benefited from amalgam restorations, which restore a tooth in the most cost-effective manner. The U.S. Public Health Service stated, “In fact, hundreds of millions of teeth have been retained that otherwise would have been sacrificed because restorative alternatives would have been too expensive for many people.”⁴

In addition to being cost-effective, amalgam is the most user-friendly direct restorative material. This is a result of a mechanism that ensures self-sealing of the amalgam to the prepared cavity walls. This quality occurs as a result of percolation of oral fluids between the amalgam and the tooth, which results in corrosion and the buildup of corrosion products in the microscopic interface. The corrosion products self-seal the restoration and reduce microleakage. This process is self-limiting and takes about 2 months.

History

Amalgam was introduced to the United States in the 1830s. Initially, amalgam restorations were made by dentists filing silver coins and mixing the filings with mercury, creating a putty-like mass that was placed into the defective tooth. As knowledge increased and research intensified, major advancements in the formulation and use of amalgam occurred. Concerns about mercury toxicity in the use of amalgam were, however, expressed in many countries; concerns reached major proportions in the early 1990s. The American Dental

Association (ADA) and the U.S. Public Health Service have issued many statements expressing their support for the use and safety of amalgam as a restorative material.^{1,4}

Current Status

Today, the popularity of amalgam as a direct restorative material has decreased.^{5,6} This decline is attributed, in part, to the reduction in caries rates and to esthetic concerns. However, the primary cause of the reduction in the use of amalgam is the recognition of the benefits and improved esthetics of composite as a restorative material. Thus, concerns about the use of amalgam restorations relate primarily to poor esthetics and the greater potential for the weakening of the tooth structure: Dental amalgams inherently require greater removal of tooth structure to accommodate its strength requirements.

Because of environmental concerns about mercury contamination, the use of amalgam as a restorative material already has decreased in many countries. Legislation restricting and, in some cases, phasing out the use of amalgam has been implemented in Japan, Denmark, Canada, Sweden, and Germany.

Even with the concern about the disposal of mercury, this textbook advocates the continued use of amalgam as a direct restorative material, especially in light of the finding that bonded composite resin restorations have an increased risk of development of secondary caries.^{7,8} Research repeatedly has shown the safety of amalgam and the success of restorations made from amalgam. Although the scope of the clinical uses of amalgam presented in this book are narrower than in the past, amalgam still is recognized as an excellent material for restoring many defects in teeth.

Types of Amalgam Restorative Materials

Low-Copper Amalgam

Low-copper amalgams were prominent before the early 1960s. When the setting reaction occurred, the material was subject to corrosion because a tin–mercury phase (γ -two) formed. This corrosion led to the rapid breakdown of amalgam restorations. Subsequent research for improving amalgam led



Fig. 13-1 Clinical example of an amalgam restoration. (From Hatrick CD, Eakle WS, Bird WF: *Dental materials: Clinical applications for dental assistants and dental hygienists*, ed 2, St. Louis, Saunders, 2011.)

to the development of high-copper amalgam materials. Low-copper amalgams are used very seldom in the United States.

High-Copper Amalgam

High-copper amalgams are the materials predominantly used today in the United States. In this book, unless otherwise specified, the term *amalgam* refers to high-copper dental amalgam. The increase in copper content to 12% or greater designates an amalgam as a high-copper type. The advantage of the added copper is that it preferentially reacts with the tin and reduces the formation of the more corrosive phase (gamma-two) within the amalgam mass. This change in composition reduces possible deleterious corrosion effects on the restoration. However, enough corrosion occurs at the amalgam–tooth interface to result in the successful sealing of the restoration.^{9,10} These materials can provide satisfactory performance for more than 12 years.^{11,12} High-copper materials can be either spherical or admixed in the composition.

Spherical Amalgam

A spherical amalgam contains small, round alloy particles that are mixed with mercury to form the mass that is placed into the tooth preparation. Because of the shape of the particles, the material is condensed into the tooth preparation with little condensation pressure. This advantage is combined with its high early strength to provide a material that is well suited for very large amalgam restorations such as complex amalgams or foundations.¹³

Admixed Amalgam

An admixed amalgam contains irregularly shaped and sized alloy particles, sometimes combined with spherical shapes,

which are mixed to form the mass that is placed into the tooth preparation. The irregular shape of many of the particles makes a mass that requires more condensation pressure (which many dentists prefer) and permits this heavier condensation pressure to assist in displacing matrix bands to generate proximal contacts more easily.

New Amalgam Alloys

Because of the concern about mercury toxicity, many new compositions of amalgam are being promoted as mercury-free or low-mercury amalgam restorative materials. Alloys with gallium or indium or alloys using cold-welding techniques are presented as alternatives to mercury-containing amalgams. None of these new alloys shows sufficient promise to become a universal replacement for current amalgam materials.¹⁴⁻¹⁶

Important Properties

The linear coefficient of the thermal expansion of amalgam is 2.5 times greater than that of tooth structure, but it is closer than the linear coefficient of thermal expansion of composite.¹⁷⁻¹⁹ Although the compressive strength of high-copper amalgam is similar to tooth structure, the tensile strength is lower, making amalgam restorations prone to fracture.^{8,20,21} Usually, high-copper amalgam fracture is a bulk fracture, not a marginal fracture. All amalgams are brittle and have low edge strength. The amalgam material must have sufficient bulk (usually 1 to 2 mm, depending on the position within the tooth) and a 90-degree or greater marginal configuration.

Creep and flow relate to the deformation of a material under load over time. High-copper amalgams exhibit no clinically relevant creep or flow.^{22,23} Because amalgam is metallic in structure, it also is a good thermal conductor. An amalgam restoration should not be placed close to the pulpal tissues of the tooth without the use of a liner or base (or both) between the pulp and the amalgam.

Amalgam Restorations

Amalgam functions as a direct restorative material because of its easy insertion into a tooth preparation and, when hardened, its ability to restore the tooth to proper form and function. The tooth preparation form not only must remove the fault in the tooth and remove weakened tooth structure, but it must also be formed to allow the amalgam material to function properly. The required tooth preparation form must allow the amalgam to (1) possess a uniform specified minimum thickness for strength, (2) produce a 90-degree amalgam angle (butt-joint form) at the margin, and (3) be mechanically retained in the tooth (Fig. 13-2). Without this preparation form, the amalgam possibly could be dislodged or could fracture. After desensitizing the prepared tooth structure, mixing, inserting, carving, and finishing the amalgam are relatively fast and easy (Fig. 13-3, A). For these reasons, it is a user-friendly material that is less technique sensitive or operator sensitive compared with composite.

Some practitioners have continued to use bonded amalgam restorations in their practice (see Fig. 13-3, B). As noted

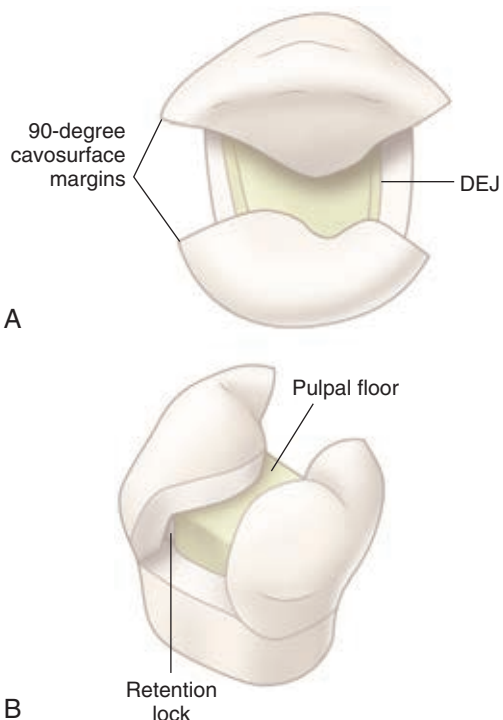


Fig. 13-2 A and B, Diagrams of Class II amalgam tooth preparations illustrating uniform pulpal and axial wall depths, 90-degree cavosurface margins, and convergence of walls or prepared retention form or both.

previously, this book no longer promotes the use of bonded amalgams.²⁴⁻²⁷ The mechanism of bonding an amalgam restoration is similar to that for bonding a composite restoration in some aspects, but it is different in others. A bonded amalgam restoration, done properly, may seal the prepared tooth structure and may strengthen the remaining unprepared tooth structure. The retention gained by bonding, however, is minimal; consequently, bonded amalgam restorations still require the same tooth preparation retention form as do non-bonded amalgam restorations.^{28,29} Isolation requirements for a bonded amalgam restoration are the same as for a composite restoration.

Another amalgam technique uses light-cured adhesive to seal the dentin under the amalgam material (see Fig. 13-3, C). This procedure, as is true of all procedures that use adhesive technology, requires proper isolation. The prepared tooth structure is etched, primed, and sealed with adhesive. The adhesive is polymerized before insertion of the amalgam. (Usually, a one-bottle sealer material that combines the primer and the adhesive is used.) This technique seals the dentinal tubules effectively.^{30,31}

Uses

Because of its strength and ease of use, amalgam provides an excellent means for restoring large defects in non-esthetic areas.³² A review of almost 3500 4-surface and 5-surface amalgams revealed successful outcomes at 5 years for 72% of the four-surface and 65% of the five-surface amalgams. This result compared favorably with the 5-year success rates for gold and porcelain crowns, which were 84% and 85%, respectively.³³

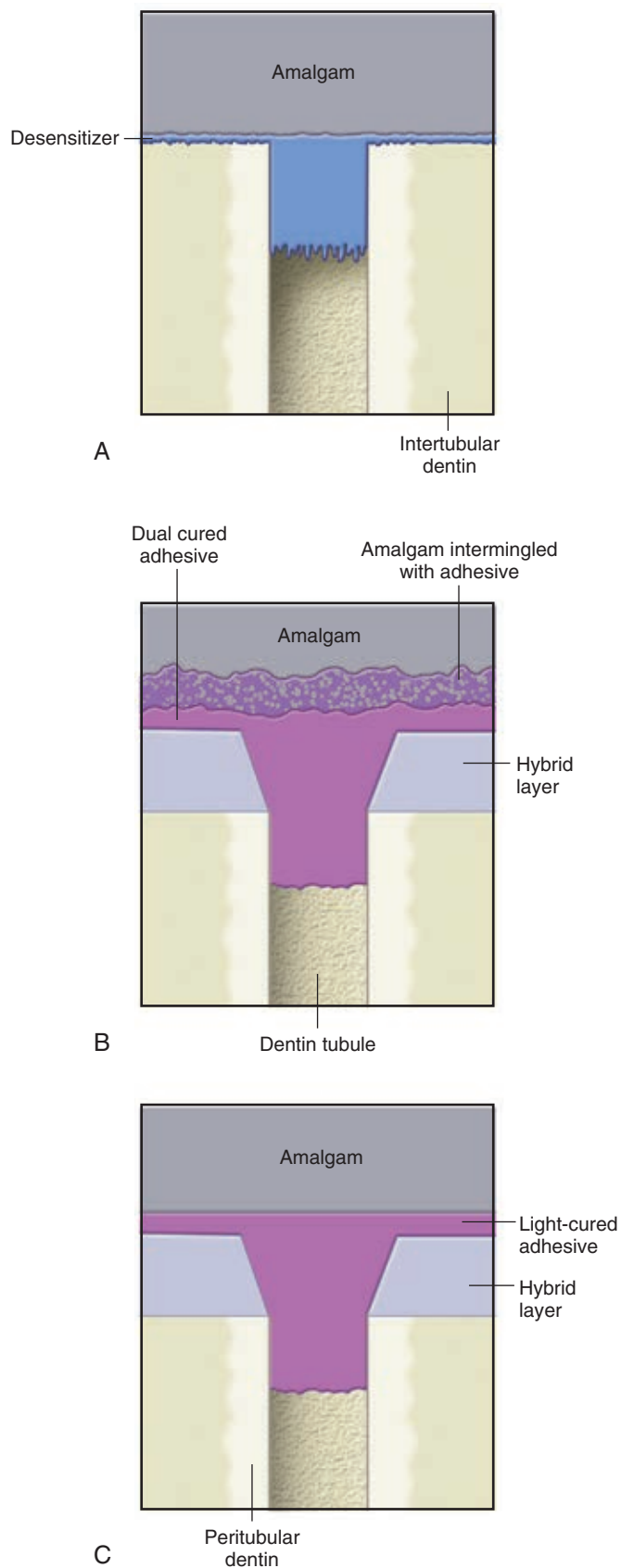


Fig. 13-3 Types of amalgam restorations. **A,** Conventional amalgam restoration with desensitizer (5% glutaraldehyde + 35% hydroxy-ethyl methacrylate [HEMA]). **B,** Bonded amalgam (amalgam intermingled with adhesive resin). **C,** Sealed amalgam (adhesive resin placed and cured before amalgam placement).

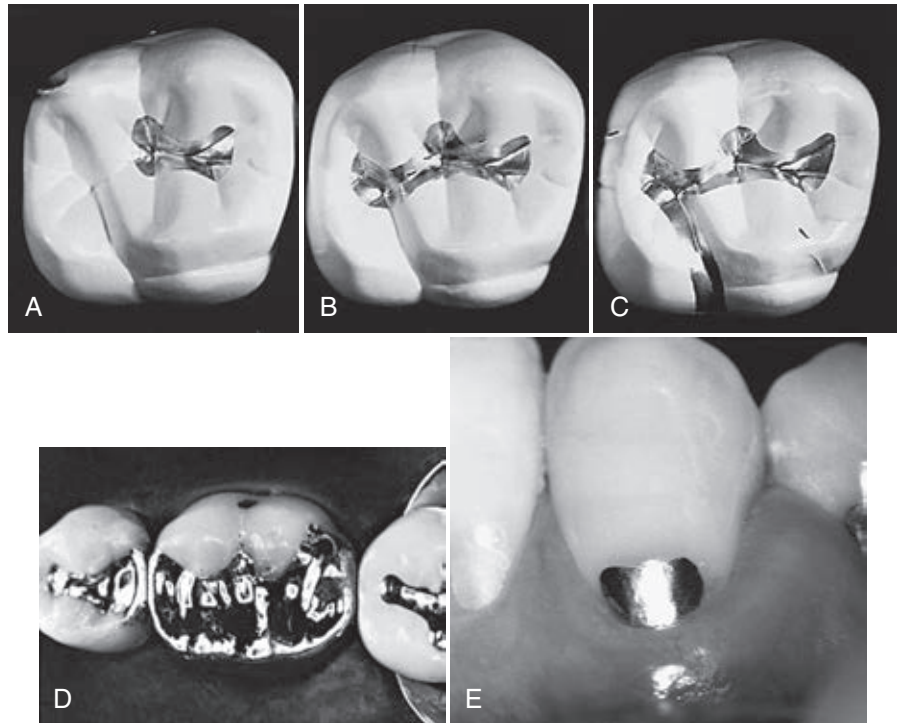


Fig. 13-4 Amalgam restorations. **A–C**, Class I. **D**, Class II. **E**, Class V. (Most practitioners would restore all of these teeth with composite, except tooth No. 30.)

Generally, amalgams can be used for the following clinical procedures:

1. Class I, II, and V restorations (Fig. 13-4)
2. Foundations (Fig. 13-5)
3. Caries-control restorations (see Chapter 2)

Handling

Because of the concern about mercury, amalgam restorations require meticulous handling to avoid unnecessary mercury exposure to the environment, the office, the personnel, or the patient. Proper mercury hygiene procedures are described in Online Chapter 1 and in the subsequent chapters on amalgam restorations.

General Considerations for Amalgam Restorations

The following sections summarize general considerations with regard to all amalgam restorations. Information for specific applications is presented in Chapters 14, 15, and 16. Because the typical decision about direct restorative materials is usually a choice between amalgam and composite, some of the following information involves a comparative analysis of these two materials.

Indications

Occlusal Factors

Amalgam has greater wear resistance than does composite.^{2,34} It may be indicated in clinical situations that have heavy occlusal functioning. It also may be more appropriate when a restoration restores all of the occlusal contacts of a tooth.

Isolation Factors

Minor contamination of an amalgam during the insertion procedure may not have as adverse an effect on the final restoration as the same contamination would produce for a composite restoration.

Operator Ability and Commitment Factors

The tooth preparation for an amalgam restoration is very exacting. It requires a specific form with uniform depths and a precise marginal form. Many failures of amalgam restorations may be related to inappropriate tooth preparations. The insertion and finishing procedures for amalgam are much easier than for composite.

Clinical Indications for Direct Amalgam Restorations

Because of the factors already presented, amalgam is considered most appropriate for the following indications:

1. Moderate to large Class I and II restorations (especially restorations that involve heavy occlusion, cannot be isolated well, or extend onto the root surface) (see Fig. 13-4, A and B).
2. Class V restorations (including restorations that are not esthetically critical, cannot be well isolated, or are located entirely on the root surface) (see Fig. 13-4, C).
3. Temporary caries-control restorations (including teeth that are badly broken and require a subsequent assessment of pulpal health before a definitive restoration) (see Chapter 2).
4. Foundations (including for badly broken teeth that require increased retention and resistance forms in

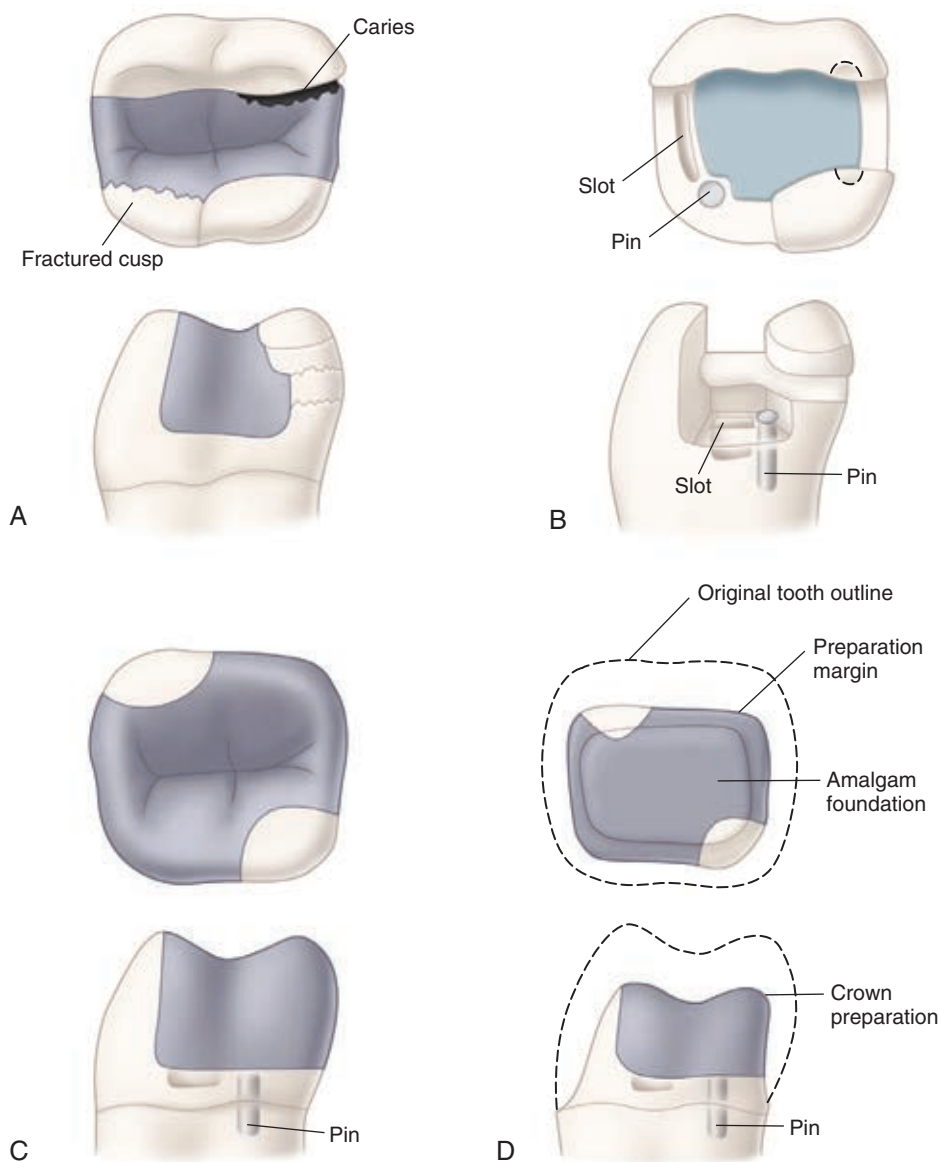


Fig. 13-5 Amalgam foundation. **A**, Defective restoration (defective amalgam, mesiolingual fractured cusp, mesiofacial caries). **B**, Tooth preparation with secondary retention and bonding, using pin and slot. **C**, Amalgam foundation placed. **D**, Tooth prepared for crown with amalgam foundation.

anticipation of the subsequent placement of a crown or metallic onlay) (see Fig. 13-5).

Contraindications

Amalgams are contraindicated in patients who are allergic to the alloy components. The use of amalgam in more prominent esthetic areas of the mouth is usually avoided. These areas include anterior teeth, premolars, and, in some patients, molars. Occasionally, a Class III amalgam restoration may be done if isolation problems exist. Likewise, in rare clinical situations, Class V amalgam restorations may be indicated in anterior areas where esthetics is not an important consideration. Amalgam should not be used when composite resin would offer better conservation of the tooth structure and equal clinical performance.

Advantages

Some of the advantages of amalgam restorations already have been stated, but the following list presents the primary reasons for the successful use of amalgam restorations for many years:

1. Ease of use
2. High compressive strength
3. Excellent wear resistance
4. Favorable long-term clinical research results
5. Lower cost than for composite restorations

Disadvantages

The primary disadvantages of amalgam restorations relate to esthetics and increased tooth structure removal during tooth

preparation. The following is a list of these and other disadvantages of amalgam restorations:

1. Noninsulating
2. Non-esthetic
3. Less conservative (more removal of tooth structure during tooth preparation)
4. More difficult tooth preparation
5. Initial marginal leakage¹⁶

Clinical Technique

Initial Clinical Procedures

A complete examination, diagnosis, and treatment plan must be finalized before the patient is scheduled for operative appointments (except in emergencies). A brief review of the chart (including medical factors), treatment plan, and radiographs should precede each restorative procedure. At the beginning of each appointment, the dentist should also examine the operating site carefully to confirm the diagnosis of the tooth or teeth scheduled for treatment.

Local Anesthesia

Because most amalgam tooth preparations are relatively more extensive, local anesthesia usually is necessary. Profound anesthesia contributes to a comfortable and uninterrupted operation and usually results in a marked reduction in salivation.

Isolation of the Operating Site

Complete instructions for the control of moisture are given in Chapter 7. Isolation for amalgam restorations can be accomplished with a rubber dam or cotton rolls, with or without a retraction cord.

Other Pre-operative Considerations

A pre-operative assessment of the occlusion should be made. This step should occur before rubber dam placement; and the dentist should identify not only the occlusal contacts of the tooth to be restored but also the contacts on opposing and adjacent teeth. Knowing the pre-operative location of occlusal contacts is important in planning the restoration outline form and in establishing the proper occlusal contacts on the restoration. Remembering the location of the contacts on adjacent teeth provides guidance in determining when the restoration contacts have been correctly adjusted and positioned.

A wedge placed pre-operatively in the gingival embrasure is useful when restoring a posterior proximal surface. This step causes separation of the operated tooth from the adjacent tooth and may help protect the rubber dam and the interdental papilla.

For smaller amalgam restorations, it also is important to visualize pre-operatively the anticipated extension of the tooth preparation. Because the tooth preparation requires specific depths, extensions, and marginal forms, the connection of the various parts of the tooth preparation should result in minimal tooth structure removal (i.e., as little as is necessary), while maintaining the strength of the cuspal and marginal ridge areas of the tooth as much as possible (Fig. 13-6). The

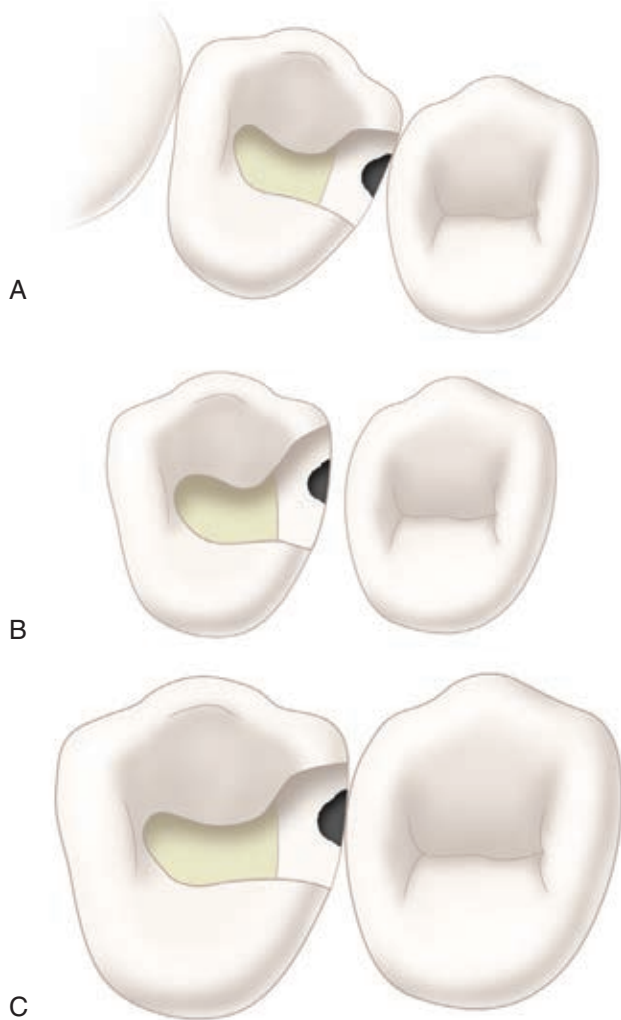


Fig. 13-6 Pre-operative visualization of tooth preparation extensions when caries is present gingival to the proximal contact and in the central groove area. **A**, Rotated tooth (lingual extension owing to faulty central groove). **B**, Open proximal contact (preparation extended wider faciolingually to develop a proximal contact with appropriate physiologic proximal contours). **C**, Normal relationship.

projected facial and lingual extensions of a proximal box should be visualized before preparing the occlusal portion of the tooth, reducing the chance of over-preparing the cuspal area while maintaining a butt-joint form of the facial or lingual proximal margins.

Tooth Preparation for Amalgam Restorations

Detailed descriptions of specific amalgam tooth preparations are presented in Chapters 5, 14, 15, and 16. As discussed in Chapter 5, the stages and steps of tooth preparation are important for amalgam tooth preparations. For an amalgam restoration to be successful, numerous steps must be accomplished correctly. After an accurate diagnosis is made, the dentist must create a tooth preparation that not only removes

the defect (e.g., caries, old restorative material, malformed structure) but also leaves the remaining tooth structure in as strong a state as possible. Making the tooth preparation form appropriate for the use of amalgam as the restorative material is equally important. Because of amalgam's physical properties, it must (1) be placed into a tooth preparation that provides for a 90-degree or greater restoration angle at the cavosurface margin (because of the amalgam's limited edge strength), (2) have a minimum thickness of 1.5 to 2 mm for adequate compressive strength (because most amalgams fail by bulk fracture), and (3) be placed into a prepared undercut form in the tooth to be mechanically retained (because of the amalgam's lack of bonding to the tooth). After appropriate tooth preparation, the success of the final restoration depends on proper insertion, carving, and finishing of the amalgam material.

Requirements

The preparation features that relate specifically to the use of amalgam as the restorative material include the following:

1. Amalgam margin 90 degrees or greater (butt-joint form)
2. Adequate depth (thickness of amalgam)
3. Adequate mechanical retention form (undercut form)

Principles

The basic principles of tooth preparation must be followed for amalgam tooth preparations to ensure clinical success. The procedure is presented in two stages, academically, to facilitate

student understanding of proper extension, form, and caries removal. The initial stage (1) places the tooth preparation extension into sound tooth structure at the marginal areas (not pulpally or axially); (2) extends the depth (pulpally or axially or both) to a prescribed, uniform dimension; (3) provides an initial form that retains the amalgam in the tooth; and (4) establishes the tooth preparation margins in a form that results in a 90-degree amalgam margin when the amalgam is inserted. The second and final stage of tooth preparation removes any remaining defect (caries or old restorative material) and incorporates any additional preparation features (grooves, slots, pins, steps, or amalgam pins) to achieve the appropriate retention and resistance forms. The following sections briefly describe certain aspects of tooth preparation that pertain to all amalgam restorations. The initial tooth preparation steps, although discussed separately, are performed at the same time. Extension, depth, tooth preparation wall shape, and marginal configuration are accomplished simultaneously.

INITIAL TOOTH PREPARATION DEPTH

All initial depths of a tooth preparation for amalgam relate to the dentinoenamel junction (DEJ) except in the following two instances: (1) when the occlusal enamel has been significantly worn thinner and (2) when the preparation extends onto the root surface. The initial depth pulpally is 0.2 mm inside (internal to) the DEJ or 1.5 mm as measured from the depth of the central groove (Fig. 13-7), whichever results in the greatest thickness of amalgam. The initial depth of the axial wall is 0.2 mm inside the DEJ when retention grooves are not used and 0.5 mm inside the DEJ when retention grooves are used (Fig. 13-8). The deeper extension allows placement of the

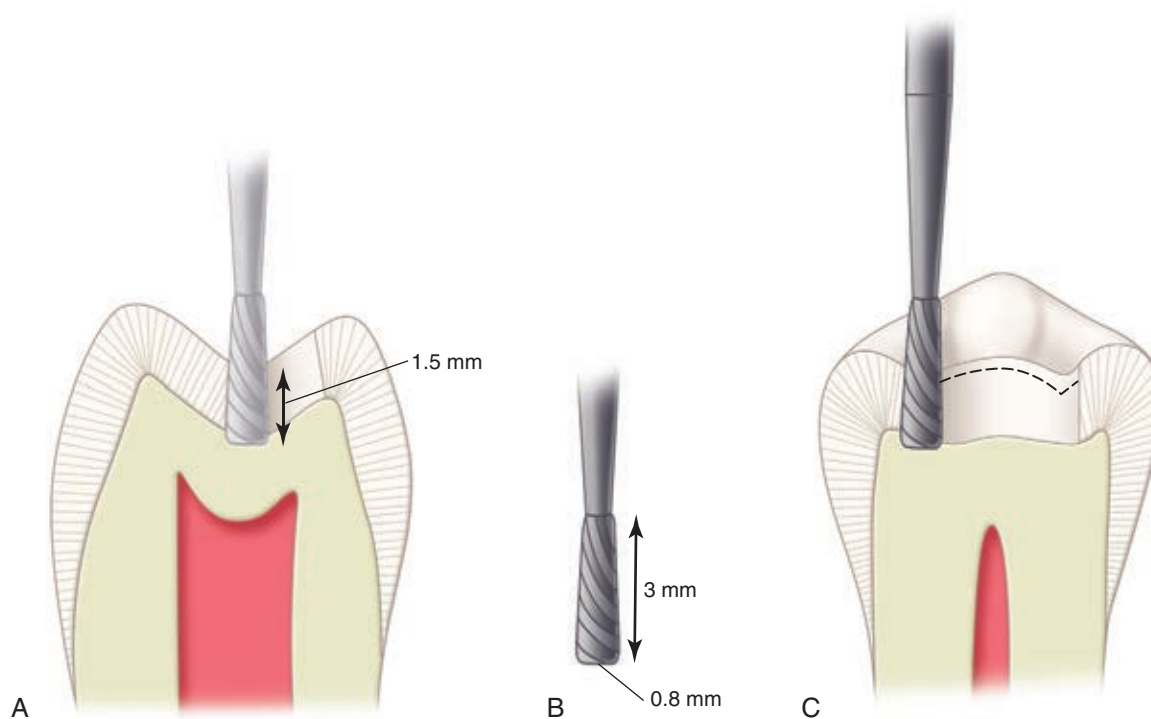


Fig. 13-7 Pulpal floor depth. **A**, Pulpal depth measured from central groove. **B**, No. 245 bur dimensions. **C**, Guides to proper pulpal floor depth: (1) one-half the length of the No. 245 bur, (2) 1.5 mm, or (3) 0.2 mm inside (internal to) the dentinoenamel junction (DEJ).

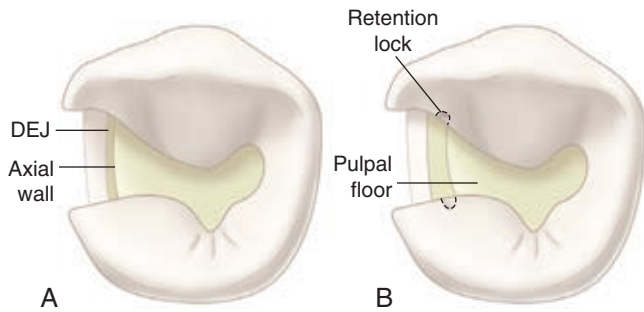


Fig. 13-8 Axial wall depth. **A**, If no retention grooves needed, axial depth 0.2 mm inside (internal to) the dentinoenamel junction (DEJ). **B**, If retention grooves needed, axial depth 0.5 mm inside (internal to) the DEJ.

retention groove without undermining marginal enamel. Axial depths on the root surface should be 0.75 to 1 mm deep so as to provide room for placement of a retention groove or cove.

OUTLINE FORM

The initial extension of the tooth preparation should be visualized preoperatively by estimating the extent of the defect, the preparation form requirements of the amalgam, and the need for adequate access to place the amalgam into the tooth. Because of the structure of enamel, enamel margins must be left in a form of 90 degrees or greater. Otherwise, enamel is subject to fracture. For enamel strength, the marginal enamel rods should be supported by sound dentin. These requirements for enamel strength must be combined with marginal requirements for amalgam (90-degree butt joint) when establishing the periphery of the tooth preparation (see Fig. 14-46).

The preparation extension is dictated primarily by the existing amount of caries, old restorative material, or defect. Adequate extension to provide access for tooth preparation, caries removal, matrix placement, and amalgam insertion also must be considered. When making the preparation extensions, every effort should be made to preserve the strength of cusps and marginal ridges. When possible, the outline form should be extended around cusps and avoid undermining the dental support of the marginal ridge enamel.

When viewed from the occlusal, the facial and lingual proximal cavosurface margins of a Class II preparation should be 90 degrees (i.e., perpendicular to a tangent drawn through the point of extension facially and lingually) (Fig. 13-9). In most instances, the facial and lingual proximal walls should be extended just into the facial or lingual embrasure. This extension provides adequate access for performing the preparation (with decreased risk of damaging the adjacent tooth), easier placement of the matrix band, and easier condensation and carving of the amalgam. Such extension provides a clearance between the cavosurface margin and the adjacent tooth (Fig. 13-10). For the more experienced operator, extending the proximal margins beyond the proximal contact into the respective embrasure is not always necessary. The less the outline form is extended, the more conservative is the resulting preparation and the less the tooth structure removed.

Factors dictating the outline form are presented in greater detail in Chapter 5. They include caries, old restorative

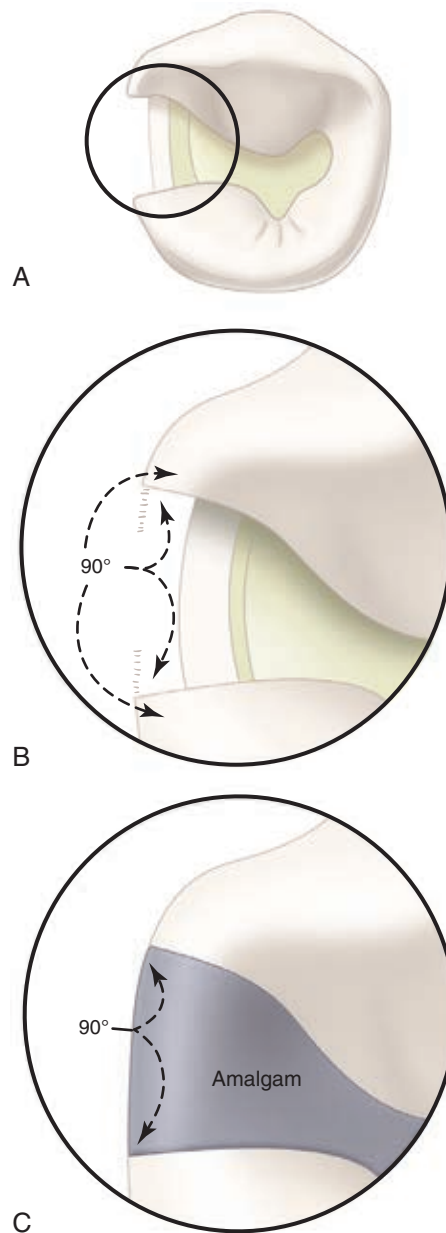


Fig. 13-9 Proximal cavosurface margins. **A**, Facial and lingual proximal cavosurface margins prepared at 90-degree angles to a tangent drawn through the point on the external tooth surface. **B**, A 90-degree proximal cavosurface margin produces a 90-degree amalgam margin. **C**, 90-degree amalgam margins.

material, inclusion of all of the defect, proximal or occlusal contact relationship, and the need for convenience form.

CAVOSURFACE MARGIN

Enamel must have a marginal configuration of 90 degrees or greater, and the amalgam must have the same. With marginal angles less than 90 degrees, enamel and amalgam will be subject to fracture, as both these materials are brittle structures. Preparation walls on vertical parts of the tooth (facial, lingual, mesial, or distal) should result in 90-degree enamel walls (representing a strong enamel margin; see Fig. 13-9) that meet the inserted amalgam at a butt joint (enamel and

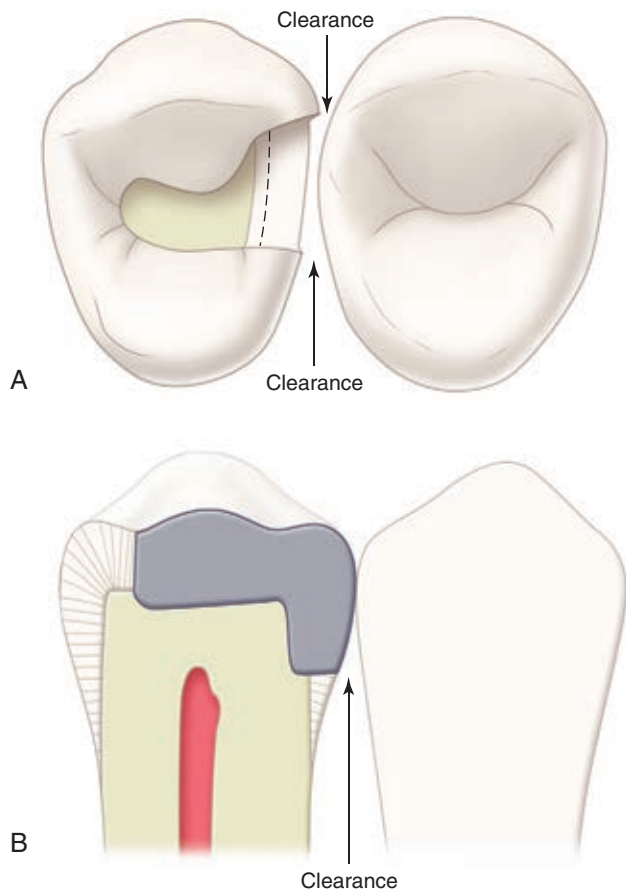


Fig. 13-10 Proximal box preparation clearance of adjacent tooth. **A**, Occlusal view. **B**, Lingual view of a cross-section through the central groove.

amalgam having 90-degree margins). Preparation walls on the occlusal surface should provide 90-degree or greater amalgam margins and usually have obtuse enamel margins (representing the strongest enamel margin; Fig. 13-11). The 90-degree occlusal amalgam margin results from the amalgam carving in the central groove area being more rounded (Fig. 13-12).

PRIMARY RETENTION FORM

Retention form preparation features lock or retain the restorative material in the tooth. For composite restorations, micro-mechanical bonding provides most of the retention needed. Amalgam restorations must be mechanically locked inside the tooth. Amalgam retention form (Fig. 13-13) is provided by (1) mechanical locking of the inserted amalgam into the surface irregularities of the preparation (even though the desired texture of the preparation walls is smooth) to allow proper adaptation of the amalgam to the tooth; (2) preparation of the vertical walls (especially facial and lingual walls) that converge occlusally; and (3) special retention features such as grooves, coves, slots, pins, steps, or amalgam pins that are placed during the final stage of tooth preparation. The first two of these are considered primary retention form features and are provided by the orientation and type of the preparation instrument. The third is a secondary retention form feature and is discussed in a subsequent section. A pear-shaped carbide bur

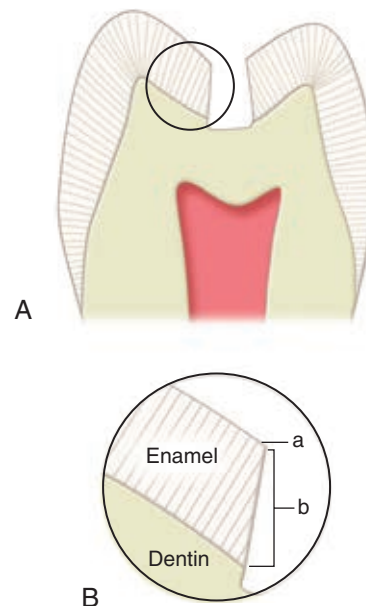


Fig. 13-11 Occlusal cavosurface margins. **A**, Tooth preparation. **B**, Occlusal margin representing the strongest enamel margin. Full-length enamel rods (a) and shorter enamel rods (b).

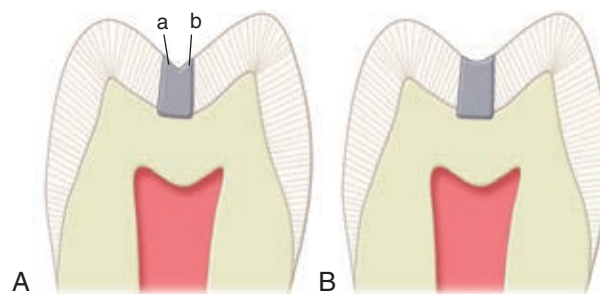


Fig. 13-12 Amalgam form at occlusal cavosurface margins. **A**, Amalgam carved too deep resulting in acute angles a and b and stress concentrations within the amalgam, increasing the potential for fracture. **B**, Amalgam carved with appropriate anatomy, resulting in an amalgam margin close to 90 degrees, although the enamel cavosurface margin is obtuse.

(No. 330 or No. 245) provides the desired wall shape and texture (see Fig. 13-7, B).

PRIMARY RESISTANCE FORM

Resistance form preparation features help the restoration and the tooth resist fracturing caused by occlusal forces. Resistance features that assist in preventing the tooth from fracturing include (1) maintaining as much unprepared tooth structure as possible (preserving cusps and marginal ridges); (2) having pulpal and gingival walls prepared perpendicular to the occlusal forces, when possible; (3) having rounded internal preparation angles; (4) removing unsupported or weakened tooth structure; and (5) placing pins into the tooth as part of the final stage of tooth preparation. The last of these features is considered a secondary resistance form feature and is discussed in a subsequent section. Resistance form features that assist in preventing the amalgam from fracturing include (1)

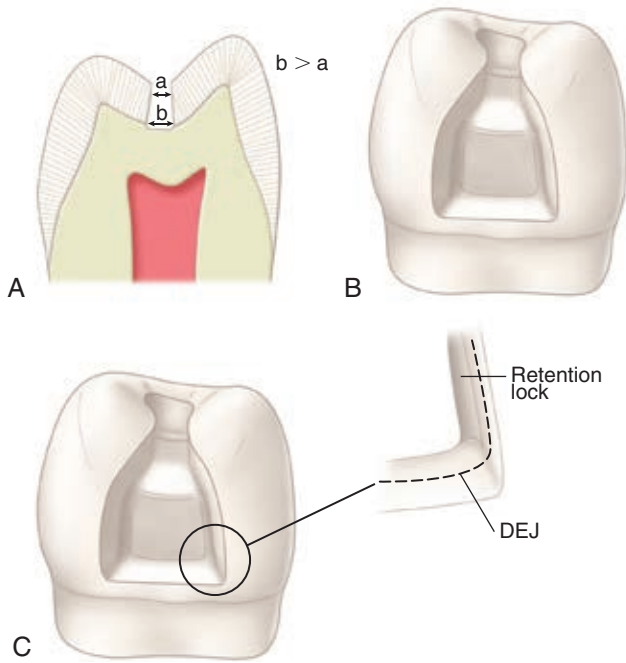


Fig. 13-13 Typical amalgam tooth preparation retention form features. **A** and **B**, Occlusal convergence of prepared walls (primary retention form). **C**, Retention grooves in proximal box (secondary retention form).

adequate thickness of amalgam (1.5–2 mm in areas of occlusal contact and 0.75 mm in axial areas); (2) marginal amalgam of 90 degrees or greater; (3) box-like preparation form, which provides uniform amalgam thickness; and (4) rounded axiopulpal line angles in Class II tooth preparations. Many of these resistance form features can be achieved using the No. 245 bur.

CONVENIENCE FORM

Convenience form preparation features are features that make the procedure easier or the area more accessible. The convenience form may include arbitrary extension of the outline form so that the marginal form can be established; caries can be accessed for removal; matrix can be placed; or amalgam can be inserted, carved, and finished. Convenience form features also may include extending the proximal margins to provide clearance from the adjacent tooth and extension of the other walls to provide greater access for caries excavation.

For simplification in teaching, all of these steps in the tooth preparation (outline, retention, resistance, and convenience forms) constitute what is referred to as *the initial stage of tooth preparation*. Although each step is an important consideration, they are accomplished simultaneously. In academic institutions, assessing the tooth preparation after the initial preparation stage provides an opportunity to evaluate a student's knowledge and ability to extend the preparation properly and establish the proper depth. If the student were to excavate extensive caries before any evaluation, the attending faculty would not know whether the prepared depths were obtained because of appropriate excavation or inappropriate overcutting of the tooth. The following factors constitute the final stage of tooth preparation.

REMOVAL OF THE REMAINING FAULT AND PULP PROTECTION

If caries or old restorative material remains after the initial preparation, it should be located only in the axial or pulpal walls (the extension of the peripheral preparation margins should have already been to sound tooth structure). Chapter 5 discusses (1) when to leave or remove old restorative material, (2) how to remove the remaining caries, and (3) what should be done to protect the pulp. Placement of a desensitizer on the prepared dentin is recommended before amalgam insertion. The objective of the desensitizer is to occlude the dentinal tubules. (Use of liners and bases under amalgam restorations is discussed in Online Chapter 18 and Chapter 5.)

SECONDARY RESISTANCE AND RETENTION FORMS

If it is determined (from clinical judgment) that insufficient retention or resistance forms are present in the tooth preparation, additional preparation is indicated. Many features that enhance the retention form also enhance the resistance form. Such features include the placement of grooves, coves, pins, slots, or amalgam pins. Usually, the larger the tooth preparation, the greater is the need for secondary resistance and retention forms.

FINAL PROCEDURES

After the previous steps are performed, the tooth preparation should be viewed from all angles. Careful assessment should be made to ensure that all caries has been removed, the depths are proper, the margins provide for correct amalgam and tooth preparation angles, and the tooth is cleaned of any residual debris.

Preparation Designs

The typical tooth preparation for amalgam is referred to as *conventional tooth preparation*. Other types include box-only and tunnel preparations for amalgam restorations. Figure 13-14 illustrates various preparation designs. Appropriate details of specific tooth preparations are presented in subsequent chapters.

Restorative Technique for Amalgam Restorations

After tooth preparation, the tooth must be readied for the insertion of amalgam. A desensitizer, which contains 5% glutaraldehyde and 35% hydroxy ethyl methacrylate (HEMA), is placed on the prepared dentin (see Fig. 13-3). This step may occur before or after the matrix application.

Matrix Placement

A matrix primarily is used when a proximal surface is to be restored. The objectives of a matrix are to (1) provide proper contact, (2) provide proper contour, (3) confine the restorative material, and (4) reduce the amount of excess material. For a matrix to be effective, it should (1) be easy to apply and remove, (2) extend below the gingival margin, (3) extend above the marginal ridge height, and (4) resist deformation

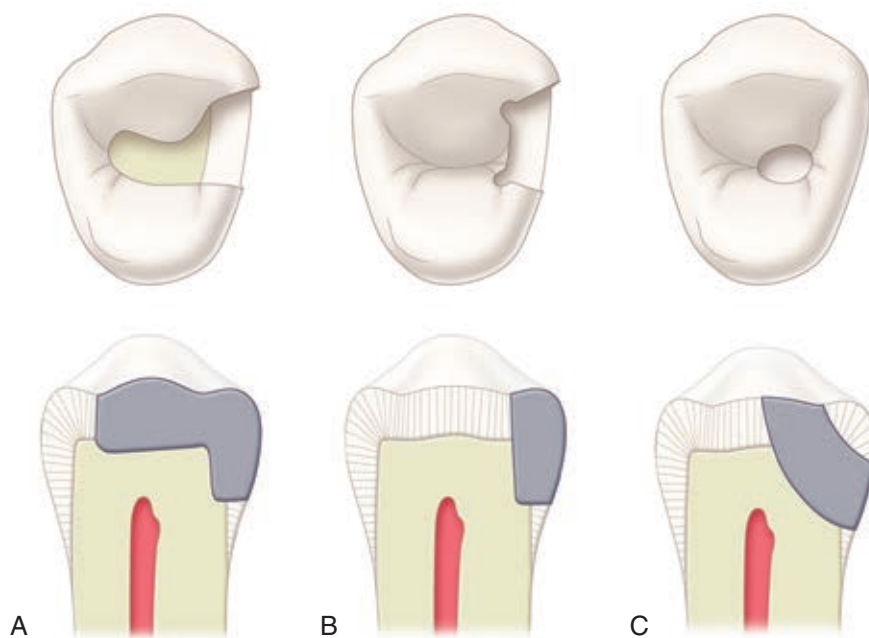


Fig. 13-14 Types of amalgam tooth preparations. **A**, Conventional. **B**, Box-only. **C**, Tunnel.

during material insertion. Chapters 14, 15, and 16 describe matrix placement for specific amalgam restorations and illustrate some of the types of matrices available.

In some clinical circumstances, a matrix may be necessary for Class I or V amalgam restorations. Examples of Class I matrices are shown in Chapter 14; examples of Class V matrices are shown in Chapter 15. Matrix application might be beneficial during tooth preparation to help protect the adjacent tooth from being damaged. The matrix, when used for this reason, would be placed on the adjacent tooth (or teeth).

Mixing (Triturating) the Amalgam Material

The manufacturer's directions should be followed when mixing the amalgam material. The speed and time of mix are factors in the setting reaction of the material. Alterations in either may cause changes in the properties of the inserted amalgam.

Inserting the Amalgam

Manipulating the amalgam during insertion is described in Online Chapter 18 as well as in Chapters 14, 15, and 16. Lateral condensation (facially and lingually directed condensation) is important in the proximal box portions of the preparation to ensure confluence of the amalgam with the margins. Spherical amalgam is more easily condensed than admixed (lathe-cut) amalgam, but some practitioners prefer the handling properties of the admixed type. Generally, smaller amalgam condensers are used first; this allows the amalgam to be properly condensed into the internal line angles and secondary retention features. Subsequently, larger condensers are used. When the amalgam is placed to slight excess with condensers, it should be precarved burnished with a large egg-shaped bur-nisher to finalize the condensation, remove excess mercury-rich amalgam, and initiate the carving process.

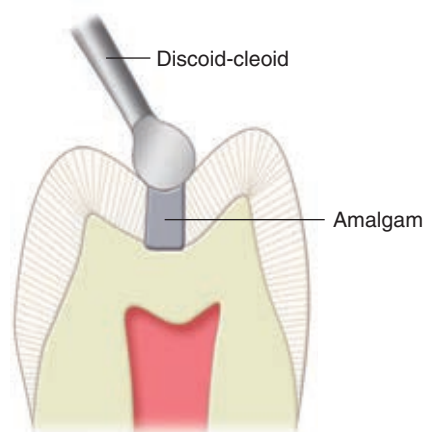


Fig. 13-15 Carving the occlusal margins.

Carving the Amalgam

The amalgam material selected for the restoration has a specific setting time. After precarve burnishing has been accomplished, the remainder of the accessible restoration must be contoured to achieve proper form and function. The insertion (condensation) and carving of the material must occur before the material has hardened so much as to be uncarvable.

OCCUSAL AREAS

A disco-cleoid instrument is used to carve the occlusal surface of an amalgam restoration. The rounded end (disco) is positioned on the unprepared enamel adjacent to the amalgam margin and pulled parallel to the margin (Fig. 13-15). This removes any excess at the margin while not allowing the marginal amalgam to be over-carved (too much removed). The pointed end (cleoid) can be used to define the

primary grooves, pits, and cuspal inclines. The Hollenbeck carver is also useful in carving these areas.

When the pit and groove anatomy is initiated with the cleoid end of the instrument, the instrument is switched, and the discoïd end is used to smooth out the anatomic form. Some semblance of pits and grooves is necessary to provide appropriate sluiceways for the escape of food from the occlusal table. The mesial and distal pits are carved to be inferior to the marginal ridge height, helping prevent food from being wedged into the occlusal embrasure. Having definite but rounded occlusal anatomy also helps achieve a 90-degree amalgam margin on the occlusal surface (see Fig. 13-12, B).

For large Class II or foundation restorations, the initial carving of the occlusal surface should be rapid, concentrating primarily on the marginal ridge height and occlusal embrasure areas. These areas are developed with an explorer tip or carving instrument by mimicking the adjacent tooth. The explorer tip is pulled along the inside of the matrix band, creating the occlusal embrasure form. When viewed from the facial or lingual direction, the embrasure form created should be identical to that of the adjacent tooth, assuming that the adjacent tooth has appropriate contour. Likewise, the height of the amalgam marginal ridge should be the same as that of the adjacent tooth (see Figs. 14-94 and 14-97). If both these areas are developed properly, the potential for fracture of the marginal ridge area of the restoration is significantly reduced. Placing the initial carving emphasis on the occlusal areas for a large restoration permits the operator to remove the matrix more quickly and carve any extensive axial surfaces of the restoration, especially the interproximal areas. Some of these areas may be relatively inaccessible and must be carved while the amalgam material is still not fully set. The remaining carving or contouring necessary on the occlusal surface can be done later, and if the amalgam is too hardened to carve, the use of rotary instruments in the handpiece may be required. When the initial occlusal carving has occurred, the matrix is removed to provide access to the other areas of the restoration that require carving.

FACIAL AND LINGUAL AREAS

Most facial and lingual areas are accessible and can be carved directly. A Hollenbeck carver is useful in carving these areas. The base of the amalgam knife (scaler 34/35) also is appropriate. With regard to the cervical areas, it is important to remove any excess and develop the proper contour of the restoration. Usually, the contour is convex; care must be exercised in carving this area. The convexity is developed by using the occlusal and gingival unprepared tooth structure as guides for initiating the carving (see Fig. 15-41). The marginal areas are blended together, resulting in the desired convexity and providing the physiologic contour that promotes good gingival health.

PROXIMAL EMBRASURE AREAS

The development of the occlusal embrasure already has been described. The amalgam knife (or scaler) is an excellent instrument for removing proximal excess and developing proximal contours and embrasures (see Figs. 14-95 and 14-96). The knife is positioned below the gingival margin, and the excess is carefully shaved away. The knife is drawn occlusally to refine the proximal contour (below the contact) and the gingival embrasure form. The sharp tip of the knife also is beneficial

in developing the facial and lingual embrasure forms. Care must be exercised in not carving away any of the desired proximal contact. If the amalgam is hardening, the amalgam knife must be used to shave, rather than cut the excess away. If a cutting motion is used, the possibility of breaking or chipping the amalgam is increased.

Developing a proper proximal contour and contact is important for the physiologic health of interproximal soft tissue. Likewise, developing a smooth proximal junction between the tooth and the amalgam is important. An amalgam overhang (excess of amalgam) may result in compromised gingival health. Voids at the cavosurface margins may result in recurrent caries.

The proximal portion of the carved amalgam is evaluated by visual assessment (reflecting light into the contact area to confirm a proximal contact) and placement of dental floss into the area. If dental floss is used, it must be used judiciously, ensuring that the contact area is not inadvertently removed. A piece of floss can be inserted through the contact and into the gingival embrasure area by initially wrapping the floss around the adjacent tooth and exerting pressure on that tooth rather than the restored tooth while moving the floss through the contact area. When the floss is into the gingival embrasure area, it is wrapped around the restored tooth and moved occlusally and gingivally to determine whether excess exists and to smooth the proximal amalgam material. If excess material is detected along the gingival margin, the amalgam knife should be used again until a smooth margin is obtained.

Finishing the Amalgam Restoration

When the carving is completed, the restoration is visualized from all angles, and the thoroughness of the carving is assessed. If a rubber dam was used, it is removed, and the occlusal relationship of the restoration is assessed. Knowing the pre-operative occlusal relationship of the restored tooth and adjacent teeth is helpful in developing appropriate contacts in the restoration; the tooth should be restored to appropriate occlusal contacts. Initially, the patient should be instructed to close very lightly, stopping when any contact is noted. At this point, the operator should assess the occlusion visually. If spacing is seen between adjacent teeth and their opposing teeth, the area of premature occlusal contact on the amalgam should be identified and relieved. Articulating paper is used to identify contact areas requiring adjustment, which continues until the proper occlusal relationship is accomplished. After the occlusion is adjusted, the discoïd–cleoid can be used to smooth the accessible areas of the amalgam. A lightly moistened cotton pellet held in the operative pliers can be used to smooth the accessible parts of the restoration. If the carving and smoothing are done properly, no subsequent polishing of the restoration is needed, and good long-term clinical performance results.

Repairing an Amalgam Restoration

If an amalgam restoration fractures during insertion, the defective area must be re-prepared as if it were a small restoration. Appropriate depth and retention form must be generated, sometimes entirely within the existing amalgam restoration. If necessary, another matrix must be placed. A new mix of amalgam can be condensed directly into the

defect, and it adheres to the amalgam already present if no intermediary material has been placed between the two amalgams. A desensitizer can be placed on any exposed dentin, but it should not be placed on the amalgam preparation walls.

Controversial Issues

Constant changes are occurring because the practice of operative dentistry is dynamic. New products and techniques have been developed, but their effectiveness cannot be assessed until appropriately designed research protocols have tested them. Numerous such developments are occurring at any time, many of which do not have the necessary documentation to prove their effectiveness, even though they receive much publicity. Varied opinions tend to generate controversy. Examples of such controversies follow.

Safety of Amalgam Restoration

A number of independent health agencies have extensively reviewed the issues of safety and efficacy of amalgam in recent years and have all concluded that available data does not justify either the discontinuance of use of amalgam or the removal of existing amalgam restorations. These agencies include the U.S. Food and Drug Administration (FDA) in 1991 and 2002 (<http://fda.gov/cdrh/consumer/amalgams>); the World Health Organization (WHO) along with the FDA in 1997; The National Institutes of Health (NIH) and the National Institute of Dental Research (NIDR) in 1991; and the U.S. Public Health Service (USPHS) in 1993. The National Council Against Health Fraud (NCAHF) warns consumers about dentists recommending unnecessary removal of serviceable amalgam restorations and states: “Promoting a dental practice as mercury free is unethical because it falsely implies that amalgam fillings are dangerous and that mercury-free methods are superior” (see www.ncahf.org).

The Life Sciences Research Organization (LSRO), a non-profit scientific organization in Bethesda, MD, released results of its independent review of all articles published on this topic between 1996 and 2003. Of the 950 published articles, 300 were accepted on the basis of scientific methodology. The report concluded: “There is little evidence to support a causal relationship between silver fillings and human health problems” (see <http://www.LSRO.org>).

An analysis of available data leads to the conclusion that mercury in amalgam restorations poses absolutely no problem for dental patients. This conclusion has been reached by experts in the field, by consumer interest groups, and by thorough reviews by governmental agencies. The authors of this textbook strongly agree with this conclusion.

Online Chapter 18 specifically addresses amalgam restoration safety as well and presents facts that indicate that amalgam restorations are safe. Likewise, the USPHS has reported the safety of amalgam restorations. In spite of these assessments, the mercury content in the current amalgam restorations still causes concerns, legitimate and otherwise. Proper handling of mercury in mixing the amalgam mass, removal of old amalgam restorations, and amalgam scrap disposal are paramount. Using the best management practices for amalgam waste as presented by the American Dental Association results in appropriate amalgam use.³⁵

Proximal Retention Grooves

The need for proximal retention grooves for all Class II amalgam tooth preparations is debatable. This book endorses the use of proximal retention grooves for large amalgam restorations; their use for smaller restorations is not deemed necessary. However, because correct placement of proximal retention grooves is difficult, this book presents many illustrations of grooves placed in smaller restorations, primarily to promote the operator gaining sufficient experience in their use.

Summary

Amalgam is a safe and effective direct restorative material. An amalgam restoration is relatively easy to accomplish, and adherence to tooth preparation and material handling requirements results in clinical success.

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Class I, II, and VI Amalgam Restorations

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Amalgam is used for the restoration of many carious or fractured posterior teeth and in the replacement of failed restorations. Understanding the physical properties of amalgam and the principles of tooth preparation is necessary to produce amalgam restorations that provide optimal service. If properly placed, an amalgam restoration provides many years of service.¹⁻⁶ Although improved techniques and materials are available, amalgam failures do occur. Much clinical time is spent replacing restorations that fail as a result of recurrent caries, marginal deterioration (i.e., ditching), fractures, or poor contours.^{7,8} Attention to detail throughout the procedure can significantly decrease the incidence of failures, however, and extend the life of any restoration.⁹⁻¹¹ Careful evaluation of existing amalgams is important because they have the potential to provide long-term clinical service and should not be replaced unless an accurate diagnosis is made.¹²

This chapter presents the techniques and procedures for Class I, II, and VI amalgam restorations (Fig. 14-1). Class I restorations restore defects on the occlusal surface of posterior teeth, the occlusal thirds of the facial and lingual surface of molars, and the lingual surfaces of maxillary anterior teeth. Class II restorations restore defects that affect one or both of the proximal surfaces of posterior teeth. Class VI restorations restore rare defects affecting the cusp tips of posterior teeth or the incisal edges of anterior teeth.

Pertinent Material Qualities and Properties

Pertinent material qualities and properties for Class I, II, and VI amalgam restorations include the following:

- Strength
- Longevity
- Ease of use
- Clinically proven success

In addition, amalgam is the only restorative material with an interfacial seal that improves over time.¹³⁻¹⁵

Indications

Amalgam is indicated for the restoration of a Class I, II, and VI defect when the defect (1) is not in an area of the mouth where esthetics is highly important, (2) is moderate to large, (3) is in an area that will have heavy occlusal contacts, (4) cannot be well isolated, (5) extends onto the root surface, (6) will become a foundation for a full coverage restoration, and (7) is in a tooth that serves as an abutment for a removable partial denture.

Contraindications

Although amalgam has no specific contraindications for use in Class I, II, and VI restorations, relative contraindications for use include (1) esthetically prominent areas of posterior teeth, (2) small to moderate Class I and II defects that can be well isolated, and (3) small Class VI defects.

Advantages

Primary advantages are the ease of use and the simplicity of the procedure. As noted in the following sections, the placing and contouring of amalgam restorations are generally easier than those for composite restorations.¹⁶

Disadvantages

The primary disadvantages of using amalgam for Class I, II, and VI defects are (1) amalgam use requires more complex

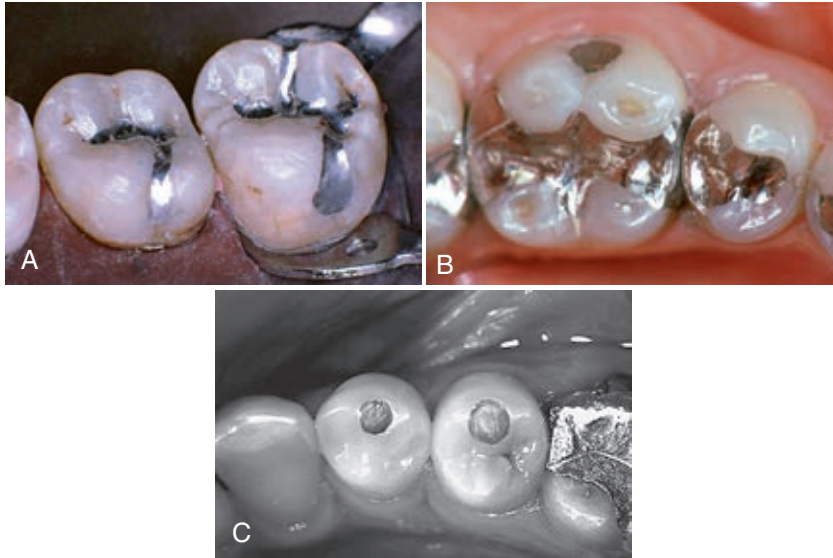


Fig. 14-1 Clinical examples of Class I, II, and VI amalgam restorations. **A**, Class I amalgam in the occlusal surface of the first molar. **B**, Class II amalgams in a premolar and molar. **C**, Class VI amalgams in premolars.

and larger tooth preparations than composite resin, and (2) amalgams may be considered to have a non-esthetic appearance by some patients.

Clinical Technique for Class I Amalgam Restorations

This section describes the use of amalgam in conservative and extensive Class I restorations.

Conservative Class I Amalgam Restorations

Conservative tooth preparation is recommended to protect the pulp, preserve the strength of the tooth, and reduce deterioration of the amalgam restoration.¹⁷⁻²¹ Such conservative preparation saves the tooth structure, minimizing pulpal irritation and leaving the remaining tooth crown as strong as possible.^{22,23} Conservative preparation also enhances marginal integrity and restoration longevity.^{20,21,24} The procedural description for a small, conservative Class I amalgam restoration clearly and simply presents the basic information relating to the entire amalgam restoration technique, including tooth preparation and placement and contouring of the restoration. This basic procedural information can be expanded to describe extensive Class I restorations where amalgam use may be indicated.

Initial Clinical Procedures

After the onset of profound anesthesia, isolation with the rubber dam is recommended to gain control over the operating field and for mercury hygiene.^{25,26} For a single maxillary tooth, where caries is not extensive, adequate control of the operating field may be achieved with cotton rolls and high-volume evacuation. A pre-operative assessment of the occlusal relationship of the involved and adjacent teeth also is necessary.

Tooth Preparation

This section describes the specific technique for preparing the tooth for a conservative Class I amalgam restoration. It is divided into initial and final stages.

INITIAL TOOTH PREPARATION

Initial tooth preparation is defined as establishing the outline form by extension of the external walls to sound tooth structure while maintaining a specified, limited depth (usually just inside the dentinoenamel junction [DEJ]) and providing resistance and retention forms. The outline form for the Class I occlusal amalgam tooth preparation should include only the defective occlusal pits and fissures (in a way that sharp angles in the marginal outline are avoided). The ideal outline form for a conservative amalgam restoration (Fig. 14-2, A) incorporates the following resistance form principles that are basic to all amalgam tooth preparations of occlusal surfaces. These principles allow margins to be positioned in areas that are sound and subject to minimal forces while conserving structure to maintain the strength and health of the tooth. The resistance principles are as follows:

- Extending around the cusps to conserve tooth structure and prevent the internal line angles from approaching the pulp horns too closely
- Keeping the facial and lingual margin extensions as minimal as possible between the central groove and the cusp tips
- Extending the outline to include fissures, placing the margins on relatively smooth, sound tooth structure
- Minimally extending into the marginal ridges (only enough to include the defect) without removing dentinal support
- Eliminating a weak wall of enamel by joining two outlines that come close together (i.e., <0.5 mm apart)
- Extending the outline form to include enamel undermined by caries

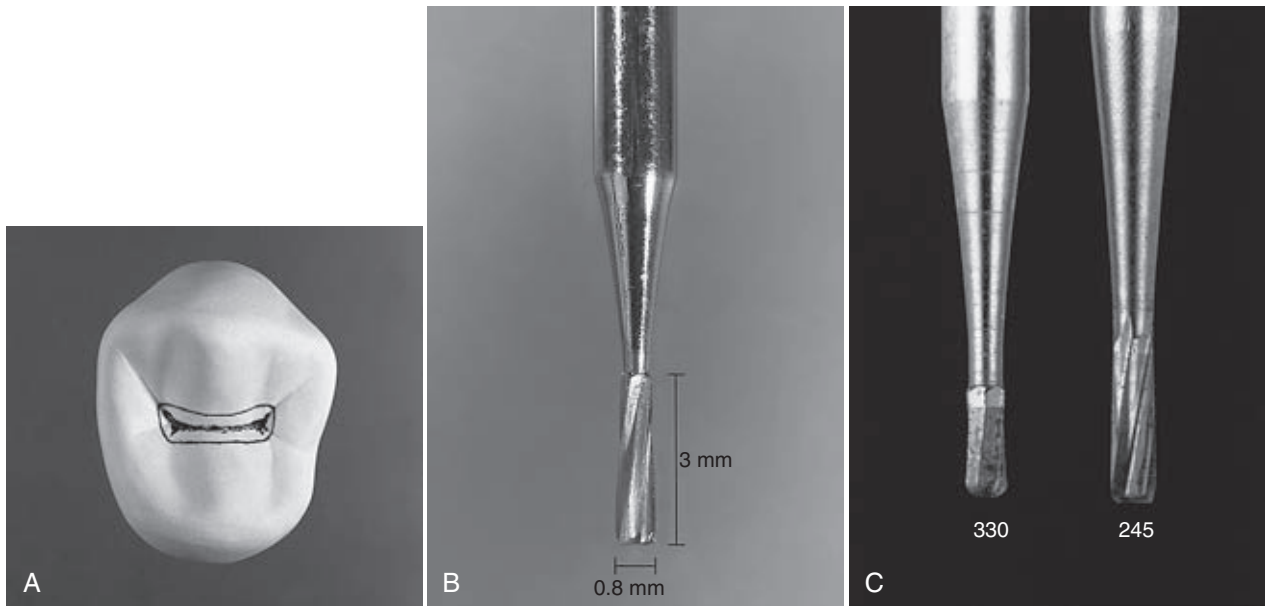


Fig. 14-2 Outline and entry. **A**, Ideal outline includes all occlusal pits and fissures. **B**, Dimensions of head of a No. 245 bur. **C**, No. 330 and No. 245 burs compared.

- Using enameloplasty on the terminal ends of shallow fissures to conserve tooth structure
- Establishing an optimal, conservative depth of the pulpal wall

A No. 245 bur with a head length of 3 mm and a tip diameter of 0.8 mm or a smaller No. 330 bur is recommended to prepare the conservative Class I tooth preparation (Fig. 14-2, B and C). The silhouette of the No. 245 bur reveals sides slightly convergent toward the shank. This produces an occlusal convergence of the facial and lingual preparation walls, providing adequate retention form for the tooth preparation. The slightly rounded corners of the end of the No. 245 bur produce slightly rounded internal line angles that render the tooth more resistant to fracture from occlusal force.²⁷ The No. 330 bur is a smaller version of the No. 245 bur. It is indicated for the most conservative amalgam preparations (see Fig. 14-2, C).

Class I occlusal tooth preparation is begun by entering the deepest or most carious pit with a punch cut using the No. 245 carbide bur at high speed with air-water spray.²⁸ A punch cut is performed by orienting the bur such that its long axis parallels the long axis of the tooth crown (Fig. 14-3, A and B). The bur is inserted directly into the defective pit. When the pits are equally defective, the distal pit should be entered as illustrated. Entering the distal pit first provides increased visibility for the mesial extension. The bur should be positioned such that its distal aspect is directly over the distal pit, minimizing extension into the marginal ridge (see Fig. 14-3, C). The bur should be rotating when it is applied to the tooth and should not stop rotating until it is removed from the tooth. Dentinal caries initially spreads at the DEJ; therefore, the goal of the initial cut is to reach the DEJ. On posterior teeth, the approximate depth of the DEJ is located at 1.5 to 2 mm from the occlusal surface. As the bur enters the pit, an initial target depth of 1.5 mm should be established. This is one-half the length of the cutting portion of the No. 245 bur. The 1.5 mm pulpal depth is measured at the central fissure (Fig. 14-3, D

and E). Depending on the cuspal incline, the depth of the prepared external walls is 1.5 to 2 mm (Fig. 14-3, D and E). The depth of the preparation is modified as needed so that the pulpal wall is established 0.1-0.2 mm into dentin. The length of the blades of an unfamiliar entry bur should be measured before it is used as a depth gauge.

Distal extension into the distal marginal ridge to include a fissure or caries occasionally requires a slight tilting of the bur distally (≤ 10 degrees). This creates a slight occlusal divergence to the distal wall to prevent undermining the marginal ridge of its dentin support (Fig. 14-4, A through C). Because the facial and lingual prepared walls converge, this slight divergence does not present any retention form concerns. For premolars, the distance from the margin of such an extension to the proximal surface usually should not be less than 1.6 mm, or two diameters of the end of the No. 245 bur (Fig. 14-4, B) measured from a tangent to the proximal surface (i.e., the proximal surface height of contour). For molars, this minimal distance is 2 mm. A minimal distal (or mesial) extension often does not require changing the orientation of the bur's axis from being parallel to the long axis of the tooth crown; the mesial and distal walls are parallel to the long axis of the tooth crown (or slightly convergent occlusally).

While maintaining the bur's orientation and depth, the preparation is extended distofacially or distolingually to include any fissures that radiate from the pit (see Fig. 14-4, D). When these fissures require extensions of more than a few tenths of a millimeter, however, consideration should be given to changing to a bur of smaller diameter, or to using enameloplasty. Both of these approaches conserve the tooth structure and minimize weakening of the tooth.

The bur's orientation and depth are maintained while extending along the central fissure toward the mesial pit, following the DEJ (see Fig. 14-4, E). When the central fissure has minimal caries, one pass through the fissure at the prescribed depth provides the desired minimal width to the isthmus. Ideally, the width of the isthmus should be just wider than the

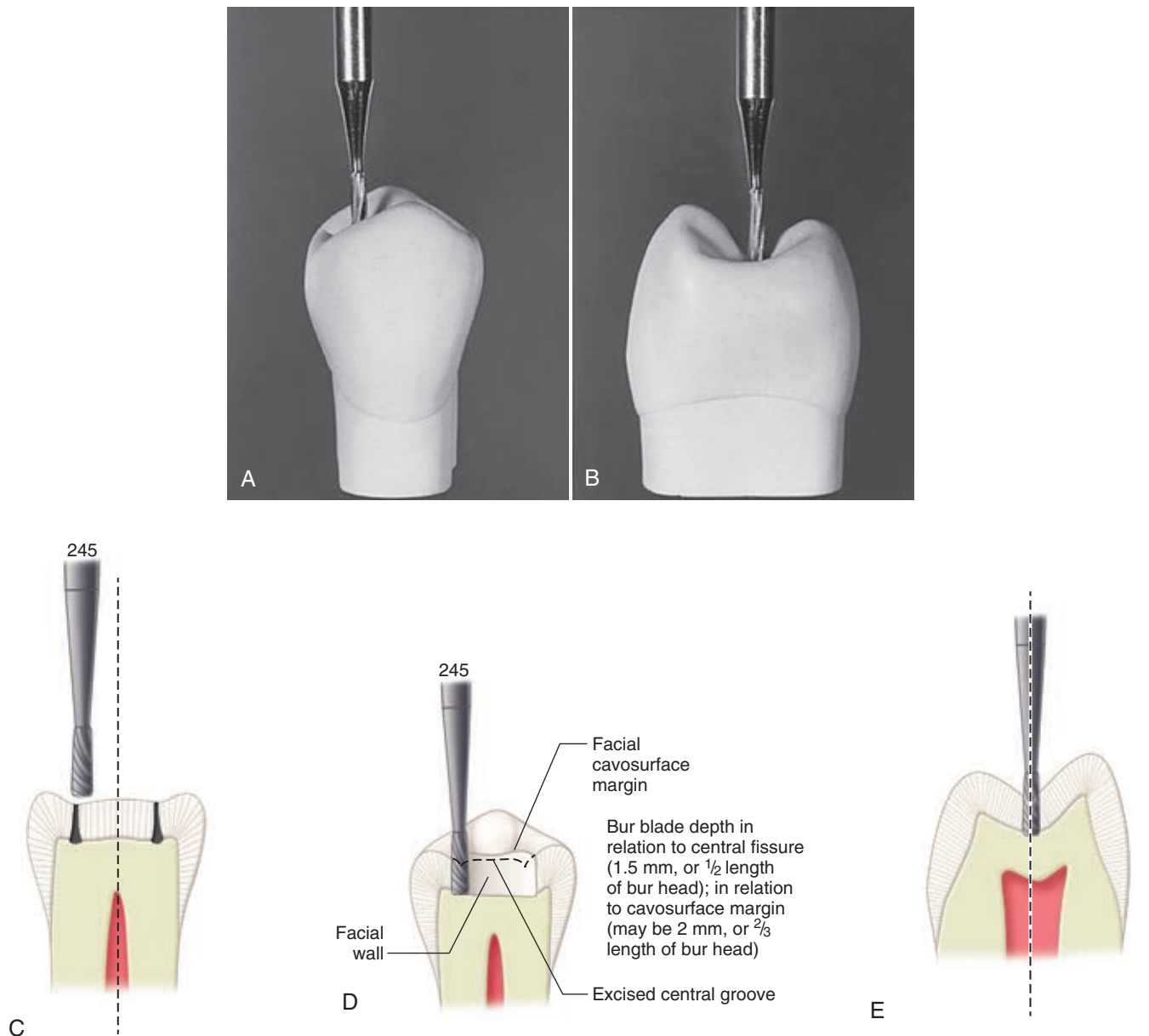


Fig. 14-3 **A**, No. 245 bur oriented parallel to long axis of tooth crown for entry as viewed from lingual aspect. **B**, The bur positioned for entry as viewed from the distal aspect. **C**, The bur is positioned over the most carious pit (distal) for entry. The distal aspect of the bur is positioned over the distal pit. **D**, Mesiodistal longitudinal section. Relationship of head of No. 245 bur to excised central fissure and cavosurface margin at ideal pulpal floor depth, which is just inside the dentinoenamel junction (DEJ). **E**, Faciolingual longitudinal section. Dotted line indicates the long axis of tooth crown and the direction of the bur.

diameter of the bur. It is well established that a tooth preparation with a narrow occlusal isthmus is less prone to fracture.^{29,30} As previously described for the distal margin, the orientation of the bur should not change as it approaches the mesial pit if the fissure extends farther onto the marginal ridge, the long axis of the bur should be changed to establish a slight occlusal divergence to the mesial wall if the marginal ridge would be otherwise undermined of its dentinal support. Figure 14-5 illustrates the correct and incorrect preparation of the mesial and distal walls. The remainder of any occlusal enamel defects is included in the outline, and the facial and lingual walls are extended, if necessary, to remove enamel undermined by caries.³¹ The

strongest and ideal enamel margin should be composed of full-length enamel rods attached to sound dentin, supported on the preparation side by shorter rods, also attached to sound dentin (Fig. 14-6).

The conservative Class I tooth preparation should have an outline form with gently flowing curves and distinct cavosurface margins. A faciolingual width of no more than 1 to 1.5 mm and a depth of 1.5 to 2 mm are considered ideal, but this goal is subject to the extension of the caries. The pulpal floor, depending on the enamel thickness, is almost always in dentin (see Fig. 14-4, C). Although conservation of the tooth structure is important, the convenience form requires that the extent of the preparation provides adequate access and visibility.

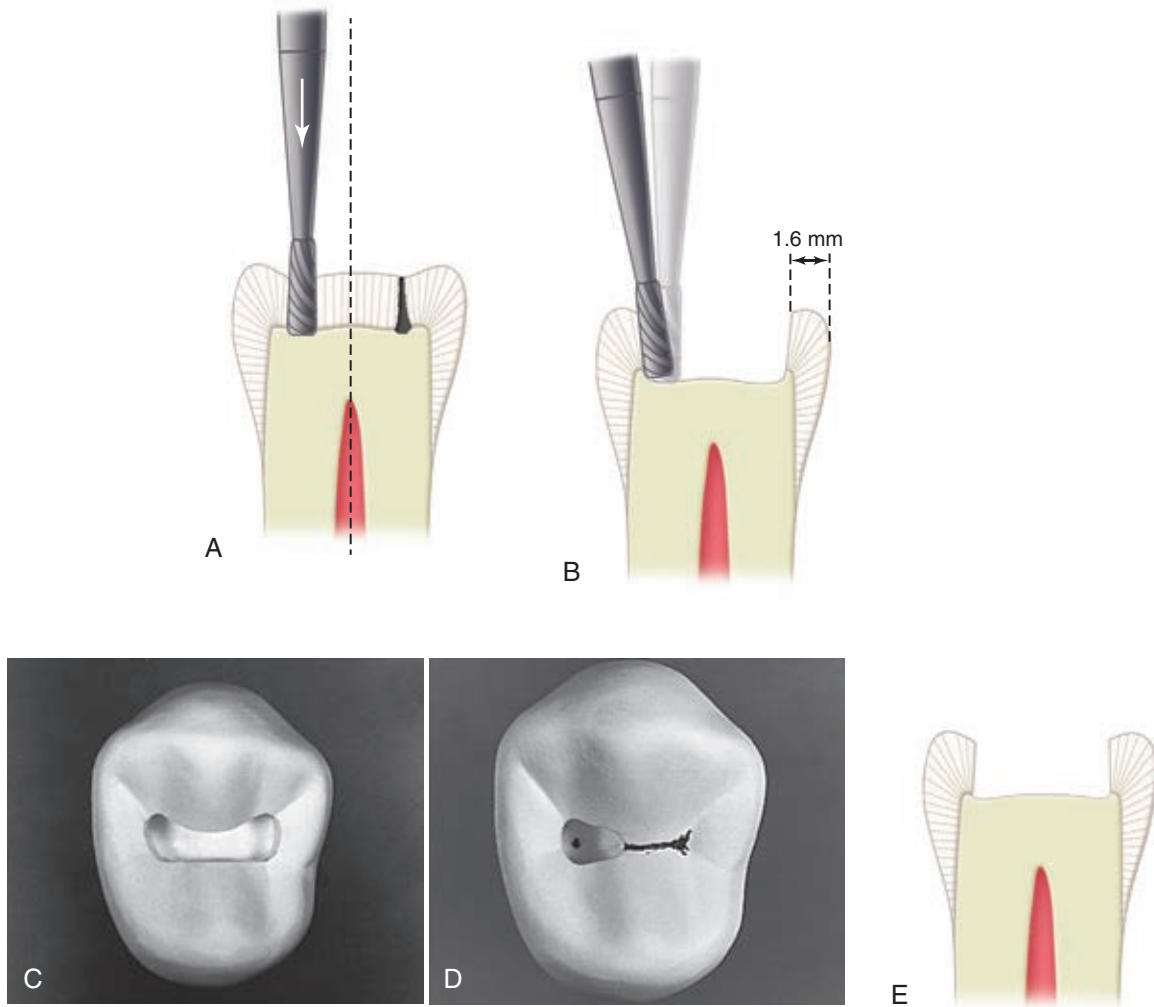


Fig. 14-4 **A**, Enter the pit with a punch cut to just inside the dentinoenamel junction (DEJ) (depth of 1.5 to 2 mm or one-half to two-thirds the head length of bur). The 1.5-mm depth is measured at central fissure; the measurement of same entry cut (but of prepared external wall) is 2 mm. **B**, Incline the bur distally to establish proper occlusal divergence to distal wall to prevent removal of the dentin supporting the marginal ridge enamel when the pulpal floor is in dentin, and distal extension is necessary to include a fissure or caries. For such an extension on premolars, the distance from the margin to the proximal surface (i.e., imaginary projection) must not be less than 1.6 mm (i.e., two diameters of end of bur). **C**, Occlusal view of the initial tooth preparation that has mesial and distal walls that diverge occlusally. **D**, Distofacial and distolingual fissures that radiate from the pit are included before extending along the central fissure. **E**, Mesiodistal longitudinal section. The pulpal floors are generally flat but may follow the rise and fall of the occlusal surface.

This completes the initial amalgam preparation for Class I caries. The extension should ensure that all caries is removed from the DEJ, resulting in a very narrow peripheral seat of healthy dentin on the pulpal wall surrounding the caries. For the initial tooth preparation, the pulpal wall should remain at the initial ideal depth, even if any restorative material or caries remains in the central area of the pulpal wall (Fig. 14-7). The remaining caries (and usually old restorative material) is removed during the final tooth preparation.

The primary resistance form is provided by the following:

- Sufficient area of relatively flat pulpal floor in sound tooth structure to resist forces directed in the long axis of the tooth and to provide a strong, stable seat for the restoration
- Minimal extension of external walls, which reduces weakening of the tooth
- Strong, ideal enamel margins

- Sufficient depth (i.e., 1.5 mm) that results in adequate thickness of the restoration, providing resistance to fracture and wear

The parallelism or slight occlusal convergence of two or more opposing, external walls provides the primary retention form.

Usually, the No. 245 bur is used for extensions into the mesial and distal fissures. During such extensions, the remaining depth of the fissure can be viewed in cross-section by looking at the wall being extended. When the remaining fissure is no deeper than one-quarter to one-third the thickness of enamel, enameloplasty is indicated. Enameloplasty refers to eliminating the developmental fault by removing it with the side of a flame-shaped diamond stone, leaving a smooth surface (Fig. 14-8, A through C). This procedure frequently reduces the need for further extension. The extent to which enameloplasty should be used cannot be determined

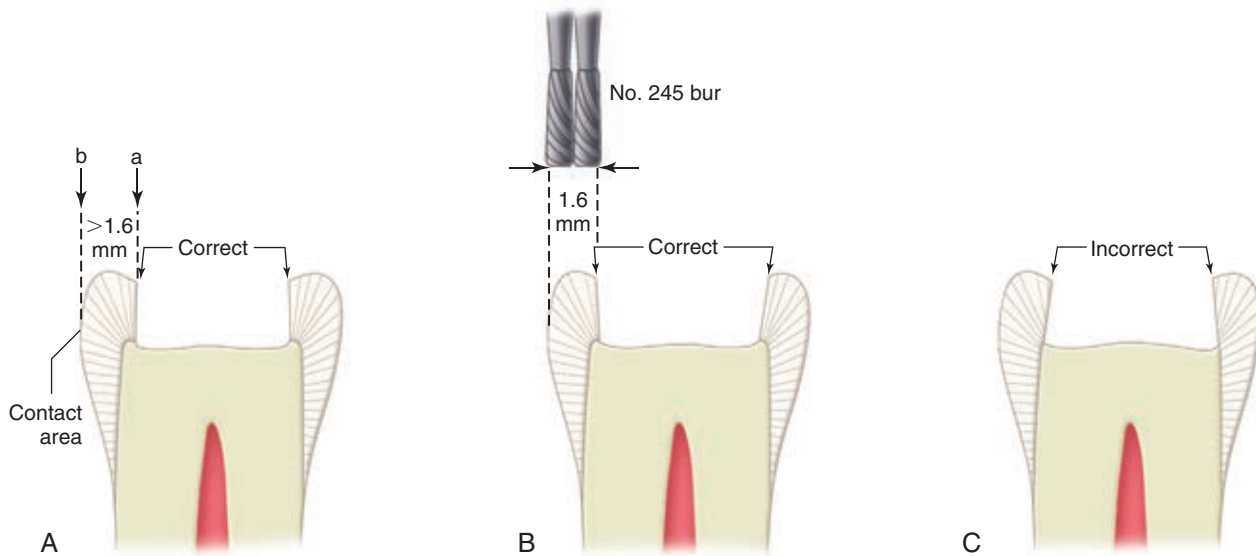


Fig. 14-5 The direction of the mesial and distal walls is influenced by the remaining thickness of the marginal ridge as measured from the mesial or distal margin (a) to the proximal surface (i.e., imaginary projection of proximal surface) (b). **A**, Mesial and distal walls should converge occlusally when the distance from a to b is greater than 1.6 mm. **B**, When the operator judges that the extension will leave only 1.6-mm thickness (two diameters of No. 245 bur) of marginal ridge (i.e., premolars) as illustrated here and in Figure 14-4, B and C, the mesial and distal walls must diverge occlusally to conserve ridge-supporting dentin. **C**, Extending the mesial or distal walls to a two-diameter limit without diverging the wall occlusally undermines the marginal ridge enamel.

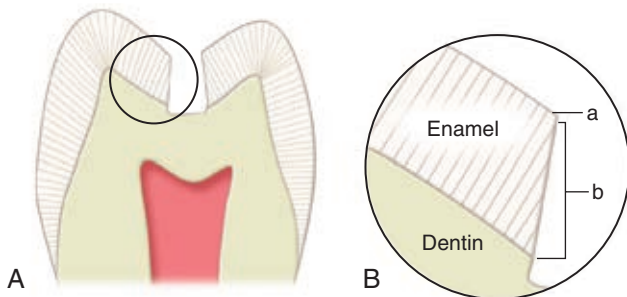


Fig. 14-6 **A** and **B**, The ideal and strongest enamel margin is formed by full-length enamel rods (a) resting on sound dentin supported on the preparation side by shorter rods, also resting on sound dentin (b).

exactly until the process of extending into the fissured area occurs, at which time the depth of the fissure into enamel can be observed. The surface left by enameloplasty should meet the tooth preparation wall, preferably with a cavosurface angle no greater than approximately 100 degrees; this would produce a distinct margin for amalgam of no less than 80 degrees (see Fig. 14-8, D). During carving, amalgam should be removed from areas of enameloplasty. Otherwise, thin amalgam left in these areas may fracture because of its low edge strength. If enameloplasty is unsuccessful in eliminating a mesial (or distal) fissure that extends to the crest of a marginal ridge or beyond, three alternatives exist:

1. Make no further change in the outline form
2. Extend through the marginal ridge when margins would be lingual to the contact (Fig. 14-9)
3. Include the fissure in a conservative Class II tooth preparation



Fig. 14-7 Mesiodistal longitudinal section showing example of the pulpal floor in dentin and caries that is exposed after the initial tooth preparation. The carious lesion is surrounded by sound dentin on the pulpal floor for the resistance form.

The first alternative usually should be strongly considered except in patients at high risk for caries. Enameloplasty is not indicated if an area of centric contact is involved. In this case, the choices are either to consider the preparation completed (an option for patients at low risk for caries) or to extend the preparation to include the fissure as previously described.

FINAL TOOTH PREPARATION

The final tooth preparation includes (1) removal of remaining defective enamel and infected dentin on the pulpal floor; (2)

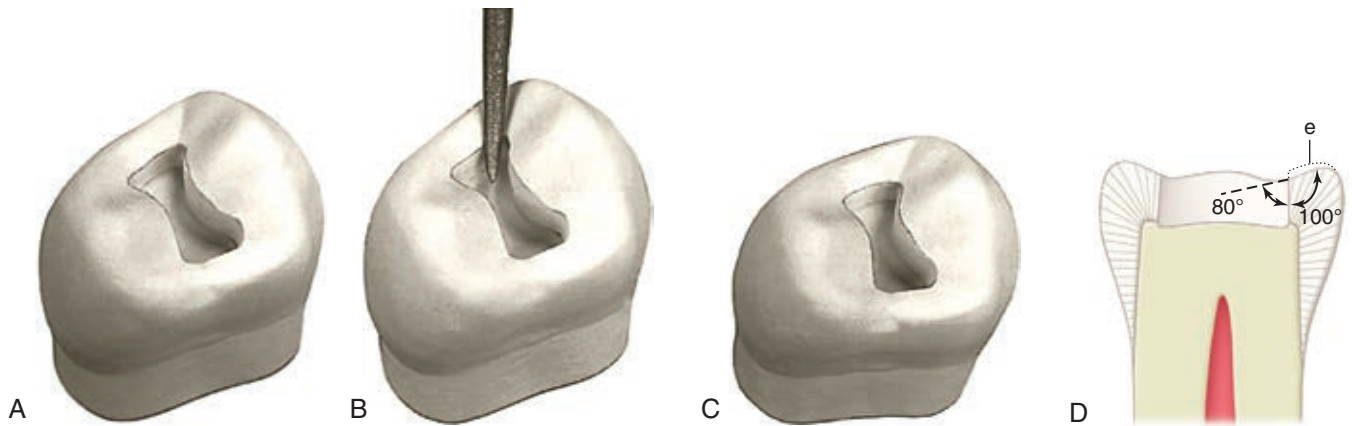


Fig. 14-8 Enameloplasty. **A**, Developmental defect at terminal end of fissure. **B**, Fine-grit diamond stone in position to remove the defect. **C**, Smooth surface after enameloplasty. **D**, The cavosurface angle should not exceed 100 degrees, and the margin–amalgam angle should not be less than 80 degrees. Enamel external surface (e) before enameloplasty.

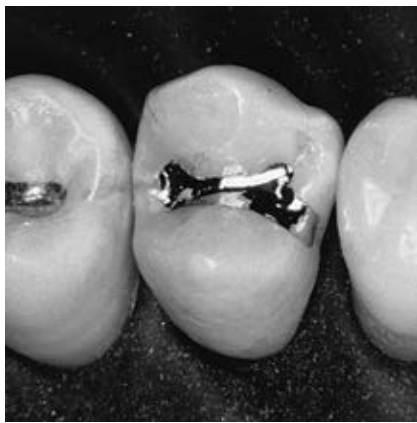


Fig. 14-9 Mesial fissure that cannot be eliminated by enameloplasty may be included in the preparation if the margins can be lingual of contact.

pulp protection, where indicated; (3) procedures for finishing the external walls; and (4) final procedures of cleaning and inspecting the prepared tooth. The use of desensitizers or bonding systems is considered the first step of the restorative technique.

If several enamel pit-and-fissure remnants remain in the floor, or if a central fissure remnant extends over most of the floor, the floor should be deepened with the No. 245 bur to eliminate the defect or to uncover the caries (Fig. 14-10). If these remnants are few and small, they can be removed with an appropriate carbide bur (Fig. 14-11). Removal of the remaining infected dentin (i.e., caries that extends pulpally from the established pulpal floor) is best accomplished using a discoid-type spoon excavator or a slowly revolving round carbide bur of appropriate size (Fig. 14-12, A and B). Using the largest instrument that fits the carious area is safest because it is least likely to penetrate the tooth in an uncontrolled manner. When removing infected dentin, the excavation should be stopped when the tooth structure feels hard or firm (i.e., the same feel as sound dentin). This situation often occurs before all lightly stained or discolored dentin is removed.³² A sharp explorer or hand instrument is more reliable than a rotating bur for judging the adequacy of removal

of infected dentin. These instruments should be used judiciously, however, in areas of possible pulpal exposure.

The removal of carious dentin should not affect the resistance form further because the periphery would not need further extension. In addition, it should not affect the resistance form if the restoration is to rest on the pulpal wall peripheral to the excavated area or areas. The peripheral pulpal floor should be at the previously described initial pulpal floor depth just inside the DEJ (see Fig. 14-12, C and D).

If the tooth preparation is of ideal or shallow depth, no liner or base is indicated. In deeper caries excavations (where the remaining dentin thickness is judged to be 0.5 to 1 mm), a thin layer (i.e., 0.5–0.75 mm) of a light-activated, resin-modified glass ionomer (RMGI) material should be placed.^{33,34} The RMGI insulates the pulp from thermal changes, bonds to dentin, releases fluoride, is strong enough to resist the forces of condensation, and reduces microleakage.³⁴⁻³⁶ The RMGI is applied only over the deepest portion of the excavation. The entire dentin surface should not be covered (Fig. 14-13). Dentin peripheral to the liner should be available for support of the restoration.³⁷ The external walls already have been finished during earlier steps in this conservative tooth preparation for amalgam. An occlusal cavosurface bevel is contraindicated in the tooth preparation for an amalgam restoration.³⁸ It is important to provide an approximate 90- to 100-degree cavosurface angle, which should result in 80- to 90-degree amalgam at the margins.³¹ This butt-joint margin of enamel and amalgam is the strongest for both. Amalgam is a brittle material with low edge strength and tends to chip under occlusal stress if its angle at the margins is less than 80 degrees.

The completed tooth preparation should be inspected and cleaned before restoration. The tooth preparation should be free of debris after the tooth has been rinsed with the air-water syringe. Disinfectants that are available may be used for cleaning the tooth preparation, but this is not considered essential.^{28,39} A cotton pellet or a commercially available applicator tip moistened only with water is generally used.

OTHER CONSERVATIVE CLASS I AMALGAM PREPARATIONS

Several other conservative Class I preparations may be restored with composite because of their small size and the maximal

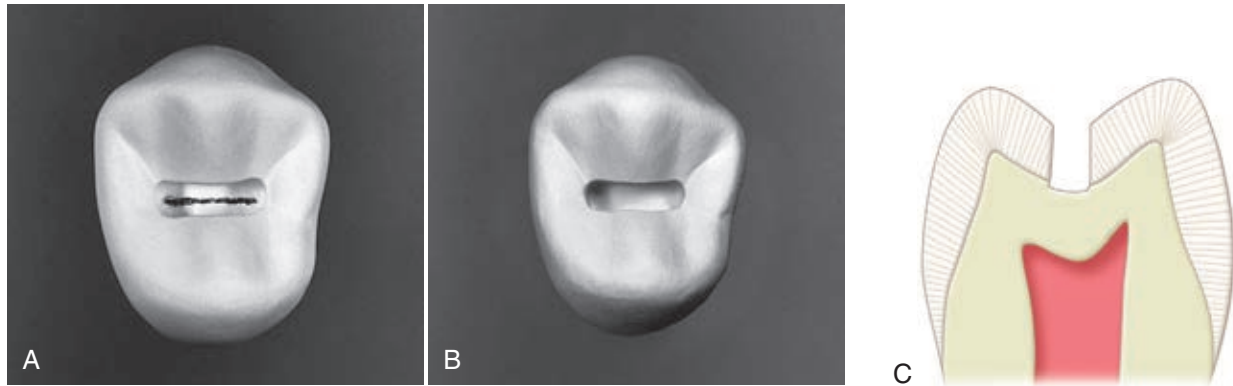


Fig. 14-10 Removal of enamel fissure extending over most of the pulpal floor. **A**, Full-length occlusal fissure remnant remaining on the pulpal floor after the initial tooth preparation. **B** and **C**, The pulpal floor is deepened to a maximum depth of 2 mm to eliminate the fissure or uncover dental caries.

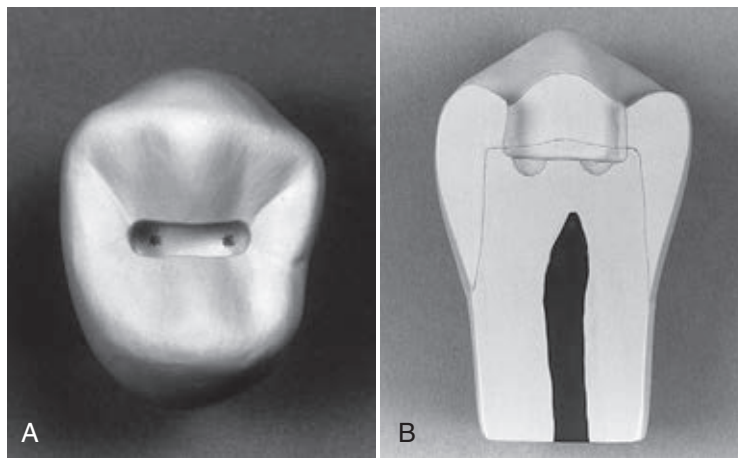


Fig. 14-11 Removal of enamel pit and fissure and infected dentin that is limited to a few small pit-and-fissure remnants. **A**, Two pit remnants remain on the pulpal floor after the initial tooth preparation. **B**, Defective enamel and infected dentin have been removed.

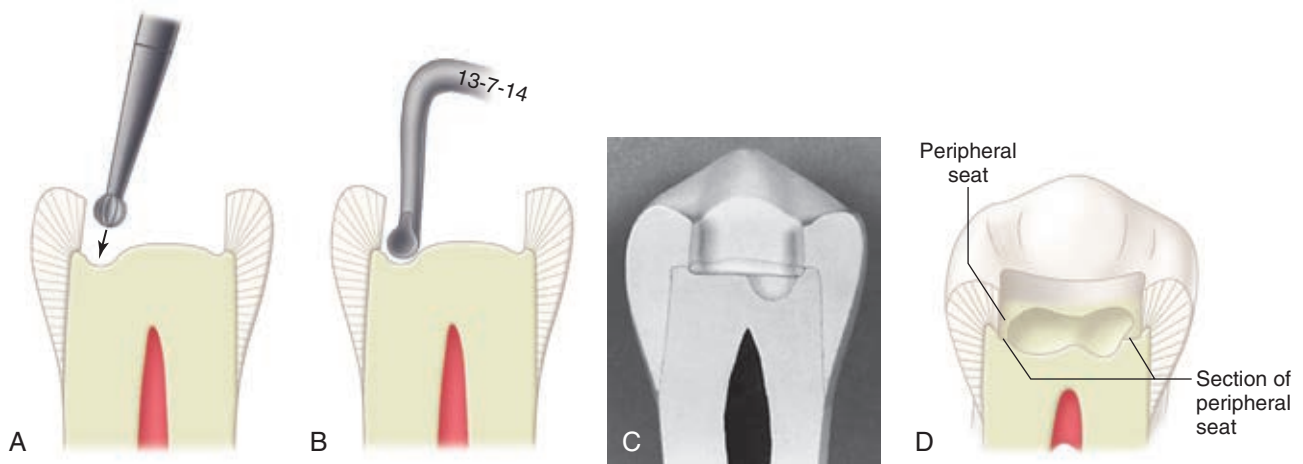


Fig. 14-12 **A** and **B**, Removal of dentinal caries is accomplished with round burs (**A**) or spoon excavators (**B**). **C** and **D**, The resistance form may be improved with a flat floor peripheral to the excavated area or areas.

thickness of enamel available for bonding around their periphery. However, these preparations could also be restored with amalgam. The preparations include the following:

- Facial pit of the mandibular molar
- Lingual pit of the maxillary lateral incisor
- Occlusal pits of the mandibular first premolar
- Occlusal pits and fissures of the maxillary first molar
- Occlusal pits and fissures of the mandibular second premolar

Examples of some of these types of preparations and restorations are provided in Figures 14-14 through 14-19.

Restorative Technique for Class I Amalgam Preparations

DESENSITIZER PLACEMENT

A dentin desensitizer is placed in the preparation before amalgam condensation (Fig. 14-20).⁴⁰ The dentin desensitizer is applied onto the prepared tooth surface according to manufacturer's recommendations; excess moisture is removed

without desiccating the dentin; and then the amalgam is condensed into place. The dentin desensitizer precipitates protein and forms lamellar plugs in the dentinal tubules.⁴¹ These plugs are thought to be responsible for reducing the permeability and sensitivity of dentin. Dentin may not be totally sealed by a desensitizing agent because no hybrid layer is formed as in bonding procedures. If amalgam adhesives are used, a separate desensitizing agent is usually unnecessary. However, concerns exist about the long-term durability of amalgam adhesives and whether resin adhesives may interfere with the self-sealing capability of the amalgam.^{15,42-44}

MATRIX PLACEMENT

Generally, matrices are unnecessary for a conservative Class I amalgam restoration except as specified in later sections.

INSERTION AND CARVING OF THE AMALGAM

Because of its superior clinical performance, high-copper amalgam is recommended. Pre-proportioned, disposable capsules are available in sizes ranging from 400 to 800 mg. Some pre-capsulated brands require activation of the capsules before trituration. Amalgam should be trituated (i.e., mixed) according to the manufacturer's directions. It is often necessary to

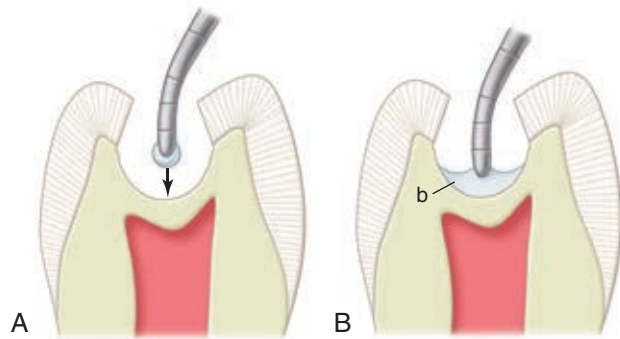


Fig. 14-13 Base application. **A**, Inserting resin-modified glass ionomer (RMGI) with periodontal probe. **B**, In moderately deep excavations, a base (*b*) thickness of 0.5 to 0.75 mm is indicated.



Fig. 14-15 Carious lingual pit and fissure and restoration on the maxillary lateral incisor.

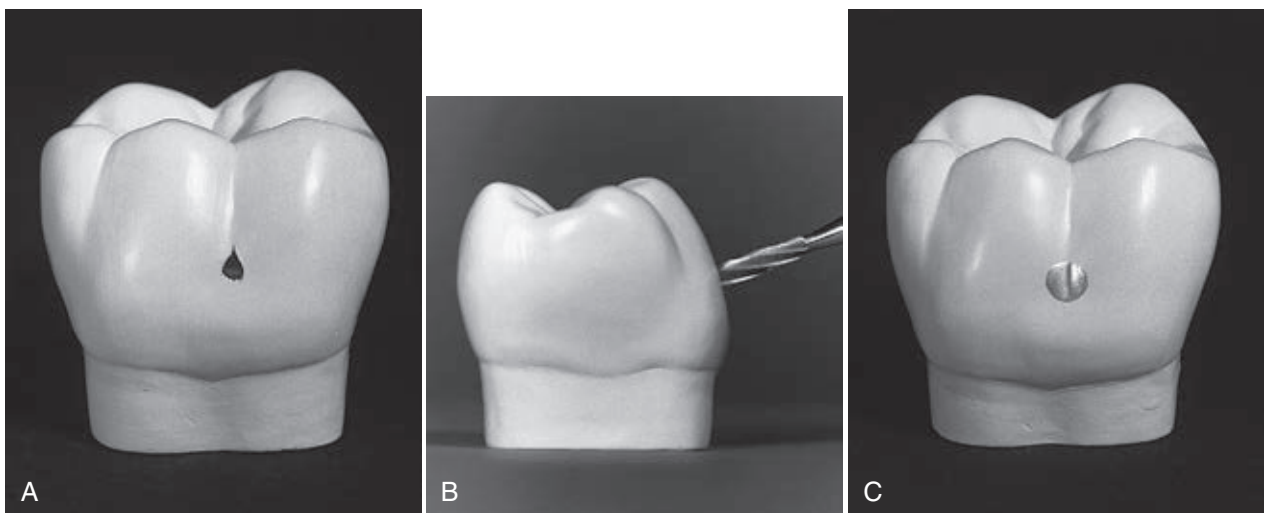


Fig. 14-14 Mandibular molar. **A**, Carious facial pit. **B**, The bur positioned perpendicular to the tooth surface for entry. **C**, Outline of restoration.

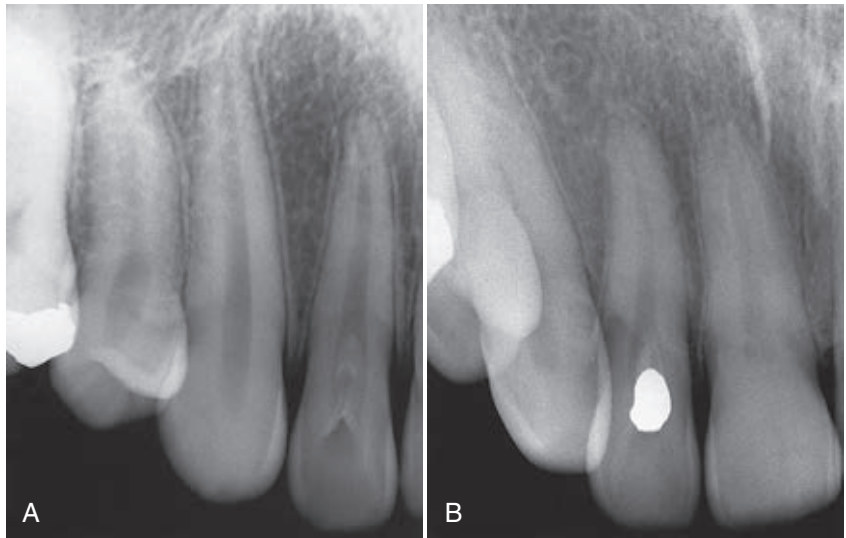


Fig. 14-16 Maxillary lateral incisor. **A**, Pre-operative radiograph of dens in dente. **B**, Radiograph of restoration after 13 years. (Courtesy of Dr. Ludwig Scott.)

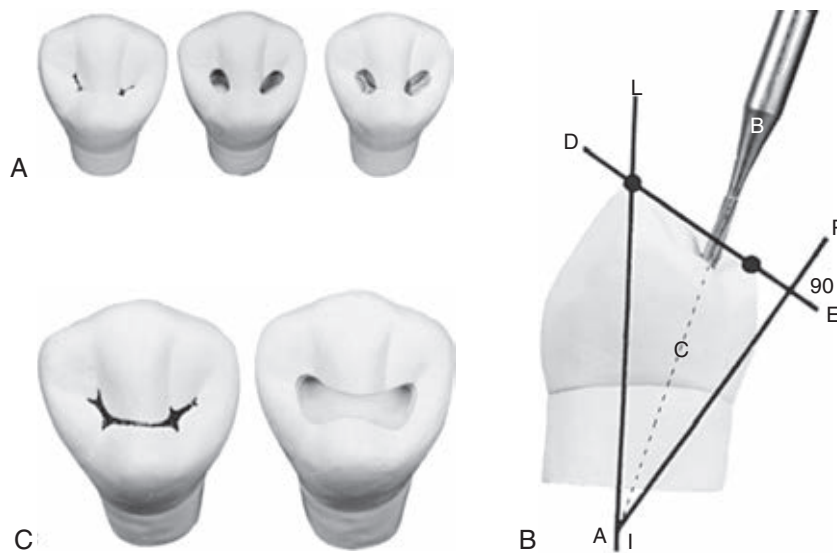


Fig. 14-17 **A**, Preparation design and restoration of carious occlusal pits on the mandibular first premolar. **B**, Bur tilt for entry. The cutting instrument is held such that its long axis (*broken line, C*) is parallel with the bisector (*B*) of the angle formed by the long axis of the tooth (*LA*) and the line (*P*) that is perpendicular to the plane (*DE*) drawn through the facial and lingual cusp points. This dotted line (*C*) is the bur position for entry. **C**, Conventional outline, including occlusal pits and central fissure.

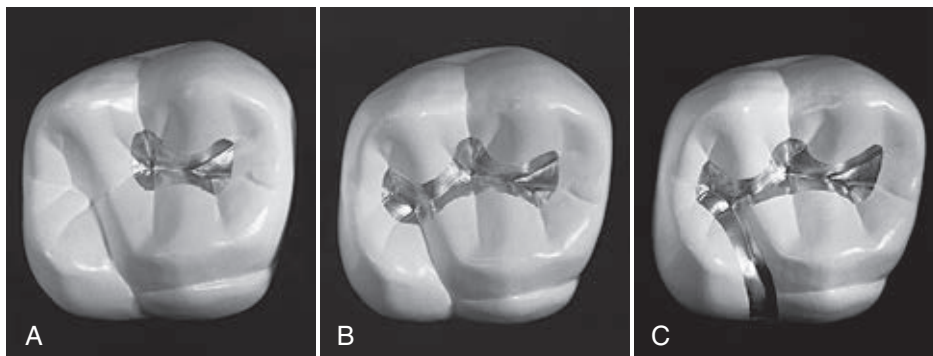


Fig. 14-18 Maxillary first molar. **A**, Outline necessary to include the mesial and central pits connected by the fissure. **B**, Preparation outline extended from outline in **A** to include distal pit and connecting deep fissure in oblique ridge. **C**, Preparation outline extended from outline in **B** to include distal oblique and lingual fissures.

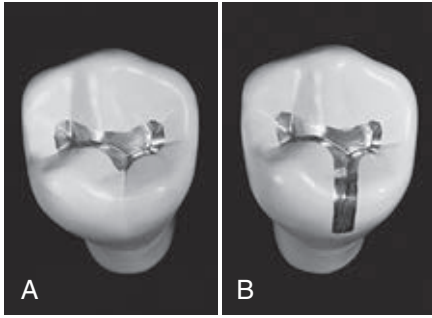


Fig. 14-19 Mandibular second premolar. **A**, Typical occlusal outline. **B**, Extension through the lingual ridge enamel is necessary when enameloplasty does not eliminate the lingual fissure.



Fig. 14-20 Use of microbrush to apply the dentin desensitizer through-out tooth preparation. (Courtesy Aldridge D. Wilder, DDS.)

make several mixes to complete the restoration, particularly for large preparations. The triturated amalgam is emptied into an amalgam well (Fig. 14-21, A). Correctly mixed amalgam should not be dry and crumbly. It has a minimal, yet sufficient, “wetness” to aid in achieving a homogeneous and well-adapted restoration.²⁵

The principal objectives during the insertion of amalgam are to condense the amalgam to adapt it to the preparation walls and the matrix (when used) and produce a restoration free of voids. Thorough condensation helps to reduce marginal leakage.^{45,46} Optimal condensation also is necessary to minimize the mercury content in the restoration to decrease corrosion and to enhance strength and marginal integrity.⁴⁷ Condensation of amalgam that contains spherical particles requires larger condensers than are commonly used for admixed amalgam. Smaller condensers tend to penetrate a mass of spherical amalgam, resulting in less effective force to compact or adapt the amalgam within the preparation. In contrast, smaller condensers are indicated for the initial increments of admixed amalgam because it is more resistant to condensation pressure. Because the area of a circular condenser face increases by the square of the diameter, doubling the diameter requires four times more force for the same pressure on a unit area.

The outline of the tooth preparation should be reviewed before inserting amalgam to allow the formation of a mental

image that will later aid in carving amalgam to the cavosurface margin. Pre-operative occlusal contact locations should be recalled (see Fig. 14-21, B). An amalgam carrier is used to transfer amalgam to the tooth preparation. Increments extruded from the carrier should be smaller (often only 50% or less of a full-carrier tip) for a small preparation, particularly during the initial insertion. A flat-faced, circular or elliptic condenser should be used to condense amalgam over the pulpal floor of the preparation. Amalgam should be carefully condensed into the pulpal line angles (see Fig. 14-21, C). Usually, a smaller condenser is used while filling the preparation and a larger one for over-packing. Each portion is thoroughly condensed prior to placement of the next increment. Each condensed increment should fill only one-third to one-half the preparation depth. Each condensing stroke should overlap the previous condensing stroke to ensure that the entire mass is well condensed. The condensation pressure required depends on the amalgam used and the diameter of the condenser nib. Condensers with larger diameter nibs require greater condensation pressure. The preparation should be over-packed 1 mm or more using heavy pressure (see Fig. 14-21, D); this ensures that the cavosurface margins are completely covered with well-condensed amalgam. Final condensation over cavosurface margins should be done perpendicular to the external enamel surface adjacent to the margins.

The condensation of a mix should be completed within the time specified by the manufacturer (usually 2.5 to 3.5 minutes). Otherwise, crystallization of the unused portion is too advanced to react properly with the condensed portion. The mix should be discarded if it becomes dry and another mix quickly made to continue the insertion.

To ensure that the marginal amalgam is well condensed before carving, the over-packed amalgam should be burnished immediately with a large burnisher, using heavy strokes mesiodistally and faciolingually, which is referred to as *pre-carve burnishing*. To maximize its effectiveness, the burnisher head should be large enough that in the final strokes, it contacts the cusp slopes but not the margins (see Fig. 14-21, E). Pre-carve burnishing produces denser amalgam at the margins of the occlusal preparations restored with high-copper amalgam alloys and initiates contouring of the restoration.^{48,49}

CONTOURING AND FINISHING OF THE AMALGAM

With care, carving may begin immediately after condensation. Sharp discoid–cleoid carvers of suitable sizes are recommended. The larger end of the discoid–cleoid instrument (No. 3–No. 6) is used first, followed by the smaller instrument (No. 4 or No. 5) in regions not accessible to the larger instrument. Alternatively, the Hollenback carver can be used. All carving should be done with the edge of the blade perpendicular to the margins as the instrument is moved parallel to the margins. Part of the edge of the carving blade should rest on the unprepared tooth surface adjacent to the preparation margin (see Fig. 14-21, F). Using this surface as a guide helps prevent over-carving amalgam at the margins and to produce a continuity of surface contour across the margins.

Deep occlusal grooves should not be carved into the restoration because these may thin the amalgam at the margins, invite chipping, and weaken the restoration (see Fig. 14-21, G). Under-carving leaves thin portions of amalgam

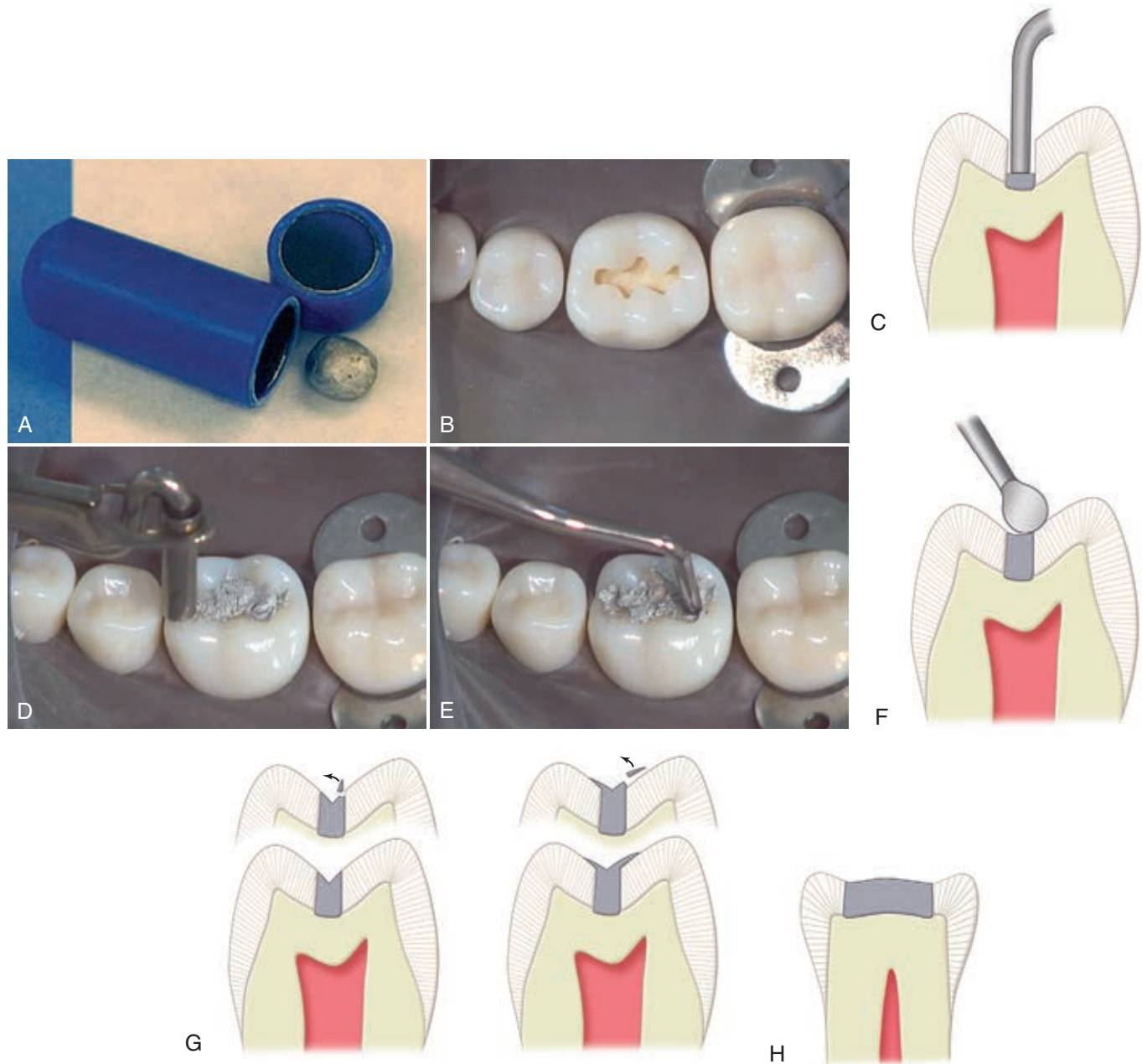


Fig. 14-21 Restoration of occlusal tooth preparation. **A**, Properly triturated amalgam is a homogeneous mass with slightly reflective surface. It flattens slightly if dropped on a tabletop. **B**, The operator should have a mental image of the outline form of the preparation before condensing amalgam to aid in locating the cavosurface margins during the carving procedure. **C**, Amalgam should be inserted incrementally and condensed with overlapping strokes. **D**, The tooth preparation should be over-packed to ensure well-condensed marginal amalgam that is not mercury-rich. **E**, Pre-carve burnishing with a large burnisher is a form of condensation. **F**, The carver should rest partially on the external tooth surface adjacent to the margins to prevent over-carving. **G**, Deep occlusal grooves invite chipping of amalgam at the margins. Thin portions of amalgam left on the external surfaces soon break away, giving the appearance that amalgam has grown out of the preparation. **H**, Carve fossae slightly deeper than the proximal marginal ridges. (**A**, From Darby ML, Walsh MM: Dental hygiene: theory and practice, ed 3, St. Louis, Saunders, 2010. **B**, **D**, **E** Courtesy of Aldridge D. Wilder, DDS.)

(subject to fracture) on the unprepared tooth surface. The thin portion of amalgam extending beyond the margin is referred to as *flash*. The mesial and distal fossae should be carved slightly deeper than the proximal marginal ridges (see Fig. 14-21, *H*).

After carving is completed, the outline of the amalgam margin should reflect the contour and location of the prepared cavosurface margin. An amalgam outline that is larger

or irregular is under-carved and requires further carving or finishing (Fig. 14-22). An amalgam restoration that is more than minimally over-carved (i.e., a submarginal defect >0.2 mm) should be replaced.⁵⁰ If the total carving time is short enough, the smoothness of the carved surface may be improved by wiping with a small, damp ball of cotton held in the operating pliers. All shavings from the carving procedure should be removed from the mouth with the aid of the oral evacuator.

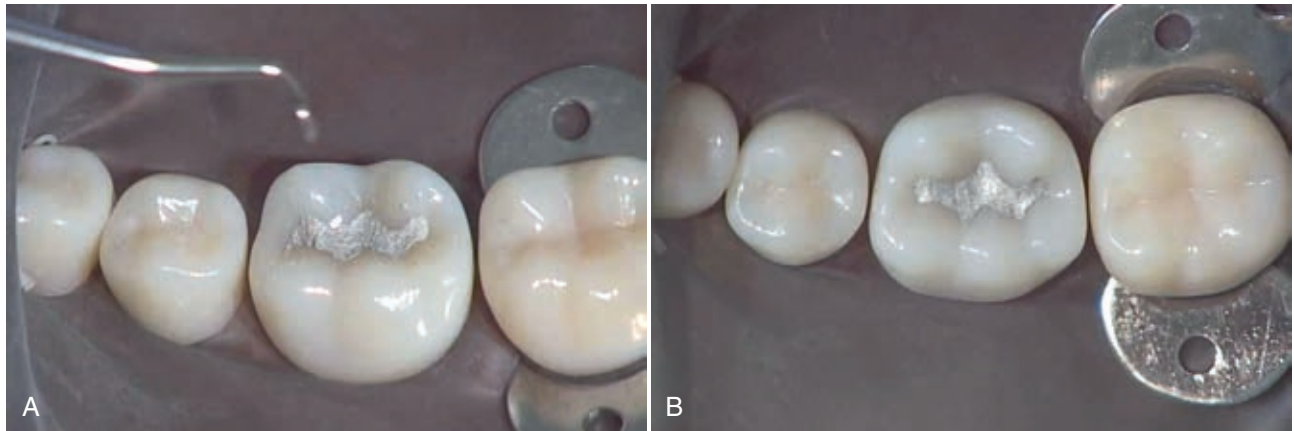


Fig. 14-22 **A**, Under-carved amalgam with flash beyond the margins. The restoration outline is irregular and larger than the preparation outline in Figure 14-21, **B**, Correctly carved amalgam restoration. (Courtesy of Aldridge D. Wilder, DDS.)

Some operators prefer to perform post-carve burnishing of the amalgam surface by using a small burnisher. Post-carve burnishing is done by lightly rubbing the carved surface with a burnisher of suitable size and shape to improve smoothness and produce a satin (not shiny) appearance. The surface should not be rubbed hard enough to produce grooves in the amalgam. Post-carve burnishing may improve the marginal integrity of low- and high-copper amalgams and may improve the smoothness of the restoration.^{51,52} Post-carve burnishing in conjunction with pre-carve burnishing may serve as a viable substitute for conventional polishing.⁵³

Next, the occlusion of the restoration must be evaluated. After completion of the carving and during the removal of the rubber dam or cotton rolls, the patient is advised not to bite because of the danger of fracturing the restoration, which is weak at this stage. Even if the carving has been carefully accomplished, the restoration occasionally is “high,” indicating a premature occlusal contact. The contact potential of the restored tooth and the extent of closure are visualized, whenever possible. A piece of articulating paper is placed over the restoration, and the patient is instructed to close gently into occlusion. If the effect of anesthesia is still present, it may be difficult for the patient to tell when the teeth are in contact. After the patient has reopened the mouth and the articulating paper is removed, the following two features of the occlusal relationship suggest that the restoration is high:

1. Cusp tips of adjacent teeth are not in occlusal contact when it is known from the pre-operative occlusal assessment that they should be touching.
2. A cusp that occludes with the new restoration contacts prematurely.

Any contact area can be recognized on the amalgam by the depth of color imparted by the paper (and especially if the colored area has a silvery center). The deeper-colored or shiny-centered areas are reduced until all markings are uniformly of a light hue (and with no shiny centers), and contacts are noted on adjacent teeth (Fig. 14-23). Observing the space (short of touching) between surfaces of nearby teeth indicates how much to reduce when carving. If these opposing surfaces are 0.5 mm apart (by visual estimation), the high area should be

reduced by approximately that amount. This expedites the occlusal adjustment compared with making an insufficient, shallower carving adjustment and then having to repeat closure and carving numerous times. The sequence of closure, observation, and carving is repeated until the appropriate surfaces of opposing teeth are touching. Carving should be accomplished so that opposing cusps contact on a surface that is perpendicular to the occlusal forces in maximum intercuspation. Occlusal contacts located on a cuspal incline or ridge slope are undesirable because they cause a deflective force on the tooth and should be adjusted until the resulting contact is stable (i.e., the force vector of the occlusal contacts should parallel the long axis of the tooth). The final anatomy of the restoration should be patterned after normal occlusal contours. The tip of an explorer should pass from the tooth surface to the restoration surface (and vice versa), without jumping or catching, thus verifying continuity of contour across the margin.

Up to this point, the patient has been instructed to close vertically into maximum intercuspation. After placing the articulating paper over the tooth, the patient is asked to occlude lightly and to slide the teeth lightly from side to side. Any additional occlusal marks are evaluated, and undesirable contact areas are eliminated. Appropriate caution is indicated, as amalgam restorations carved out of occlusion may result in undesirable tooth movement. Finally, the patient should be cautioned to protect the restoration from any heavy biting pressure for 24 hours.

Most amalgams do not require further finishing and polishing. These procedures are occasionally necessary, however, to (1) complete the carving; (2) refine the anatomy, contours, and marginal integrity; and (3) enhance the surface texture of the restoration. Additional finishing and polishing procedures for amalgam restorations are not attempted within 24 hours of insertion because crystallization is incomplete.²⁵ If used, these procedures are often delayed until all of the patient’s amalgam restorations have been placed, rather than finishing and polishing periodically during the course of treatment. An amalgam restoration is less prone to tarnish and corrosion if a smooth, homogeneous surface is achieved.^{25,31,54} Polishing of high-copper amalgams is less important than it is for low-copper amalgams because high-copper amalgams are less susceptible to tarnishing and marginal breakdown.^{5,55-60}

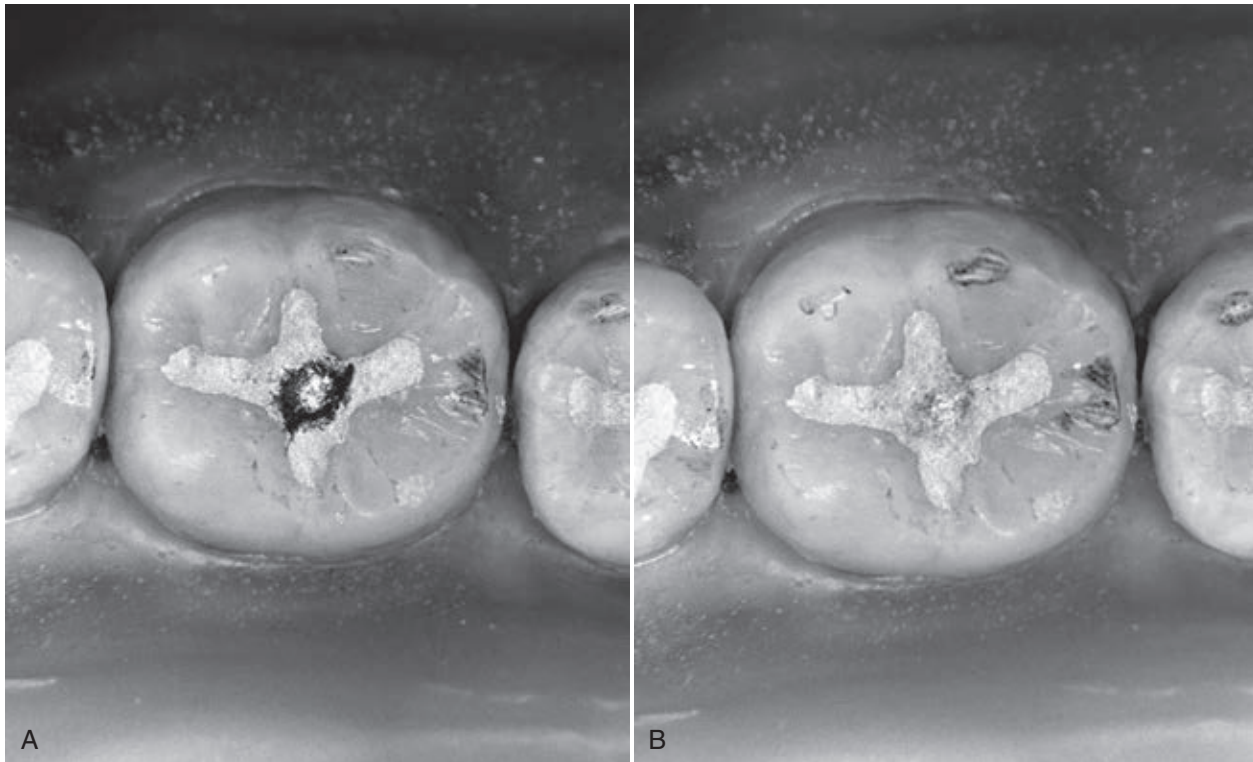


Fig. 14-23 Occluding the restoration. **A**, Heavy occlusal contacts on new amalgam should be avoided. Articulating paper marks heavy contacts as dark areas, and it marks very heavy contacts as dark areas with shiny centers. **B**, Amalgam should not be carved out of occlusion. Rather, it should have light occlusal contact or contacts, as indicated by faint markings.

The finishing procedure is initiated by marking the occlusion with articulating paper and evaluating the margins with an explorer. If the occlusion can be improved, or a continuity of surface contour across the margins is not present, a white alumina stone or a green carborundum stone is used to correct the discrepancy (Fig. 14-24, A). The green stone is more abrasive than the white stone; the tip of either stone may be blunted on a diamond wheel before use. This helps prevent marring the center of the restoration while the margins are being adjusted. During the surfacing of amalgam, the stone's long axis is held at a 90-degree angle to the margins. Reduction of any occlusal contact should be avoided. After the stone is used, the margins should be re-evaluated with an explorer tine. If no discrepancy is detected, the area may be smoothed further using light pressure with an appropriate finishing bur (see Fig. 14-24, B). A large, round finishing bur (comparable with a No. 4 or No. 6) is generally used for this finishing step. If the groove and fossa features are not sufficiently defined, a small round finishing bur also may accentuate them without reducing the centric holding areas. The long axis of the bur or stone should be at a 90-degree angle to the margin to allow the unprepared tooth structure to guide the bur and prevent unnecessary removal of amalgam (see Fig. 14-24, C). A smooth surface should be achieved before the polishing procedure is initiated. The finishing bur should remove the minor scratches which resulted from use of the green or white stone. Often, however, these scratches can be removed only with the use of a rubber abrasive point.

The polishing procedure is started by using a coarse, rubber abrasive point at low speed and air-water spray to produce an amalgam surface with a smooth, satiny appearance (see Fig.

14-24, D and E). If the amalgam surface does not exhibit this appearance after only a few seconds of polishing, the surface was too rough at the start. In this instance, resurfacing with a finishing bur is necessary, followed by the coarse, rubber abrasive point to develop the satiny appearance. It is important that the rubber points be used at low speed or just above "stall out" speed for two reasons:

1. The danger of the point disintegrating at high speeds
2. The danger of elevating the temperature of the restoration and the tooth

An excessive temperature increase (i.e., >140°F [>60°C]) can cause irreparable damage to the pulp, the restoration, or both. When overheated, the amalgam surface appears cloudy, even though it may have a high polish. This cloudy appearance indicates that mercury has been brought to the surface, which results in corrosion of the amalgam and loss of strength.²⁵

After polishing with the coarse, abrasive rubber point, no deep scratches should remain on the amalgam surface, only the moderately polished surface left by the rubber point. After the area is washed free of abrasive particles, a high polish may be imparted to the restoration with a series of medium-grit and fine-grit abrasive points (see Fig. 14-24, F). As with the more abrasive points, the finer abrasive points must be used at a low speed. If a high luster does not appear within a few seconds, the restoration requires additional polishing with the more abrasive points. The system that is illustrated includes coarse-grit, medium-grit, and fine-grit rubber abrasive points. Using these points in sequence, from coarse to fine, produces an amalgam surface with a brilliant luster (see Fig. 14-24, G).

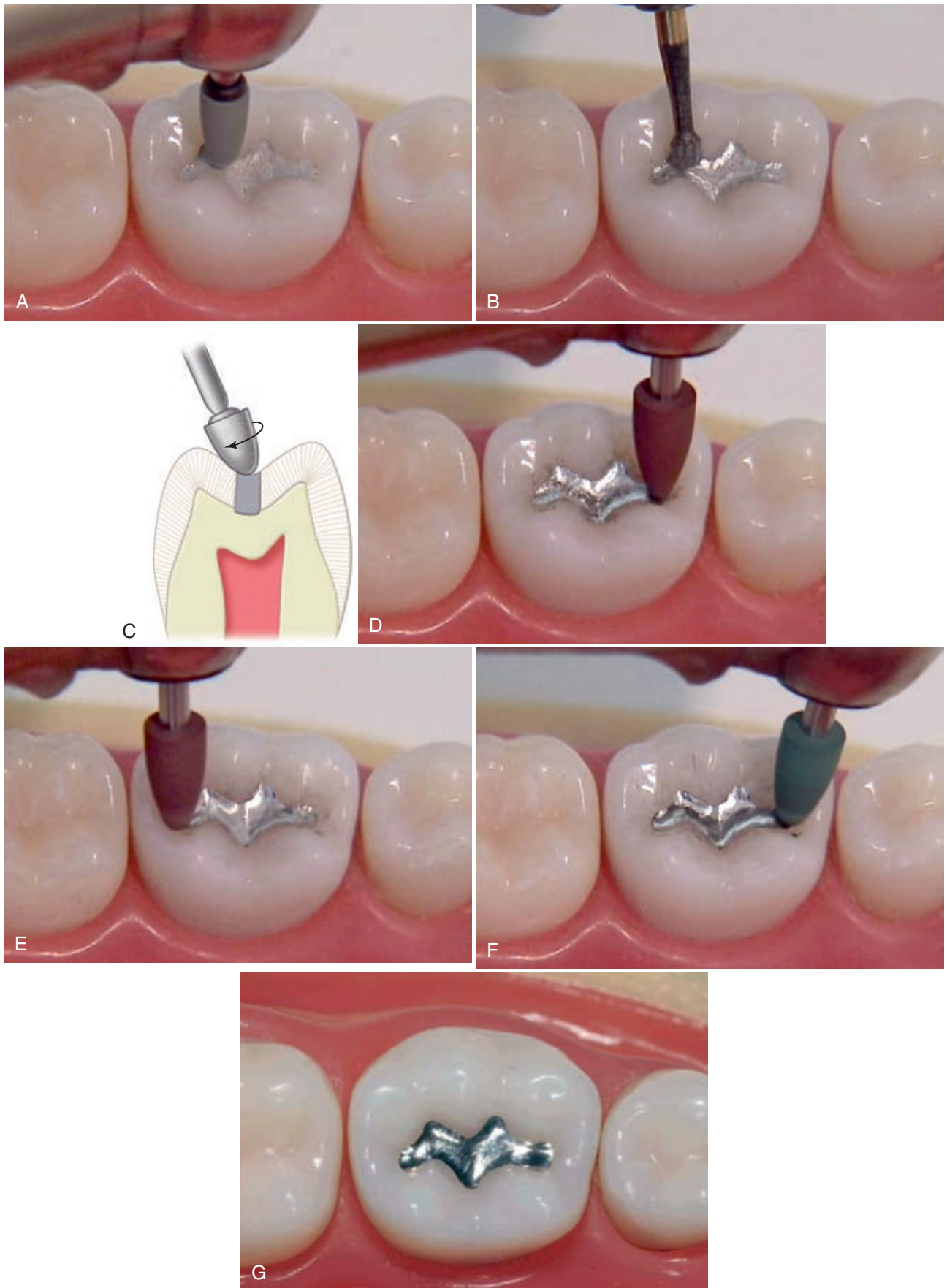


Fig. 14-24 Polishing the amalgam. **A**, When necessary, fine-grit alumina or carborundum stone is used to develop continuity of surface from the tooth to the restoration. **B**, The restoration is surfaced with a round finishing bur. **C**, The stone's long axis or the bur's long axis is held at a right angle to the margin. **D**, Polishing is initiated with a coarse, rubber abrasive point at low speed. **E**, The point should produce a smooth, satiny appearance. **F**, A high polish is obtained with medium-grit and fine-grit abrasive points. **G**, Polished restoration. (Courtesy of Aldridge D. Wilder, DDS.)

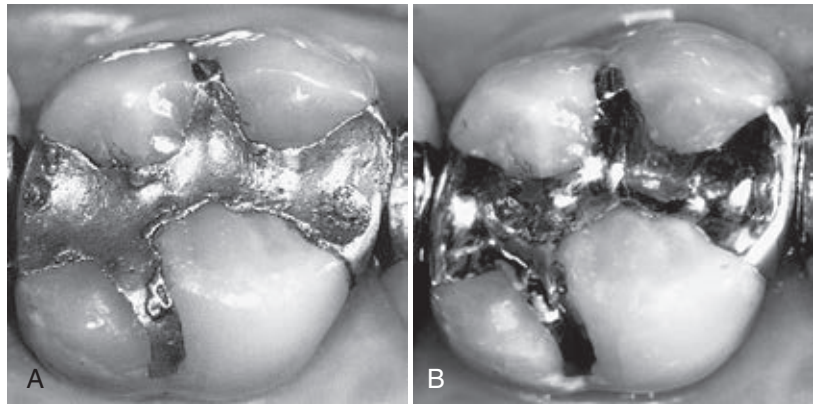


Fig. 14-25 **A**, Existing amalgam restoration exhibiting marginal deterioration and surface roughness. **B**, Same restoration after finishing and polishing.

As an alternative to rubber abrasive points, final polishing may be accomplished using a rubber cup with flour of pumice followed by a high-luster agent, such as precipitated chalk. Finishing and polishing of older, existing restorations may be performed to improve their contour, margins, surface, or anatomy, when indicated (Fig. 14-25).

Extensive Class I Amalgam Restorations

Caries is considered extensive if the distance between infected dentin and the pulp is judged to be less than 1 mm or when the faciolingual extent of the defect is up the cuspal inclines. Extensive caries requires a more extensive restoration (which is a more typical indication for amalgam). The use of amalgam in large Class I restorations provides good wear resistance and occlusal contact relationships. For very large Class I restorations, a bonding system may be used, although this book no longer promotes such use. The perceived benefits of bonded amalgams have not been substantiated.^{58,61-63} Bonded amalgams have no advantages compared with the conventional technique, when done correctly.

Initial Clinical Procedures

The rubber dam should be used for isolation of the operating site when caries is extensive. If caries excavation exposes the pulp, pulp capping may be more successful if the site is isolated with a properly applied rubber dam. In addition, the dam prevents moisture contamination of the amalgam mix during insertion.²⁵

Tooth Preparation

INITIAL TOOTH PREPARATION

In teeth with extensive caries, excavation of infected dentin and, if necessary, insertion of a liner may precede the establishment of the outline, resistance, and retention forms. This approach protects the pulp as early as possible from any additional insult of tooth preparation. Normally, however, the outline form and the primary resistance and retention forms are established through proper orientation of the No. 245 bur and preparation extension. An initial depth to reach the DEJ (measured approximately 1.5 mm at any pit or fissure and 2 mm on the prepared external walls) should be established and maintained. The preparation is extended laterally at the

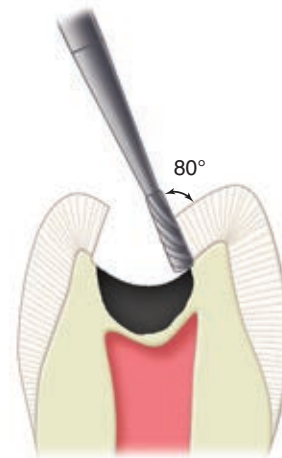
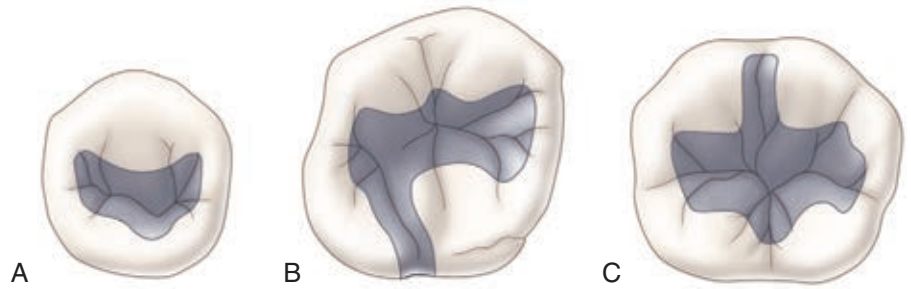


Fig. 14-26 Initial tooth preparation with extensive caries. When extending laterally to remove enamel undermined by caries, the bur's long axis is altered to prepare a 90- to 100-degree cavosurface angle. A 100-degree cavosurface angle on the cuspal incline results in an 80-degree marginal amalgam angle.

DEJ to remove all enamel undermined by caries by alternately cutting and examining the lateral extension of the caries. For caries extending up the cuspal inclines, it may be necessary to alter the bur's long axis to prepare a 90- to 100-degree cavosurface angle while maintaining the initial depth (Fig. 14-26). If not, a significantly obtuse cavosurface angle may remain (resulting in an acute, or weak, amalgam margin), or the pulpal floor may be prepared too deeply. The primary resistance form is obtained by extending the outline of the tooth preparation to include only undermined and defective tooth structure while preparing strong enamel walls and allowing strong cuspal areas to remain. Primary retention is obtained by the occlusal convergence of the enamel walls; the secondary retention form may result from undercut areas that are occasionally left in dentin (and that are not covered by a liner) after removal of infected dentin.

When extending the outline form, enameloplasty should be used, when possible (as described previously). When the defect extends to more than one-half the distance between the primary groove and a cusp tip, capping the cusp (i.e., reducing the cuspal tooth structure and restoring it with amalgam) may

Fig. 14-27 Examples of Class I amalgam tooth preparation outline forms. **A**, Occlusal outline form in the mandibular second premolar. **B**, Occlusolingual outline form in the maxillary first molar. **C**, Occlusofacial outline form in the mandibular first molar.



be indicated. When that distance is two-thirds, cusp capping usually is required because of the risk of cusp fracture post-operatively. Figure 14-27 illustrates some examples of large Class I amalgam preparation outlines.

FINAL TOOTH PREPARATION

Removal of any remaining infected dentin is accomplished in the same manner as described previously for the conservative preparation. Pulp exposure will require a direct pulp cap with calcium hydroxide or endodontic treatment.

For pulpal protection in very deep caries excavations (where the remaining dentin thickness is judged to be <0.5 mm and a pulpal exposure is suspected), a thin layer (i.e., 0.5–0.75 mm) of a calcium hydroxide liner may be placed. The calcium hydroxide liner may stimulate secondary dentin formation in an area where a micro-exposure is suspected or may elicit tertiary dentin formation if the original odontoblasts were no longer vital. If the calcium hydroxide liner is used, it is placed by using the same instrument and the same technique as described for the RMGI liner. The calcium hydroxide liner should be placed only over the deepest portion of the excavation (nearest the pulp). An RMGI base should be used to cover the calcium hydroxide.⁴⁷ The entire dentin surface should not be covered (Fig. 14-28). The RMGI base is recommended to cover the calcium hydroxide to resist the forces of condensation and to prevent dissolution over time by sealing the deeply excavated area.³⁵ Usually, no secondary resistance or retention form features are necessary for extensive Class I amalgam preparations. The external walls of the preparation are finished as described previously.

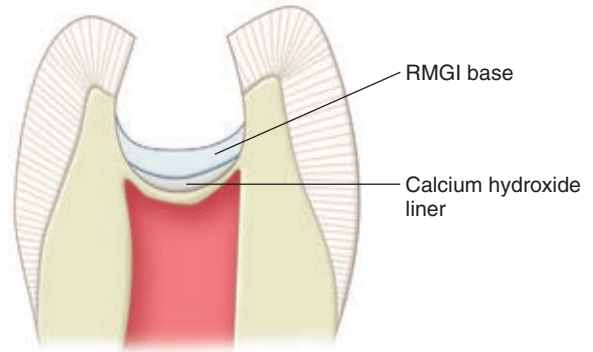


Fig. 14-28 Placement of calcium hydroxide liner and resin-modified glass ionomer (RMGI) base.

Restorative Technique

After any indicated liner or base has been placed, regardless of the depth of the excavation, a dentin desensitizer is used. Trituration of the amalgam material is performed as described previously. The preparation is slightly overfilled, and final condensation is enhanced with precarve burnishing. Carving the extensive Class I restoration is often more complex because more cuspal inclines are included in the preparation. Appropriate contours, occlusal contacts, and groove and fossa anatomy must be provided. Finishing and polishing indications and techniques are as described previously.

Class I Occlusolingual Amalgam Restorations

Occlusolingual amalgam restorations may be used on maxillary molars when a lingual fissure connects with the distal

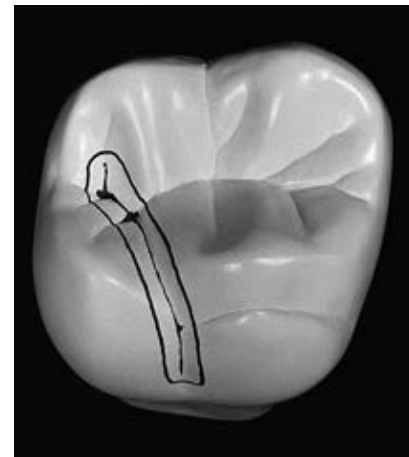


Fig. 14-29 Outline of margins for occlusolingual tooth preparation.

oblique fissure and distal pit on the occlusal surface (Fig. 14-29). Composite also may be used as the restorative material, especially in smaller restorations.

Initial Clinical Procedures

After local anesthesia and evaluation of the occlusal contacts, the use of a rubber dam is generally recommended for isolation of the operating field. In most cases, typical Class I preparations can be adequately isolated with cotton rolls.



Fig. 14-30 Small distal inclination of the bur on smaller teeth may be indicated to conserve the dentinal support and the strength of the marginal ridge.

Tooth Preparation

The initial tooth preparation involves the establishment of the outline, primary resistance, and primary retention forms, as well as initial preparation depth. The accepted principles of the outline form (previously presented) should be observed with special attention to the following:

- The tooth preparation should be no wider than necessary; ideally, the mesiodistal width of the lingual extension should not exceed 1 mm except for extension necessary to remove carious or undermined enamel or to include unusual fissuring.
- When indicated, the tooth preparation should be cut more at the expense of the oblique ridge, rather than centering over the fissure (weakening the small distolingual cusp).
- Especially on smaller teeth, the occlusal portion may have a slight distal tilt to conserve the dentin support of the distal marginal ridge (Fig. 14-30).
- The margins should extend as little as possible onto the oblique ridge, distolingual cusp, and distal marginal ridge.

These objectives help conserve the dentinal support and the strength of the tooth, and they aid in establishing an enamel cavosurface angle as close to 90 degrees as possible (Fig. 14-31). They also minimize deterioration of the restoration margins by locating the margins away from enamel eminences where occlusal forces may be concentrated.

The distal pit is identified with indirect vision and entered with the end of the No. 245 bur (Fig. 14-32, A). The long axis of the bur usually should be parallel to the long axis of the tooth crown. The dentinal support and strength of the distal marginal ridge and the distolingual cusp should be observed, and the bur positioned such that it cuts more of the tooth structure mesial to the pit rather than distal to the pit (e.g., 70:30 rather than 50:50), if needed. The initial cut is to the level of the DEJ (a depth of 1.5 to 2 mm) (see Fig. 14-32, B). At this depth, the pulpal floor is usually in dentin. When the entry cut is made (see Fig. 14-32, C), the bur (maintaining the initial established depth) is moved to include any remaining fissures facial to the point of entry (see Fig. 14-32, D). The bur is then moved along the fissure toward the lingual surface (see Fig. 14-32, E). As with Class I occlusal preparations, a slight distal inclination of the bur is indicated occasionally (e.g.,

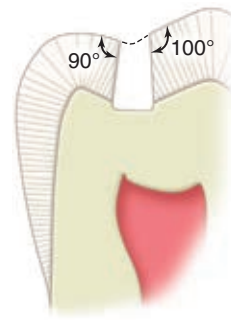


Fig. 14-31 Enamel cavosurface angles of 90 to 100 degrees are ideal.

smaller teeth) to conserve the dentinal support and strength of the marginal ridge and the distolingual cusp. To ensure adequate strength for the marginal ridge, the distopulpal line angle should not approach the distal surface of the tooth closer than 2 mm. On large molars, the bur position should remain parallel to the long axis of the tooth, particularly if the bur is offset slightly mesial to the center of the fissure. Keeping the bur parallel to the long axis of the tooth creates a distal wall with slight occlusal convergence, providing favorable enamel and amalgam angles. The bur is moved lingually along the fissure, maintaining a uniform depth until the preparation is extended onto the lingual surface (see Fig. 14-32, F). The pulpal floor should follow the contour of the occlusal surface and the DEJ, which usually rises occlusally as the bur moves lingually.

The mesial and distal walls of the occlusal portion of the preparation should converge occlusally because of the shape of the bur. This convergence provides a sufficient retention form to the occlusal portion of the preparation. If the slight distal bur tilt was required, the mesial and distal walls still should converge relative to each other (although the distal wall may be divergent occlusally, relative to the tooth's long axis). Occlusal retention form usually is adequate.

The lingual portion is prepared at this point by using one of two techniques. In one technique, the lingual surface is prepared with the bur's long axis parallel with the lingual surface (see Fig. 14-33, A and B). The tip of the bur should be located at the gingival extent of the lingual fissure. The bur should be controlled so that it does not "roll out" onto the lingual surface, which may "round over" or damage the cavosurface margin. The facial inclination of the bur must be altered as the cutting progresses to establish the axial wall of the lingual portion at a uniform depth of 0.5 mm inside the DEJ (see Fig. 14-33, C). The axial wall should follow the contour of the lingual surface of the tooth. An axial depth of 0.5 mm inside the DEJ is indicated if retentive grooves are required; an axial depth of 0.2 mm inside the DEJ is permissible if retentive grooves are not required.

The No. 245 bur may be used with its long axis perpendicular to the axial wall to accentuate (i.e., refine) the mesioaxial and distoaxial line angles; this also results in the mesial and distal walls converging lingually because of the shape of the bur (see Fig. 14-33, D and E). During this step, the axial wall depth is not altered (see Fig. 14-33, F). The occlusal and lingual convergences usually provide a sufficient preparation retention form; no retention grooves are needed.

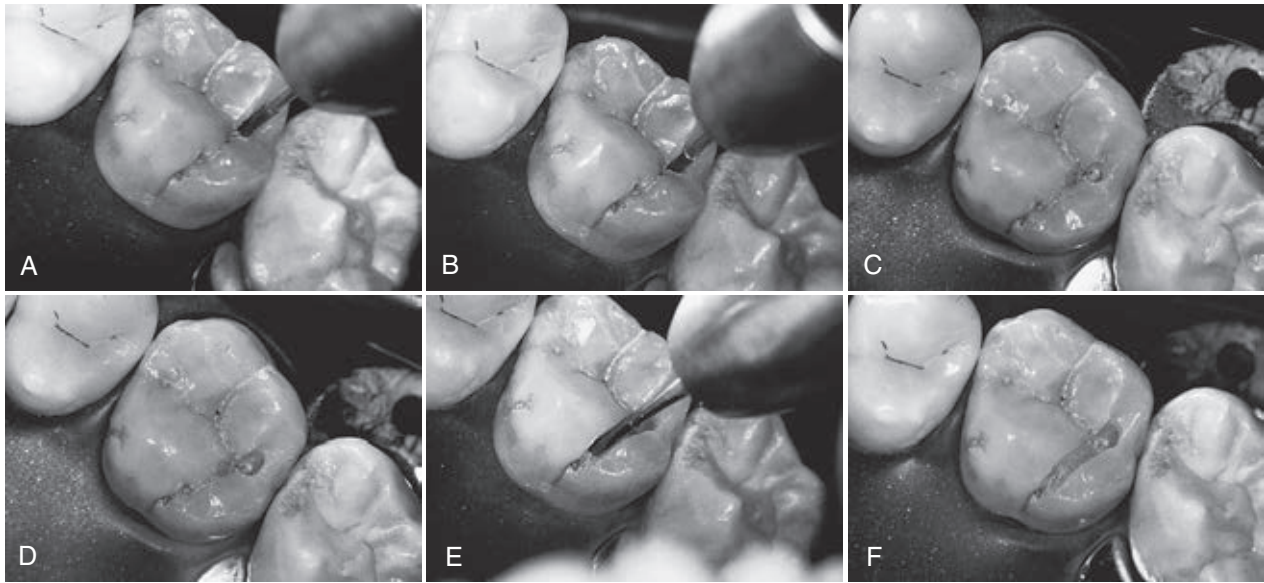


Fig. 14-32 Occlusolingual tooth preparation. **A**, No. 245 bur positioned for entry. **B**, Penetration to a minimal depth of 1.5 to 2 mm. **C**, Entry cut. **D**, The remaining fissures facial to the point of entry are removed with the same bur. **E** and **F**, A cut lingually along the fissure until the bur has extended the preparation onto the lingual surface.

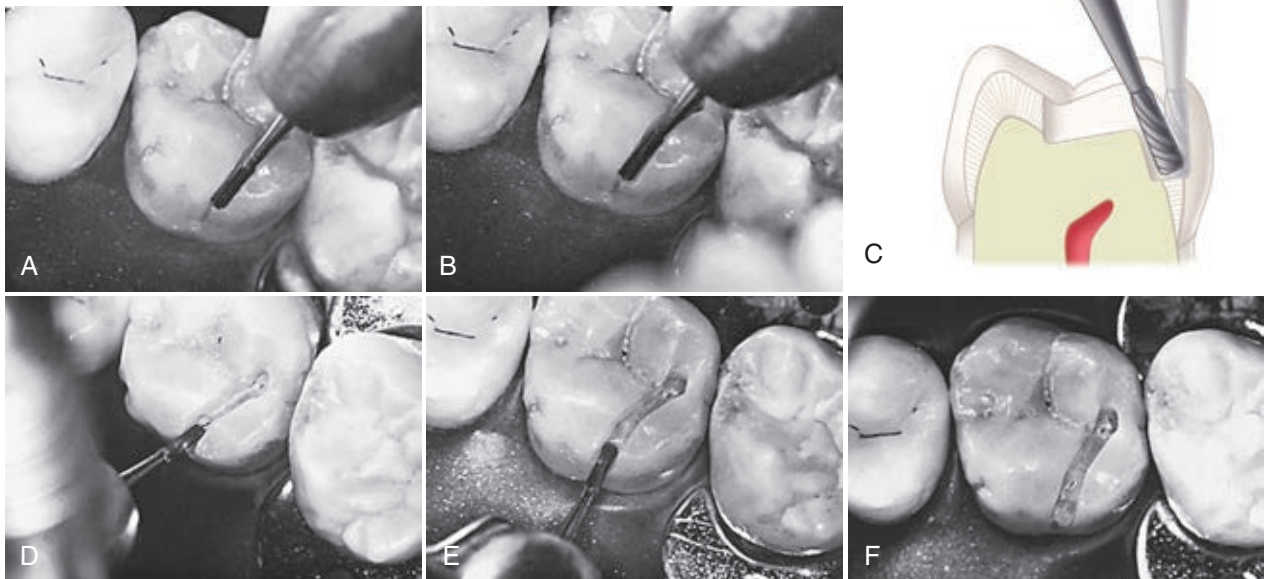


Fig. 14-33 Occlusolingual tooth preparation. **A**, Position of bur to cut the lingual portion. **B**, Initial entry of the bur for cutting the lingual portion. **C**, The inclination of the bur is altered to establish the correct axial wall depth. **D** and **E**, The bur is directed perpendicular to the axial wall to accentuate the mesioaxial and distoaxial line angles. **F**, The axial wall depth should be 0.2 to 0.5 mm inside the dentinoenamel junction (DEJ).

The axiopulpal line angle must be rounded to limit the areas of stress concentration and ensure adequate preparation depth and amalgam thickness (Fig. 14-34). Initial tooth preparation of the occlusolingual preparation is now complete. As mentioned previously, enameloplasty may be performed to conserve the tooth structure and limit extension.

The second technique is more difficult. In this case, the No. 245 bur is held perpendicular to the cusp ridge and the lingual surface, as it extends the preparation from the occlusal surface gingivally (to include the entire defect). This technique also results in opposing preparation walls that converge lingually.

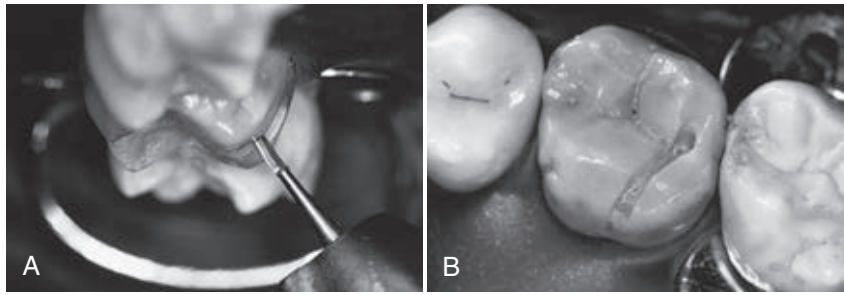


Fig. 14-34 **A**, Bur position for rounding the axiopulpal line angle. **B**, Axiopulpal line angle rounded.

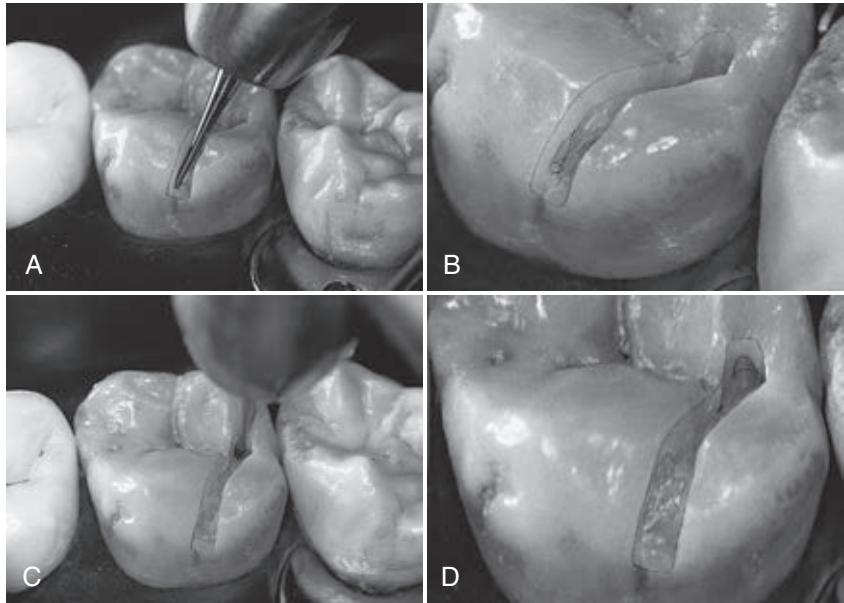


Fig. 14-35 Secondary retention form. **A**, Bur position for preparing groove in mesioaxial line angle. **B**, Completed groove. **C**, Bur position for the retention cove in the faciopulpal line angle. **D**, Completed cove.

Additional retention in the lingual extension may be required if the extension is wide mesiodistally or if it was prepared without a lingual convergence. If additional retention is required, the No. $\frac{1}{4}$ or No. 169 bur can be used to prepare grooves into the mesioaxial and distoaxial line angles (Fig. 14-35, A). If these angles are in enamel, the axial wall must be deepened to 0.5 mm axially of the DEJ (because the grooves must be in dentin so as to not undermine enamel). The depth of the grooves at the gingival floor is one-half the diameter of the No. $\frac{1}{4}$ bur. The cutting direction for each groove is the bisector of the respective line angle. The groove is slightly deeper pulpally than the correctly positioned axial wall and is 0.2 mm axial to the DEJ. The grooves should diminish in depth toward the occlusal surface, terminating midway along the axial wall (see Fig. 14-35, B). The adequacy of the groove should be tested by inserting the tine of an explorer into the groove and moving it lingually. The mesial or distal depth of the groove should prevent the explorer from being withdrawn lingually. (See the section on secondary resistance and retention forms for a description of placing retentive grooves in the proximal boxes of Class II amalgam preparations; the techniques are similar.)

Extension of a facial occlusal fissure may have required a slight divergence occlusally to the facial wall to conserve

support of the facial ridge. If so and if deemed necessary, the $\frac{1}{4}$ round bur may be used to prepare a retention cove in the faciopulpal line angle (see Fig. 14-35, C and D). The tip of the No. 245 bur held parallel to the long axis of the tooth crown also might be used to prepare this cove. Care should be taken so as not to undermine the occlusal enamel (this retentive cove is recommended only if occlusal convergence of the mesial and distal walls of the occlusal portion is absent or inadequate).

The final tooth preparation is accomplished by removal of remaining caries on the pulpal and axial walls (Fig. 14-36) with an appropriate round bur, a discoid-type spoon excavator, or both. A liner or base (alone or together) is placed in the deep excavations for pulpal protection. The external walls are finished. Any irregularities at the margins may indicate weak enamel that may be removed by the side of the No. 245 bur rotating at slow speed.

Final Procedures: Cleaning and Inspecting

The usual procedure in cleaning is to free the preparation of visible debris with water from the syringe and then to remove the visible moisture with a few light bursts of air from the air syringe. In some instances, debris clings to walls and angles

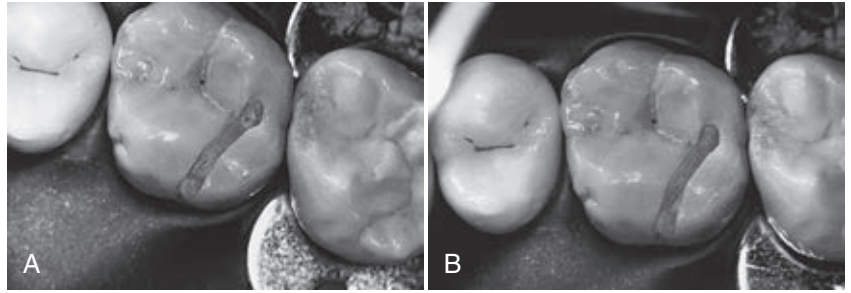


Fig. 14-36 **A**, Any remaining pit and fissure in enamel and infected dentin on established pulpal and axial walls are removed. **B**, Completed tooth preparation.

despite the aforementioned efforts, and it may be necessary to loosen this material with an explorer or small cotton pellet. After all of the visible debris has been removed, the excess moisture is removed. It is important not to dehydrate the tooth by overuse of air as this may damage the odontoblasts associated with the desiccated tubules. When the preparation has been cleaned adequately, it is visually inspected to confirm complete debridement and that the preparation does not require any additional modification.

Restorative Technique

DESENSITIZER PLACEMENT

After any indicated liner or base or both is placed, a dentin desensitizer is placed.

MATRIX PLACEMENT (IF NECESSARY)

Using a rigid matrix to support the lingual portion of the restoration during condensation is occasionally necessary. A matrix is helpful to prevent “landsliding” during condensation and to ensure marginal adaptation and strength of the restoration. The Tofflemire matrix retainer is used to secure a matrix band to the tooth (as described later). Because this type of matrix band does not intimately adapt to the lingual groove area of the tooth (Fig. 14-37, *A*), an additional step may be necessary to provide a matrix that is rigid on the lingual portion of the tooth preparation. If so, a piece of stainless steel matrix material (0.002 inch [0.05 mm] thick, $\frac{5}{16}$ inch [8 mm] wide) is cut to fit between the lingual surface of the tooth and the band already in place (see Fig. 14-37, *B*). The gingival edge of this segment of matrix material is placed slightly gingival to the gingival edge of the band to help secure the band segment. A quick setting rigid polyvinyl siloxane (PVS)-based material may be used, between the sectional matrix and the Tofflemire matrix band, to prevent lingual displacement of the sectional matrix during condensation of the amalgam. Alternatively, green stick compound may be used. In this case, the end of a toothpick wedge is covered with softened (heated) compound. The compound-coated wedge is then immediately inserted between the Tofflemire band and the cut piece of matrix material (see Fig. 14-37, *D*). While the compound is still soft, a suitable burnisher is used to press the compound gingivally, securing the matrix tightly against the gingival cavosurface margin and the lingual surface of the tooth to provide a rigid, lingual matrix (see Fig. 14-37, *E* and *F*). This matrix for the occlusolingual amalgam restoration is referred to as the *Barton matrix*. Occasionally, the piece of strip matrix can be positioned appropriately by using only the wedge (without the rigid PVS or compound matrix support).

INSERTION OF THE AMALGAM

The insertion of amalgam is accomplished as previously described for the Class I occlusal tooth preparation. Condensation is begun at the gingival wall. Care must be taken to ensure that landsliding of the amalgam does not occur because two adjoining surfaces of the tooth are being restored. For this technique, the last increments of amalgam may be condensed on the lingual surface with the side of a large condenser. Its long, broadly rounded contour conforms to the rectangular shape for the lingual groove preparation. Appropriate care should be taken (when condensing the occlusal surface) so as to not fracture the lingual amalgam. Another technique is to have the assistant secure the condensed lingual surface with a broad condenser nib, while the operator completes the condensation of the occlusal surface. Regardless of the technique used, the amalgam must be well condensed.

CONTOURING AND FINISHING OF THE AMALGAM RESTORATION

When the preparation is sufficiently overfilled, carving of the occlusal surface may begin immediately with a sharp discoid-cleoid instrument or a Hollenback carver. All carving should be done with the edge of the blade perpendicular to the margin and with the blade moving parallel to the margin. To prevent over-carving, the blade edge should be guided by the unprepared tooth surface adjacent to the margin. An explorer is used to remove excess amalgam adjacent to the lingual matrix before matrix removal (see Fig. 14-37, *G*). After carving is completed (see Fig. 14-37, *H*), the rubber dam is removed, and the restoration is adjusted to ensure proper occlusion. Most amalgams do not require finishing and polishing (the procedure is described in the section on conservative class I amalgam restorations). Figure 14-37, *I*, illustrates a polished occlusolingual restoration.

Class I Occlusofacial Amalgam Restorations

Occasionally, mandibular molars exhibit fissures that extend from the occlusal surface through the facial cusp ridge and onto the facial surface. The preparation and restoration of these defects are very similar to those described for Class I occlusolingual amalgam restorations. Although these may be restored with composite, an illustration of preparation and restoration with amalgam is provided in Figure 14-38. The amalgam restoration may be polished after it is completely set. The shape of abrasive points may need to be modified to allow optimal polishing (Fig. 14-38, *I* and *J*).

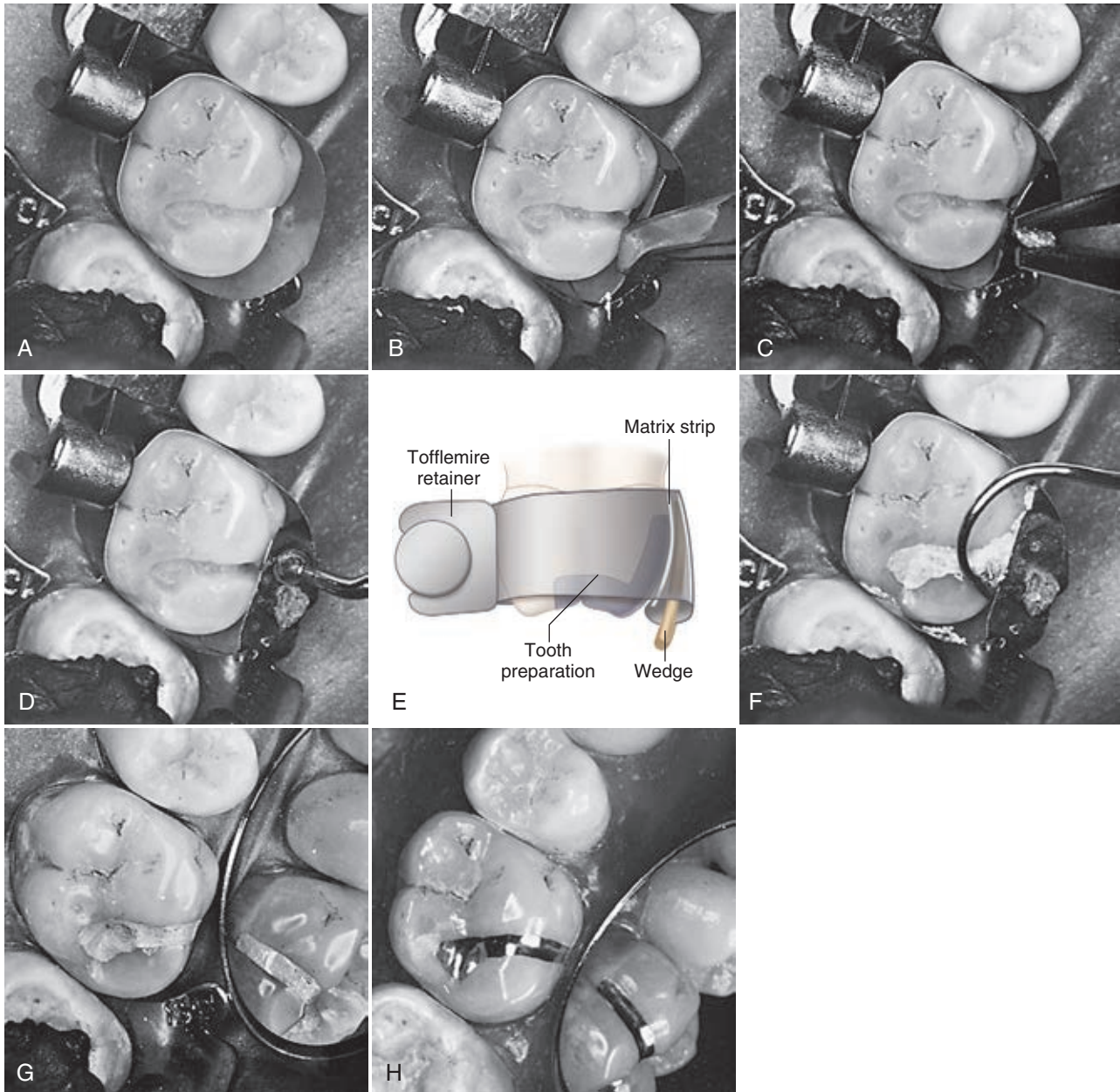


Fig. 14-37 Matrix for occlusolingual tooth preparation. **A**, Matrix band secured to the tooth with Tofflemire retainer. **B**, Positioning a small strip of stainless steel matrix material between the tooth and the band already in place. **C**, Inserting the wedge and the compound. **D**, Compressing the compound gingivally, which adapts the steel strip to the lingual surface. **E**, Cross-section of the tooth preparation and the matrix construction. **F**, Using the explorer to remove excess amalgam adjacent to the lingual matrix. **G**, Carving completed. **H**, Polished restoration.

Clinical Technique for Class II Amalgam Restorations

Amalgam restorations that restore one or both of the proximal surfaces of the tooth may provide years of service to the patient when (1) the tooth preparation is correct, (2) the matrix is suitable, (3) the operating field is isolated, and (4) the restorative material is manipulated properly. Inattention to these criteria may produce inferior restorations that are prone to early failure. This section discusses principles, techniques, and procedures using classic examples of Class II

preparations. The outline forms should always conform to the restoration requirements of the tooth and not to the classic example of a Class II tooth preparation. Application of the principles discussed here will result in high-quality Class II amalgam restorations.

Initial Clinical Procedures

Occlusal contacts should be marked with articulating paper before tooth preparation. A mental image of these contacts will serve as a guide in tooth preparation and restoration. Any

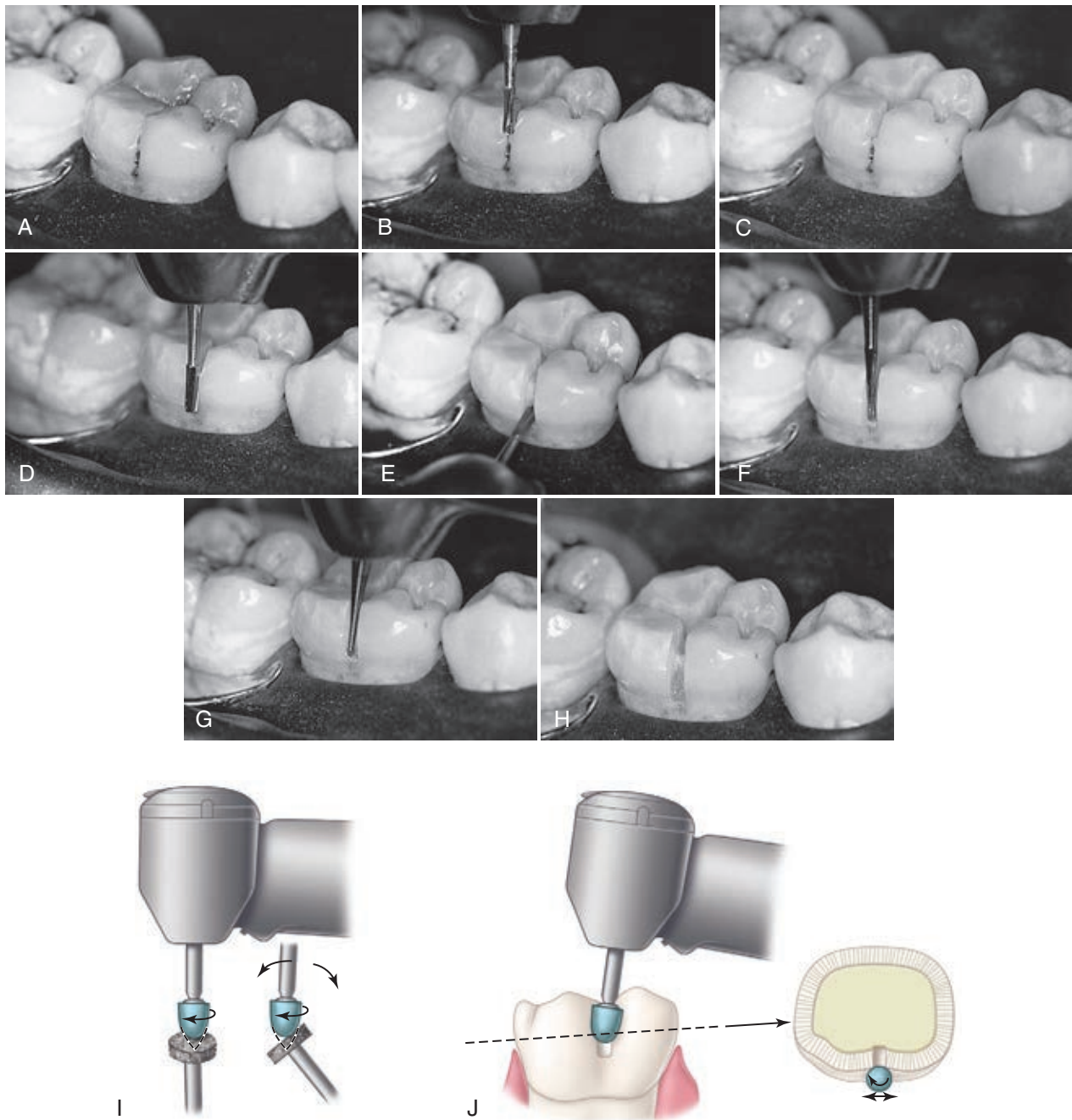


Fig. 14-38 Fissure extension. **A**, Facial occlusal fissure continuous with the fissure on the facial surface. **B**, Extension through the facial ridge onto the facial surface. **C**, Appearance of the tooth preparation after extension through the ridge. **D**, The facial surface portion of the extension is cut with the side of the bur. **E**, The line angles are sharpened by directing the bur from the facial aspect. **F**, Sharpening the line angles from the occlusal direction with a No. 169 L bur. **G**, Ensuring the retention form by preparing retention grooves with a No. ¼ round bur. **H**, Completed tooth preparation. **I**, The rubber polishing point may be trued up and blunted on a coarse diamond wheel. **J**, Proper orientation of the rubber point when polishing the facial surface groove area.

opposing “plunging cusp” or other pointed cusp may need to be recontoured to reduce the risk of fracture of the new restoration or the cusp from occlusal forces. Before tooth preparation for amalgam, the placement of a rubber dam is generally recommended. It is especially beneficial when the restoration is large, when the caries is extensive, and when quadrant dentistry is practiced. If the existing restoration has rough proximal contacts, the restoration may be removed before rubber

dam application. Infected dentin should be removed with the rubber dam in place, however, especially if a pulpal exposure is a possibility. Insertion of an interproximal wedge or wedges is the last step in rubber dam application when Class II tooth preparations are scheduled. The wedges depress and protect the rubber dam and underlying soft tissue, separate teeth slightly, and may serve as a guide to prevent gingival overextension of the proximal boxes.

Tooth Preparation**Class II Amalgam Restorations Involving Only One Proximal Surface**

This section introduces the principles and techniques of a Class II tooth preparation for an amalgam restoration involving a carious lesion on one proximal surface. For illustration, a mesio-occlusal tooth preparation on the mandibular second premolar is presented. Although this restoration typically would use composite as the restorative material, the use of a small, conservative Class II amalgam restoration is presented to provide the basic concepts of Class II amalgam tooth preparation and restoration more clearly and simply.

INITIAL TOOTH PREPARATION**Occlusal Outline Form (Occlusal Step)**

The occlusal outline form of a Class II tooth preparation for amalgam is similar to that for a Class I tooth preparation. Using high speed with air-water spray, the operator enters the pit nearest the involved proximal surface with a punch cut using a No. 245 bur oriented as illustrated in [Figure 14-39, A and B](#). Entering the pit nearest the involved proximal surface

allows the mesial pit (in this case) not to be included if it is sound. The bur should be rotating when it is applied to the tooth and should not stop rotating until removed. Viewed from the proximal and lingual (facial) aspects, the long axis of the bur and the long axis of the tooth crown should remain parallel during the cutting procedures. Dentine caries initially spreads at the DEJ, and therefore, the goal of the initial cut is to reach the DEJ. The DEJ location in posterior teeth is approximately 1.5 to 2.0 mm from the occlusal surface. As the bur enters the pit, a target depth of 0.1–0.2 mm into dentin should be established (i.e., one-half to two-thirds the length of the cutting portion of a No. 245 bur); 1.5 mm as measured at the central fissure, and approximately 2 mm on the prepared external walls such that the DEJ is identified. While maintaining the same depth and bur orientation, the bur is moved to extend the outline to include the central fissure and the opposite pit (the distal pit, in this example), if necessary (see [Fig. 14-39, C and D](#)). For the very conservative preparation, the isthmus width should be as narrow as possible, preferably no wider than one-quarter the intercusp distance.^{18,19,30,64,65} Ideally, it should be the width of the No. 245 bur. Narrow restorations provide a greater length of clinical service.^{20,24} Generally, the amount of remaining tooth

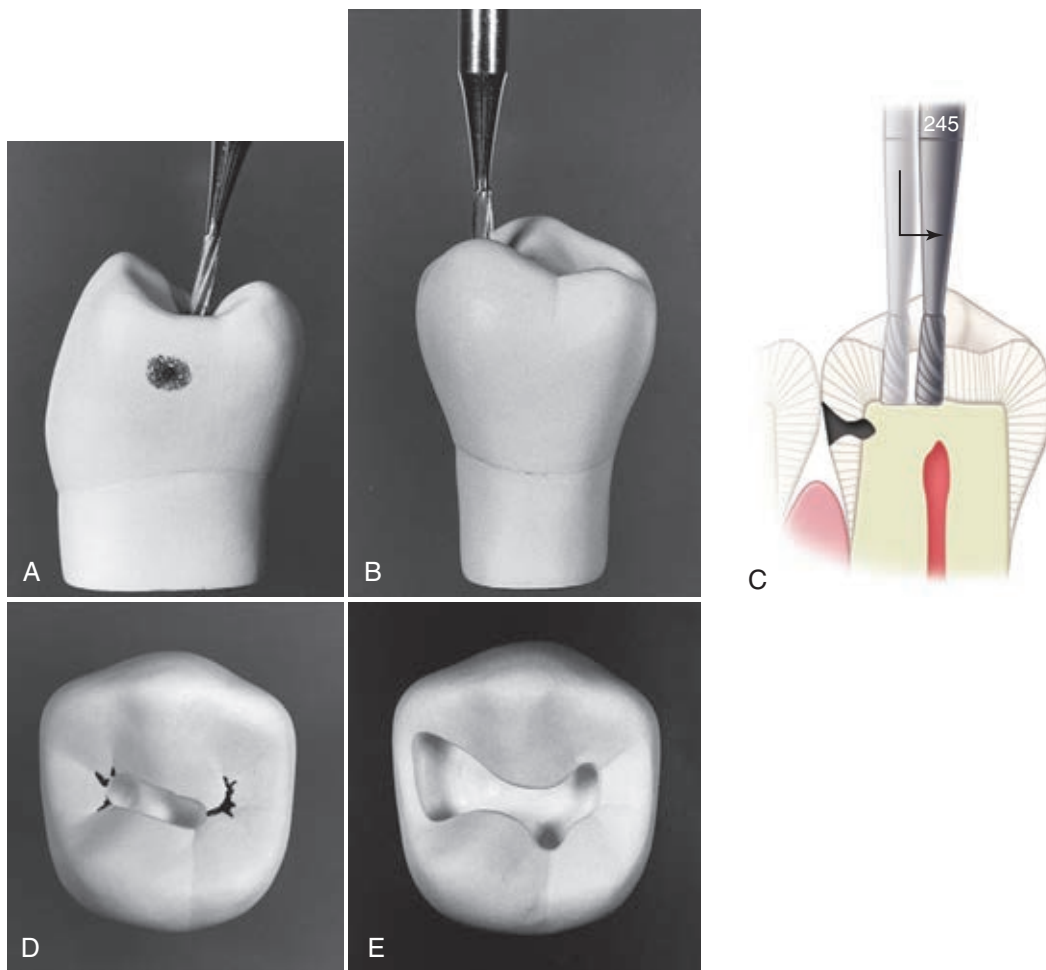


Fig. 14-39 Entry and occlusal step. **A**, Bur position for entry, as viewed proximally. Note the slight lingual tilt of the bur. **B**, Bur position as viewed lingually. **C**, The tooth is entered with a punch cut, and extension is done distally along central fissure at a uniform depth of 1.5 to 2 mm (1.5 mm at fissure; because of the inclination of the unprepared tooth surface, the corresponding measurement on the prepared wall is greater). **D**, Occlusal view of **C**. **E**, Completed occlusal step.

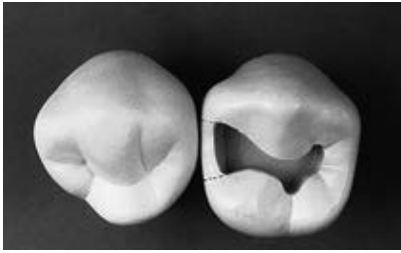


Fig. 14-40 Visualize final location of proximo-occlusal margins (dotted lines) before preparing the proximal box.

structure is more important to restoration longevity than is the restorative material used.⁶⁶ Ultimately, the extension of the caries at the DEJ will determine the amount of preparation extension and the resultant width. The pulpal floor of the preparation should follow the slight rise and fall of the DEJ along the central fissure in teeth with prominent triangular ridges.

Maintaining the bur parallel to the long axis of the tooth crown creates facial, lingual, and distal walls with a slight occlusal convergence, which provides favorable amalgam angles at the margins. The facial, lingual, and distal walls should be extended until a sound DEJ is reached. Proper extension will result in the formation of the peripheral seat which aids in the primary resistance form. It may be necessary to tilt the bur to diverge occlusally at the distal wall if further distal extension would undermine the marginal ridge of its dentinal support. During development of the distal pit area of the preparation, extension to include any distofacial and distolingual developmental fissures radiating from the pit may be indicated. The distal pit area (in this example) provides a dovetail retention form, which may prevent mesial displacement of the completed restoration. The dovetail feature is not required in the occlusal step of a single proximal surface preparation, unless a fissure emanating from an occlusal pit indicates it. Without a dovetail, however, the occlusal step should not be in a straight direction, which may reduce the retention form. This type of retention form also is provided by any extension of the central fissure preparation that is not in a straight direction from pit to pit (see Fig. 14-39, E). A dovetail outline form in the distal pit is not required if radiating fissures are not present.^{67,68} Enameloplasty should be performed, where indicated, to conserve the tooth structure.

Before extending into the involved proximal marginal ridge (the mesial ridge, in this example), the final locations of the facial and lingual walls of the proximal box are visualized. This action prevents overextension of the occlusal outline form (i.e., occlusal step) where it joins the proximal outline form (i.e., proximal box). Figure 14-40 illustrates visualization of the final location of the proximo-occlusal margins before preparing the proximal box. Showing the view from the occlusal aspect, Figure 14-41 illustrates a reverse curve in the occlusal outline of a Class II preparation, which often results when developing the mesiofacial wall perpendicular to the enamel rod direction while, at the same time, conserving as much of the facial cusp structure as possible.⁶⁵ The extension into the mesiofacial cusp is limited to that amount required to permit a 90-degree mesiofacial margin which is indicated when using amalgam. Lingually, the reverse curve usually is minimal (if necessary at all) because the embrasure form is larger.

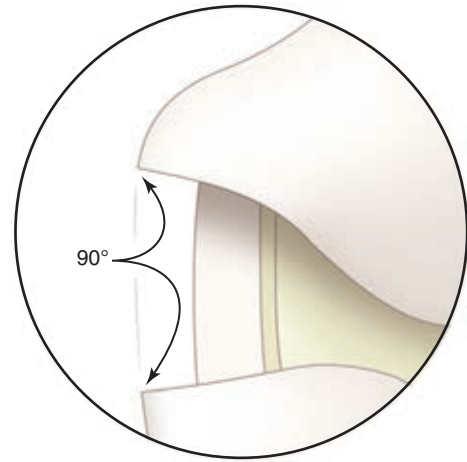


Fig. 14-41 The reverse curve in the occlusal outline usually is created when the mesiofacial enamel wall is parallel to the enamel rod direction. Lingually, the reverse curve is very slight, often unnecessary.

While maintaining the established pulpal depth and with the bur parallel to the long axis of the tooth crown, the preparation is extended mesially, stopping approximately 0.8 mm short of cutting through the marginal ridge into the contact area. The occlusal step in this region is made slightly wider faciolingually than in the Class I preparation because additional width is necessary for the proximal box. The proper depth of the occlusal portion of the preparation increases the strength of the restoration, however, more than does faciolingual width (see Fig. 14-39, E, for an illustration of the completed occlusal outline form). Although this extension includes part of the mesial marginal ridge, it also exposes the marginal ridge DEJ. The location of the DEJ is an important guide in the development of the proximal preparation.

Proximal Outline Form (Proximal Box)

The desired final location of the facial and lingual walls of the proximal box or the proximal outline form relative to the contact area is visualized. The objectives for the extension of the proximal margins are as follows:

- Include all caries, defects, or existing restorative material
- Create 90-degree cavosurface margins (i.e., butt-joint margins)
- Establish (ideally) not more than 0.5 mm clearance with the adjacent proximal surface facially, lingually, and gingivally

The initial procedure in preparing the outline form of the proximal box is the isolation of the proximal (i.e., mesial) enamel by the proximal ditch cut. While maintaining the same orientation of the bur, it is positioned over the DEJ in the pulpal floor next to the remaining mesial marginal ridge (Fig. 14-42, A). The end of the bur is allowed to cut a ditch gingivally along the exposed DEJ, two-thirds at the expense of enamel and one-third at the expense of dentin. The 0.8-mm diameter bur end cuts approximately 0.5 to 0.6 mm into enamel and 0.2 to 0.3 mm into dentin. Pressure is directed gingivally and lightly toward the mesial surface to keep the bur against the proximal enamel, while the bur is moved facially and lingually along the DEJ. The ditch is extended gingivally

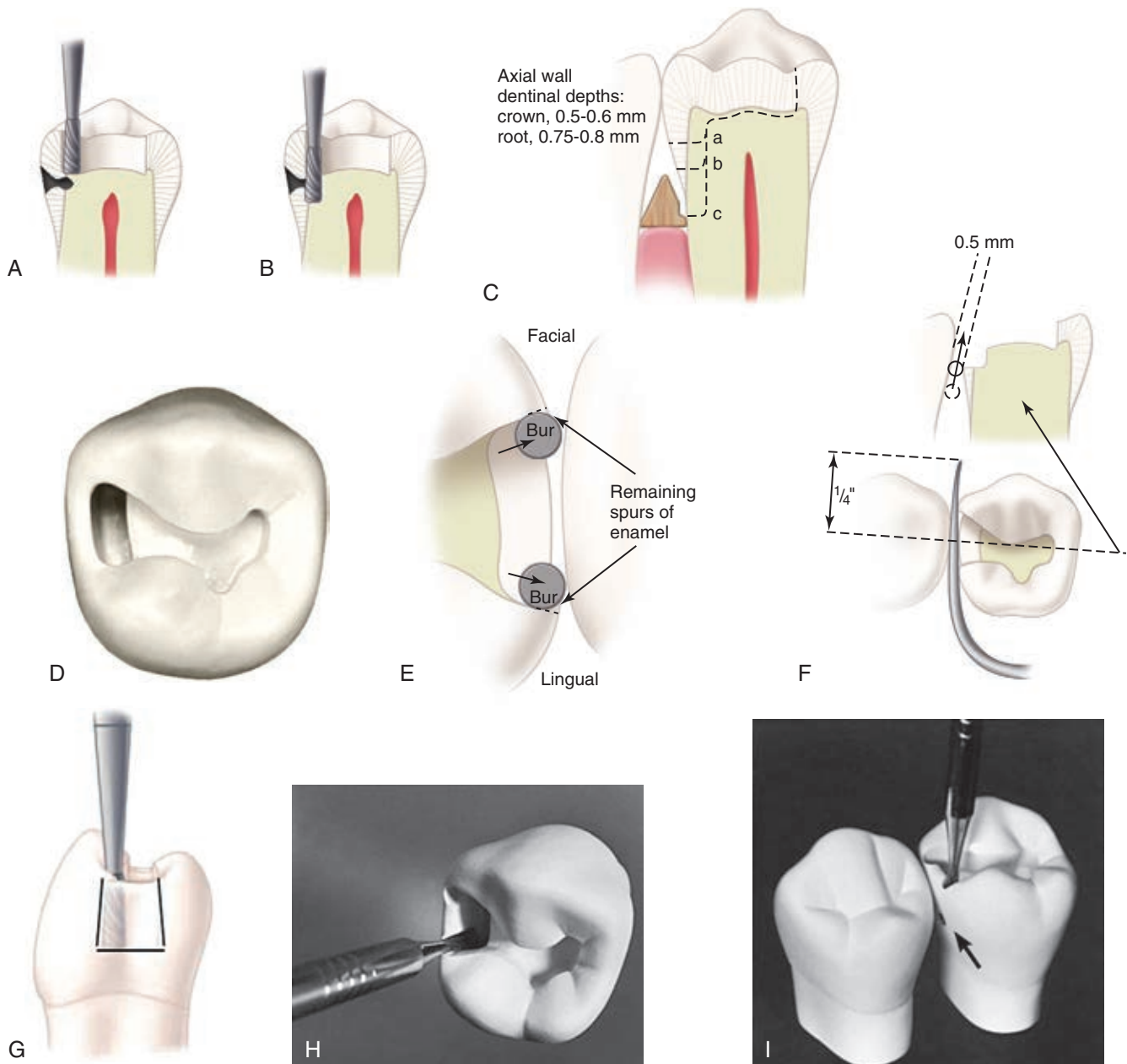


Fig. 14-42 Isolation of proximal enamel. **A**, Bur position to begin the proximal ditch cut. **B**, The proximal ditch is extended gingivally to the desired level of the gingival wall (i.e., floor). **C**, Variance in the pulpal depth of the axiogingival line angle as the extension of the gingival wall varies: *a*, at minimal gingival extension; *b*, at moderate extension; *c*, at extension that places gingival margin in cementum, whereupon the pulpal depth is 0.75 to 0.8 mm and the bur may shave the side of wedge. **D**, The proximal ditch cut results in the axial wall that follows the outside contour of the proximal surface. **E**, The position of the proximal walls (i.e., facial, lingual, gingival) should not be overextended with the No. 245 bur, considering additional extension will occur when the remaining spurs of enamel are removed. **F**, When a small lesion is prepared, the gingival margin should clear the adjacent tooth by only 0.5 mm. This clearance may be measured with the side of the explorer. The diameter of the tine of a No. 23 explorer is 0.5 mm, $\frac{1}{4}$ inch (6.3 mm) from its tip. **G**, The faciolingual dimension of the proximal ditch is greater at the gingival level than at the occlusal level. **H**, To isolate and weaken the proximal enamel further, the bur is moved toward and perpendicular to the proximal surface. **I**, The side of the bur may emerge slightly through the proximal surface at the level of the gingival floor (arrow).

just beyond the caries or the proximal contact, whichever is greater (see Fig. 14-42, *B*). Because dentin is softer and cuts more easily than enamel, the bur should be cutting away the dentin immediately supporting the enamel. Axial wall dentinal depths will vary based on the gingival extension of the preparation (see Fig. 14-42, *C*). The harder enamel acts to guide the bur, creating an axial wall that follows the

faciolingual contour of the proximal surface and the DEJ (see Fig. 14-42, *D*).

It is necessary to visualize the completed mesiofacial and mesiolingual margins as right-angle projections of the facial and lingual limits of the ditch to establish the proper faciolingual ditch extension (see Fig. 14-42, *E*). When preparing a tooth with a small lesion, these margins should clear

the adjacent tooth by only 0.2 to 0.3 mm.⁶⁵ A guide for the gingival extension is the visualization that the finished gingival margin will be only slightly gingival to the gingival limit of the ditch. This gingival margin should clear the adjacent tooth by only 0.5 mm in a small tooth preparation (see Fig. 14-42, *F*).⁶⁷ Clearance of the proximal margins (i.e., mesiofacial, mesiolingual, gingival) greater than 0.5 mm is excessive, unless indicated to include any caries, undermined enamel, or existing restorative material. The location of the final proximal margins (i.e., facial, lingual, gingival) should be established with hand instruments (i.e., chisels, hatchets, trimmers) in conservative proximal box preparations. Otherwise, these margins may be overextended to achieve 90-degree cavosurface margins with the No. 245 bur (see Fig. 14-42, *E*). Extending gingival margins into the gingival sulcus should be avoided, where possible, because subgingival margins are more difficult to restore and may be a contributing factor to periodontal disease.⁶⁹⁻⁷¹

The depth of the axial dentinal wall should be adjusted to approximately 0.5 mm if retention grooves are deemed necessary. This will allow the grooves to be prepared into the axiolingual and axiofacial line angles without undermining the proximal enamel. If the proximal ditch cut is entirely in dentin, the axial wall usually is too deep. Because the proximal enamel becomes thinner from the occlusal to the gingival aspect, the end of the bur comes closer to the external tooth surface as the cutting progresses gingivally (see Fig. 14-42, *B*). Premolars may have proximal boxes that are shallower pulpally than are molars because premolars typically have thinner enamel. In the tooth crown, the ideal dentinal depth of the axial wall of the proximal boxes of premolars and molars should be the same (two-thirds to three-fourths the diameter of the No. 245 bur [or 0.5–0.6 mm]).⁶⁵ When the extension places the gingival margin in cementum, the initial pulpal depth of the axio-lingual line angle should be 0.7 to 0.8 mm (the diameter of the tip end of the No. 245 bur is 0.8 mm). The bur may shave the side of the wedge that is protecting the rubber dam and the underlying gingiva (see Fig. 14-42, *C*).

The gingival extension of the proximal ditch may be measured by first noting the depth of the nonrotating bur in the ditch. The dentist removes the bur from the preparation and holds it in the facial embrasure at the same level to observe the relationship of the end of the bur to the proximal contact. A periodontal probe also may be used.

The proximal ditch cut may diverge gingivally to ensure that the faciolingual dimension at the gingival aspect is greater than at the occlusal aspect (see Fig. 14-42, *G*). The shape of the No. 245 bur should provide this divergence. The gingival divergence contributes to the retention form and provides for the desirable extension of the facial and lingual proximal margins to include defective tooth structure or old restorative material at the gingival level, while conserving the marginal ridge and providing for 90-degree amalgam at the margins on this ridge.¹⁹

Occasionally, it is permissible not to extend the outline of the proximal box facially or lingually beyond the proximal contact to conserve the tooth structure.⁶⁷ An example of this modification is a narrow proximal lesion where broad proximal contact is present in a patient with low risk for caries. If it is necessary to extend 1 mm or more to break the contact arbitrarily, the proximal margin is left in the contact. Usually, the facial margin is affected by this rule, which may not extend beyond the proximal contact into the facial embrasure.

The proximal extensions are completed when two cuts, one starting at the facial limit of the proximal ditch and the other starting at the lingual limit, extending toward and perpendicular to the proximal surface (until the bur is nearly through enamel at the contact level), are made (see Fig. 14-42, *H*). The side of the bur may emerge slightly through the surface at the level of the gingival floor (see Fig. 14-42, *I*); this weakens the remaining enamel by which the isolated portion is held. If this level is judged to be insufficiently gingival, additional gingival extension should be accomplished using the isolated proximal enamel that is still in place to guide the bur. This prevents the bur from marring the proximal surface of the adjacent tooth. At this stage, however, the remaining wall of enamel often breaks away during cutting, especially when high speed is used. At such times, if additional use of the bur is indicated, a matrix band may be used around the adjacent tooth to prevent marring its proximal surface. The isolated enamel, if still in place, may be fractured with a spoon excavator (Fig. 14-43) or by additional movement of the bur.

To protect the gingiva and the rubber dam when extending the gingival wall gingivally, a wooden wedge should already be in place in the gingival embrasure to depress soft tissue and the rubber dam.¹⁹ A round toothpick wedge is preferred unless a deep gingival extension is anticipated (Fig. 14-44, *A*). A triangular (i.e., anatomic) wedge is more appropriate for deep

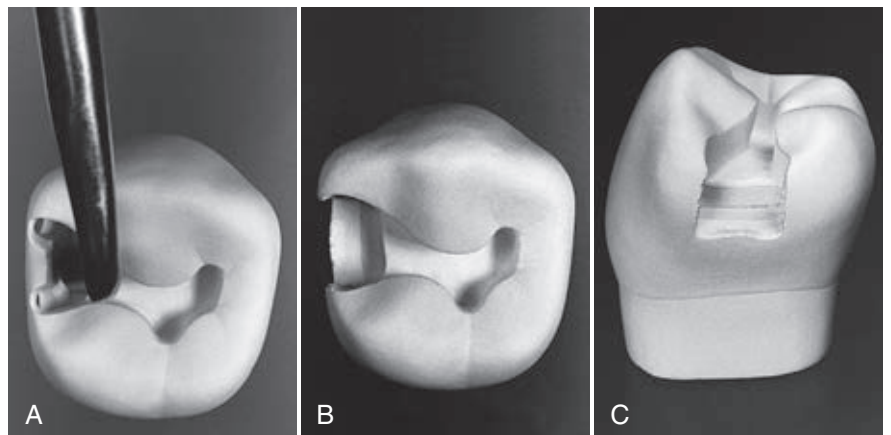


Fig. 14-43 Removing isolated enamel. **A**, Using a spoon excavator to fracture the weakened proximal enamel. **B**, Occlusal view with the proximal enamel removed. **C**, Proximal view with the proximal enamel removed.

gingival extensions because the greatest cross-sectional dimension of the wedge is at its base; as the gingival wall is cut, the bur's end corner may shave the wedge slightly (see Fig. 14-44, B). With the enamel hatchet (10-7-14), the bin-angle chisel (12-7-8), or both, the dentist cleaves away any remaining undermined proximal enamel (Fig. 14-45), establishing the proper direction to the mesiolingual and mesiofacial walls.

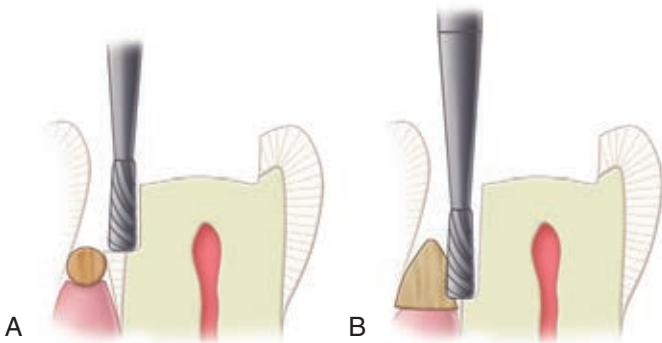


Fig. 14-44 Wedging. **A**, A round toothpick wedge placed in the gingival embrasure protects the gingiva and the rubber dam during preparation of the proximal box. **B**, A triangular wedge is indicated when a deep gingival extension of the proximal box is anticipated because the wedge's greatest cross-sectional dimension is at its base. Consequently, it more readily engages the remaining clinical tooth surface.

Proximal margins having cavosurface angles of 90 degrees are desired.¹⁹ Cavosurface angles of 90 degrees ensure that no undermined enamel rods remain on the proximal margins and that the maximal edge strength of amalgam is maintained. The cutting edge of the instrument should not be aggressively forced against the gingival wall because this can cause a craze line (i.e., fracture) that extends gingivally in enamel, perhaps to the cervical line. Figure 14-46 shows the importance of the correct direction of the mesiofacial and mesiolingual walls, dictated by enamel rod direction and the physical properties of amalgam. If hand instruments were not used to remove the remaining spurs of enamel, the proximal margins would have undermined enamel. To create 90-degree facial and lingual proximal margins with the No. 245 bur, the proximal margins would have to be significantly overextended for an otherwise conservative preparation. The weakened enamel along the gingival wall is removed by using the enamel hatchet in a scraping motion (see Fig. 14-45, C).

When the isolation of the proximal enamel has been executed properly, the proximal box can be completed easily with hand-cutting instruments. Otherwise, more cutting with rotary instruments may be indicated. When a rotary instrument is used in a proximal box after the proximal enamel is removed, the instrument may either mar the adjacent proximal surface or “crawl out” of the box into the gingiva or across the proximal margins. The latter mishap produces a rounded cavosurface angle, which, if not corrected, results in a weak amalgam margin of less than 90 degrees. The risk of this

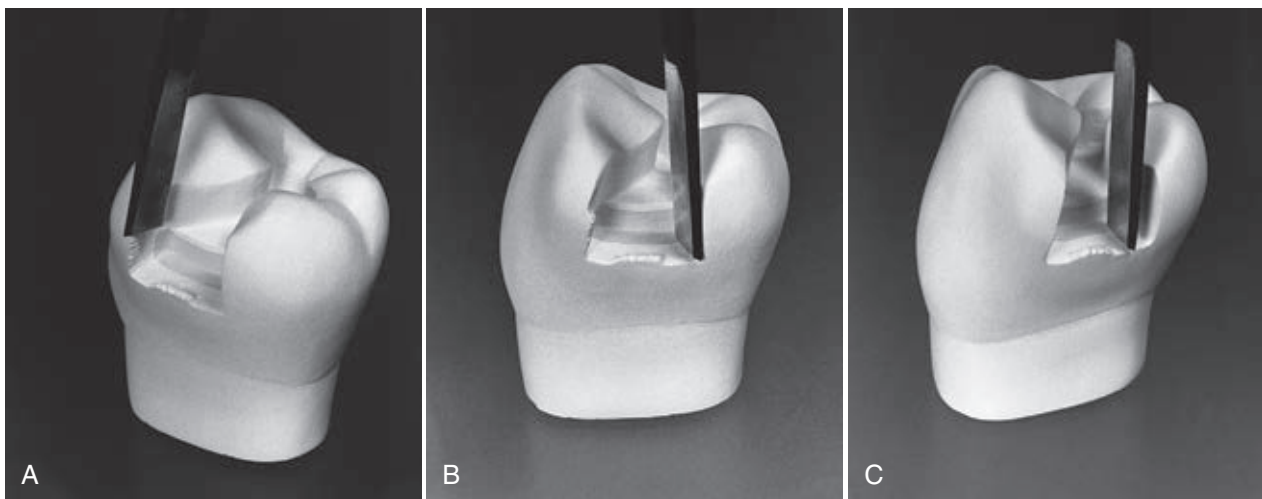
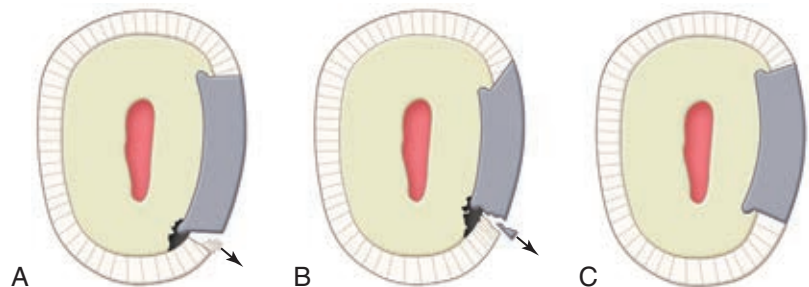


Fig. 14-45 Removing the remaining undermined proximal enamel with an enamel hatchet on the facial proximal wall (A), the lingual proximal wall (B), and the gingival wall (C).

Fig. 14-46 Direction of mesiofacial and mesiolingual walls. **A**, Failure caused by a weak enamel margin. **B**, Failure caused by a weak amalgam margin. **C**, Proper direction to the proximal walls results in full-length enamel rods and 90-degree amalgam at the preparation margin. Retention grooves have been cut 0.2 mm inside the dentinoenamel junction (DEJ), and their direction of depth is parallel to the DEJ.



occurring is markedly reduced when high-speed burs are used. When finishing enamel margins by using a rotary instrument, intermittent application of the bur along with air coolant is used to improve visualization.

The primary resistance form is provided by (1) the pulpal and gingival walls being relatively level and perpendicular to forces directed with the long axis of the tooth; (2) restricting the extension of the walls to allow strong cusps and ridge areas to remain with sufficient dentin support, at the same time establishing the peripheral seat; (3) restricting the occlusal outline form (where possible) to areas receiving minimal occlusal contact;²¹ (4) the reverse curve optimizing the strength of the amalgam and tooth structure at the junction of the occlusal step and proximal box; (5) slightly rounding the internal line angles to reduce stress concentration in the tooth structure (automatically created by bur design except for the axiopulpal line angle); and (6) providing enough thickness of the restorative material to prevent its fracture from the forces of mastication. The primary retention form is provided by the occlusal convergence of the facial and lingual walls and by the dovetail design of the occlusal step, if present.

After completing the initial tooth preparation, the adjacent proximal surface should be evaluated. An adjacent proximal restoration may require recontouring and smoothing to develop proper contact, contour, and embrasure form for the new restoration; this may be done with finishing burs, abrasive finishing strips, disks, or a combination of all of these. If inadvertent minimal damage occurs to the adjacent proximal surface during the initial tooth preparation, the proximal surface should be recontoured or restored.

FINAL TOOTH PREPARATION

Removal of Any Remaining Defective Enamel and Infected Carious Dentin

Removing enamel pit-and-fissure remnants and infected dentin on the pulpal wall in Class II preparations is accomplished in the same manner as in the Class I preparation. Infected carious dentin is removed with a slowly revolving round bur of appropriate size, a discoid-type spoon excavator, or both. The excavation should stop when a hard or firm feel with an explorer or small spoon excavator is achieved; this often occurs before all of the stained or discolored dentin is removed. Removing enamel pit-and-fissure remnants and infected dentin should not affect the resistance form. To achieve an enhanced resistance form, the occlusal step should have pulpal seats at the initial preparation depth, perpendicular to the long axis of the tooth in sound tooth structure and peripheral to the excavated area (Fig. 14-47). Infected carious dentin in the axial wall is removed with appropriate round burs, spoon excavators, or both (Fig. 14-48).

Any old restorative material (including base and liner) remaining may be left if no evidence of caries exists, if its periphery is intact, and if the tooth has been asymptomatic (assuming the pulp is vital). This concept is particularly important if removal of all remaining restorative material may increase the risk of pulpal exposure.

After completion of the minimal gingival extension (gingivoaxial line angle is in sound dentin), a remnant of the enamel portion of a carious lesion may remain on the gingival floor (wall), seen in the form of a decalcified (i.e., white, chalky) or

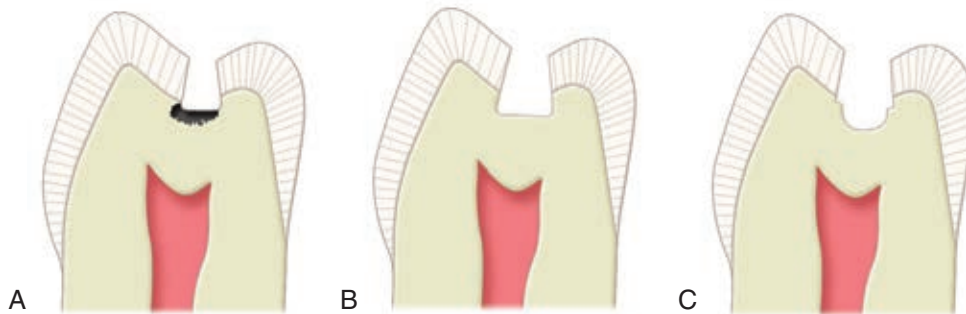


Fig. 14-47 Management of small- to moderate-sized carious lesion on the pulpal wall. **A**, Infected carious dentin extending beyond the ideal pulpal wall position. **B**, Incorrect lowering of the pulpal wall to include infected carious dentin. **C**, Correct extension facially and lingually beyond the infected carious dentin. Note the excavation below the ideal pulpal wall level and the facial and lingual seats at the ideal pulpal wall level.

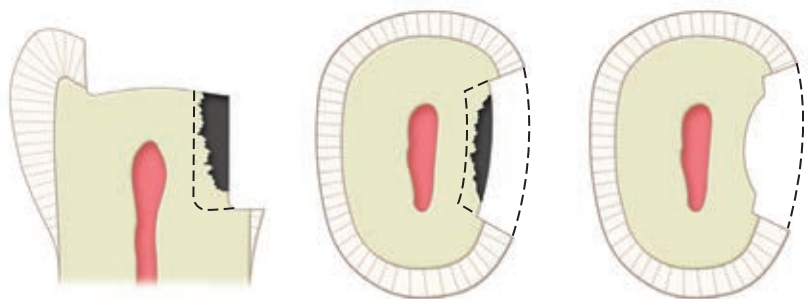


Fig. 14-48 Management of a moderate to extensive carious lesion. Infected dentin on the axial wall does not call for the preparation of the axial wall toward the pulp, as shown by dotted lines. Infected carious dentin extending pulpally from the ideal axial wall position is removed with a round bur.

faulty area bordering the margin (Fig. 14-49). This situation dictates extending a part or all of the gingival floor gingivally to place it in sound tooth structure. Extension of the entire gingival wall to include a large caries lesion may place the gingival margin so deep that proper matrix application and wedging become extremely difficult to do. Figure 14-50, A, illustrates an outline form that extends gingivally in the central portion of the gingival wall to include caries that is deep gingivally, although leaving the facial and lingual gingival corners at a more occlusal position. This partial extension of the gingival wall permits wedging of the matrix band where otherwise it may be difficult and damaging to soft tissue. In this instance, the gingival wedge may not tightly support a small portion of the band. Special care must be exercised by placing small amounts of amalgam in this area first and condensing lightly but thoroughly. In addition, care is exercised in carving the restoration in this area to remove any excess that may have extruded gingivally during condensation.

Figure 14-50, B, illustrates a caries excavation facially and gingivally beyond the conventional margin position. Such minor variations from the ideal preparation form permit conservation of the tooth structure. A partial extension of a facial

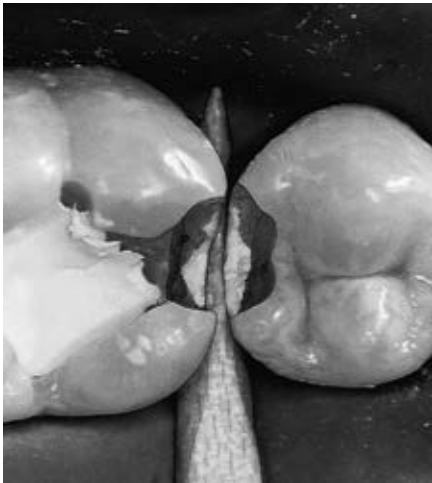


Fig. 14-49 Remnant of carious lesion bordering the enamel margin after insufficient gingival extension. Such a lesion indicates extending part or all of the gingival floor gingivally to place it in sound tooth structure. (Courtesy of Dr. C. L. Sockwell.)

or lingual wall is permissible if (1) the entire wall is not weakened, (2) the extension remains accessible and visible, (3) sufficient gingival seats remain to support the restoration, and (4) a butt-joint fit at the amalgam–enamel margin (90-degree amalgam angle and 90-degree cavosurface angle) is possible.

Pulp Protection

The reader is referred to this same step in tooth preparation in the previous section on conservative Class I amalgam preparations.

Secondary Resistance and Retention Forms

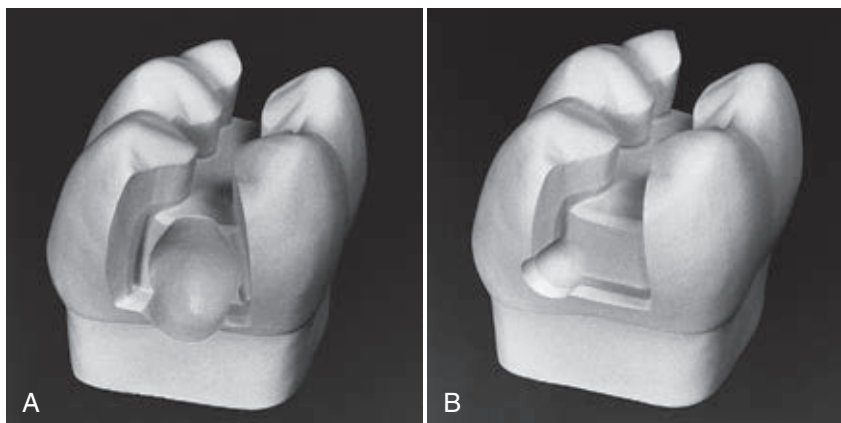
Secondary resistance form in final tooth preparation involves resistance of the remaining tooth structure against fracture from oblique forces and resistance of restorative material against fracture. Restricting extensions of external walls provides the former; the latter is enhanced by using the gingival margin trimmer or a bur to round the axiopulpal line angle (Fig. 14-51), increasing the bulk of and decreasing the stress concentration within the restorative material.

The use of retention grooves in proximal boxes is controversial. It has been reported that proximal retention grooves in the axiofacial and axiolingual line angles may increase the fracture resistance and significantly strengthen the isthmus of a Class II amalgam restoration and that these



Fig. 14-51 Rounding the axiopulpal line angle.

Fig. 14-50 A, Outline form that permits extension of the center portion of the gingival wall to facilitate proper matrix construction and wedging in situations where caries extends deep gingivally. **B**, Outline form that permits partial wall extension facially and gingivally to conserve the tooth structure.



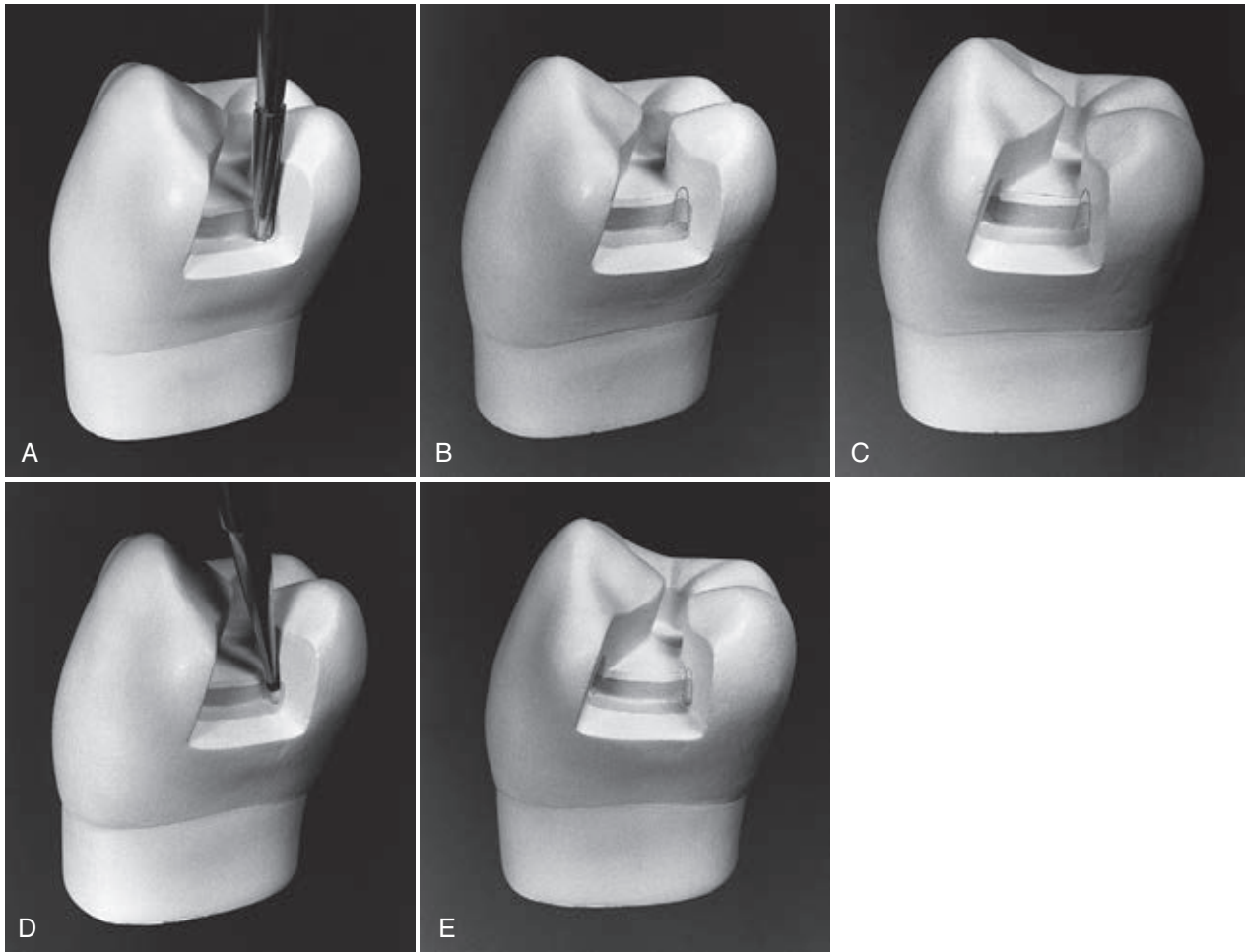


Fig. 14-52 Proximal retention grooves. **A**, Position of the No. 169 L bur to prepare the retention groove as the bur is moved lingually and pulpally. **B**, Lingual groove. Note the dentin support of the proximal enamel. **C**, Completed grooves. **D**, Grooves prepared with a No. $\frac{1}{4}$ round bur. **E**, Completed grooves.

grooves are significantly superior to the axiokingival grooves in increasing the restoration's fracture strength.⁷²⁻⁷⁵ Other investigators have suggested, however, that retention grooves located occlusal to the axiopulpal line angle provide more resistance than do conventional grooves.⁷⁶ It also has been reported that with high-copper amalgams, proximal retention grooves are unnecessary in preparations that include dovetails.^{77,78} The use of retention grooves is recommended, however, in tooth preparations with extensive proximal boxes.

Ideally, the secondary retention forms for the occlusal and proximal portions of the preparation should be independent of each other. The occlusal convergence of the facial and lingual walls and the dovetail design (if needed) provide a sufficient retention form to the occlusal portion of the tooth preparation. To enhance the retention form of the proximal portion, proximal grooves may be indicated to counter proximal displacement.^{19,76,79,80} Proximal grooves are routinely used because of the notion that it is essential to ensure that each portion of the tooth preparation is independently retentive. Evidence suggests, however, that retentive grooves may not be needed in conservative, narrow proximal boxes.⁸⁰

A No. 169 L or No. $\frac{1}{4}$ round bur is used with air coolant (to improve visualization) and reduced speed (to improve

tactile “feel” and control) to prepare a retention groove. The bur is placed in the properly positioned axiolingual line angle and directed (i.e., translated) to bisect the angle (Fig. 14-52) approximately parallel to the DEJ (Fig. 14-53). This positions the retention groove 0.2 mm inside the DEJ, maintaining the enamel support. The bur is tilted to allow cutting to the depth of the diameter of the end of the bur at the point angle and to permit the groove to diminish in depth occlusally, terminating at the axio-linguo-pulpal point angle. The facial groove in the axiofacial line angle is accomplished in a similar manner. When the axiofacial and axiolingual line angles are less than 2 mm in length, the tilt of the bur is reduced slightly so that the proximal grooves are extended occlusally to disappear midway between the DEJ and the enamel margin (see Fig. 14-52, B and C).

The four characteristics or determinants of proximal grooves are (1) position, (2) translation, (3) depth, and (4) occlusogingival orientation (see Fig. 14-53). *Position* refers to the axiofacial and axiolingual line angles of initial tooth preparation (0.5 mm axial to the DEJ). The retention grooves should be placed 0.2 mm inside the DEJ, regardless of the depth of the axial walls and axial line angles. *Translation* refers to the direction of movement of the axis of the bur. *Depth*

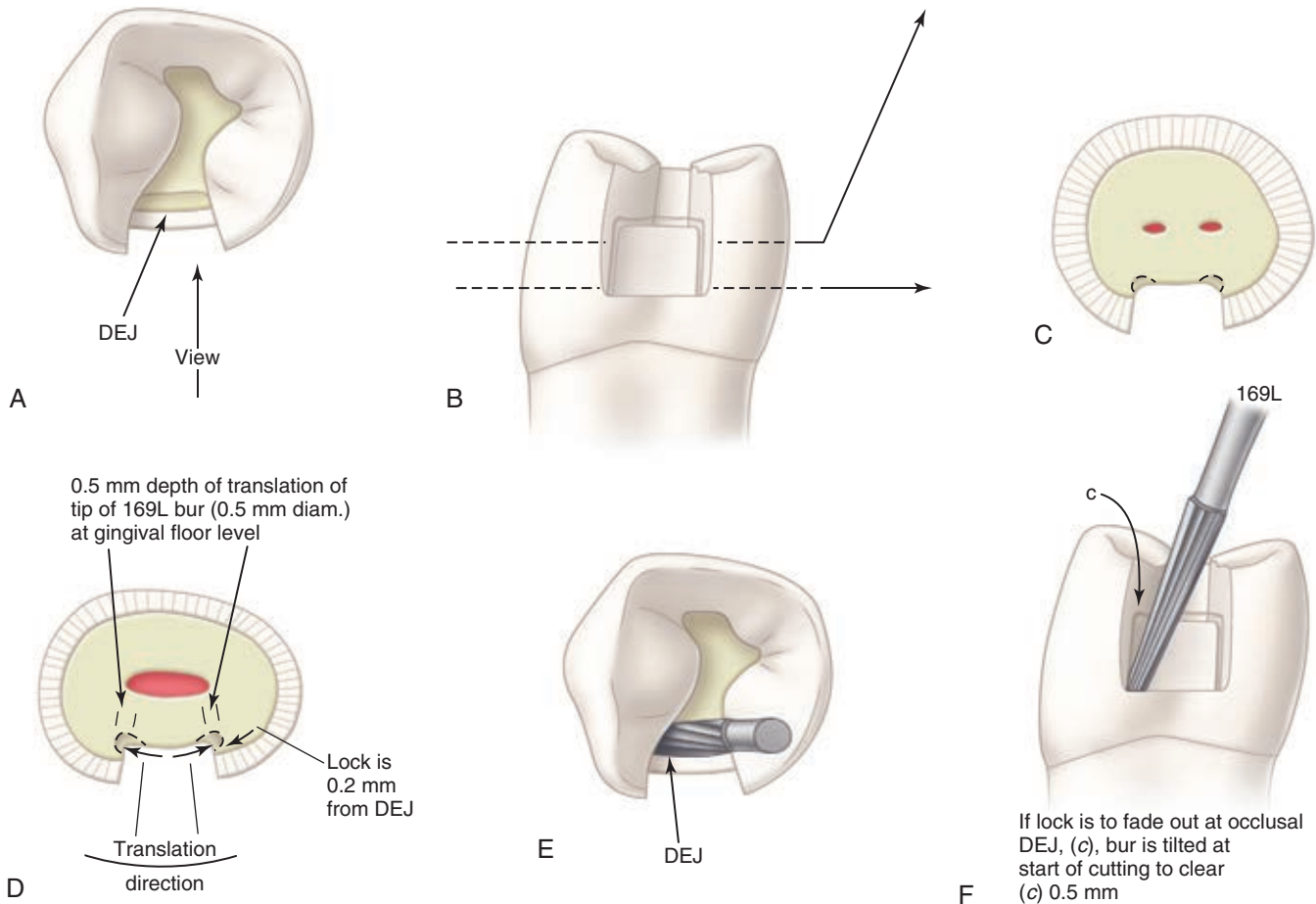


Fig. 14-53 Four characteristics of retentive grooves. **A**, Occlusal view of the mesio-occlusal preparation before placement of the retention grooves. **B**, Proximal view of the mesio-occlusal preparation. **C** and **D**, Position, translation, and depth. **E** and **F**, Occlusogingival orientation.

refers to the extent of translation (i.e., 0.5 mm at the gingival floor level). *Occlusogingival orientation* is considered when using the No. 169 L bur and refers to the tilt of the bur. The tilt dictates the occlusal height of the groove, given a constant depth. When using the No. $\frac{1}{4}$ bur to cut the proximal groove, the rotating bur is carried into the axio-linguo-gingival (or axio-facio-gingival) point angle, then moved parallel to the DEJ to the depth of the diameter of the bur. It is then drawn occlusally along the axiolingual (or axiofacial) line angle, allowing the groove to become shallower and to terminate at the axio-linguo-pulpal (or axio-facio-pulpal) point angle (or more occlusally if the line angles are <2 mm in length) (see Fig. 14-52, *D* and *E*).

Regardless of the method used in placing the grooves, extreme care is necessary to prevent the removal of dentin that immediately supports the proximal enamel. In addition, it is essential not to prepare the grooves entirely in the axial wall (i.e., incorrect translation [moving the bur only in a pulpal direction]) because no effective retention is obtained, and a risk of pulpal involvement exists.

An improperly positioned axiofacial or axiolingual line angle must not be used as a positional guide for the proximal groove. If the axial line angle is too shallow, the groove may undermine enamel or dentinal support. If the line angle is too deep, preparation of the groove may result in exposure of the

pulp. Retention grooves always should be placed in the facial and lingual proximal walls (0.2 mm inside the DEJ), regardless of the depth of the axial wall.

Finishing the External Walls

The preparation walls and margins should not have unsupported enamel and marginal irregularities.⁸¹ No occlusal cavosurface bevel is indicated in the tooth preparation for amalgam. Ideally, a 90-degree cavosurface angle (maximum of 100 degrees) should be present at the proximal margin. The occlusal line angle may be 90 to 100 degrees or greater. This angle aids in obtaining a marginal amalgam angle of 90 degrees (≥ 80 degrees). Clinical experience has established that this “butt-joint” relationship of enamel and amalgam creates the strongest margin.¹⁹ Amalgam is a brittle material and may fracture under occlusal stress if its angle at the margin is less than 80 degrees.

The mesial gingival margin trimmer (13-85-10-14, R and L) is used to establish a slight cavosurface bevel at the gingival margin (6 centigrades [or 20 degrees] declination gingivally) if it is in enamel. The bevel is angled no more than necessary to ensure that full-length enamel rods form the gingival margin and that it is no wider than the enamel (Fig. 14-54). When the gingival margin is positioned gingival to the cemento-enamel junction (CEJ) on the tooth root, the bevel is not

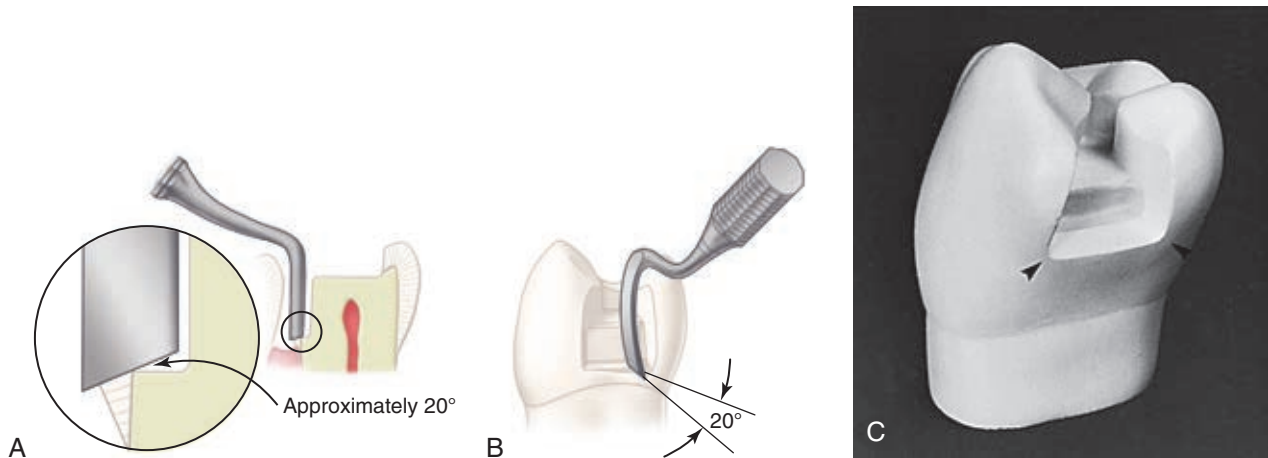


Fig. 14-54 **A**, The bevel of the enamel portion of the gingival wall is established with a gingival margin trimmer to ensure full-length enamel rods forming the gingival margin. **B** and **C**, The sharp angles at the linguogingival and faciogingival corners are rounded by rotational sweeping with a gingival margin trimmer.

indicated.¹⁹ When beveling the gingival margin on the distal surface, the distal gingival margin trimmer (13-95-10-14, R and L) is used. Alternatively, the side of an explorer tine may be used to remove any friable enamel at the gingival margin. The tine is placed in the gingival embrasure apical to the gingival margin. With some pressure against the prepared tooth, the tine is moved occlusally across the gingival margin to “trim” the margin by removing enamel that is not supported.

Final Procedures: Cleaning and Inspecting

The reader is referred to the similar section earlier under conservative Class I amalgam restorations.

VARIATIONS OF PROXIMAL SURFACE TOOTH PREPARATIONS

The following sections describe variations in tooth preparation for some conservative Class II amalgam restorations. In most clinical situations, the restoration presented would be done with composite. If amalgam is used, the features presented should be considered in the tooth preparation portion of the procedure.

Mandibular First Premolar

For the conservative Class II tooth preparation for amalgam on the mandibular first premolar, the conventional approach and technique must be modified because the morphologic structure of this tooth is different from other posterior teeth (particularly because of the diminished size of the lingual cusp). For this tooth, as in all teeth, the principles of tooth preparation for amalgam must be correlated with the physical properties of the restorative material and the anatomic structure of the tooth. The relationship of the pulp chamber to the DEJ and the relatively small size of the lingual cusp are illustrated in [Figure 14-55](#) (this figure also illustrates the correct position of the pulpal wall and how it differs in direction compared with the second premolar). Incorrect preparation of the central groove area could weaken the lingual cusp, and excessive extension in a facial direction could approach or expose the facial pulp horn. When preparing the occlusal

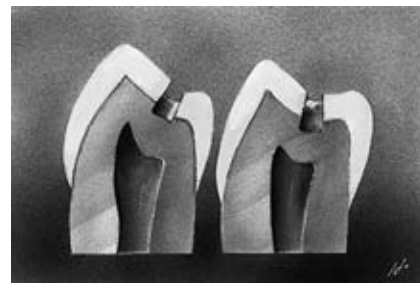


Fig. 14-55 The mandibular first and second premolars are compared. Note differences in the sizes of the pulp chambers, lingual cusps, and direction of pulpal walls.

portion, the bur is tilted slightly lingually to establish the correct pulpal wall direction (see [Fig. 14-17, B](#)).

In addition, the mandibular first premolar presents a variety of occlusal patterns, most of which exhibit a large transverse ridge of enamel. Often, such a ridge has no connecting fissure between the mesial and distal pits, dictating a Class II preparation with an outline form that does not extend to, or across, the ridge ([Fig. 14-56, A](#)). If the opposite pit or proximal surface is faulty, it is restored with a separate restoration.

For a preparation that does not cross the transverse ridge, the proximal box is prepared before the occlusal portion to prevent removing the tooth structure that will form the isthmus between the occlusal dovetail and the proximal box. The pit adjacent to the involved proximal surface is entered with the No. 245 bur. Immediately after the entry, the bur is directed into the proximal marginal ridge and then pulpally (if necessary) until the proximal DEJ is visible. The bur axis for the proximal ditch cut should be parallel to the tooth crown, which is tilted slightly lingually for mandibular posterior teeth. The proximal enamel is isolated and the proximal box completed as previously described for the mandibular second premolar. The bur is then returned to the area of entry, and the occlusal step is prepared with a dovetail, if needed. When preparing the occlusal portion, the bur is tilted slightly lingual to establish the correct pulpal wall direction (which maintains the dentin support for the small lingual

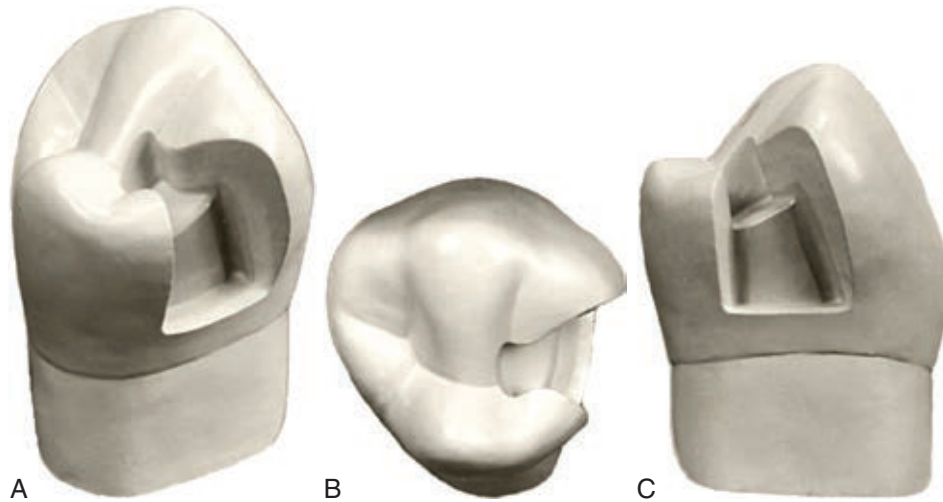


Fig. 14-56 The mandibular first premolar with a sound transverse ridge. **A**, A two-surface tooth preparation that does not include the opposite pit. **B**, Occlusal outline form. **C**, Proximal view of the completed preparation.

cusps and prevents encroachment on the facial pulp horn). The primary difference in tooth preparation on this tooth, compared with the preparation on other posterior teeth, is the facial inclination of the pulpal wall. The isthmus is broadened as necessary, but maintains the dovetail retention form, if required. **Figure 14-56, B**, illustrates the correct occlusal outline form. Removing any remaining caries (if present) and inserting necessary liners, bases, or both precede the placement of proximal grooves and the finishing of the enamel margins to complete the preparation (see **Fig. 14-56, C**).

Maxillary First Molar

When mesial and distal proximal surface amalgam restorations are indicated on the maxillary first molar that has an unaffected oblique ridge, separate two-surface tooth preparations are indicated (rather than a mesiooccluso-distal preparation) because the strength of the tooth crown is significantly greater when the oblique ridge is intact.¹⁹ The mesio-occlusal tooth preparation is generally uncomplicated (**Fig. 14-57, A**). Occasionally, extension through the ridge and into the distal pit is necessary because of the extent of caries. The outline of this occlusolingual pit-and-fissure portion is similar to that of the Class I occlusolingual preparation. **Figure 14-57, B and C**, illustrates a mesio-occlusal preparation extended to include the distal pit and the outline form that includes the distal oblique and lingual fissures.

When the occlusal fissure extends into the facial cusp ridge and cannot be removed by enameloplasty, the defect should be eliminated by extension of the tooth preparation. Occasionally, this can be accomplished by tilting the bur to create an occlusal divergence of the facial wall while maintaining the dentin support of the ridge. If this fault cannot be eliminated without extending the margin to the height of the cusp ridge or undermining the enamel margin, the preparation should be extended facially through the ridge (see **Fig. 14-57, D**). The pulpal wall of this facial extension may have remaining enamel, but a depth of 1.5 to 2 mm is necessary to provide sufficient bulk of material for adequate strength. For the best esthetic results, minimal extension of the proximal mesiofacial margin is indicated.

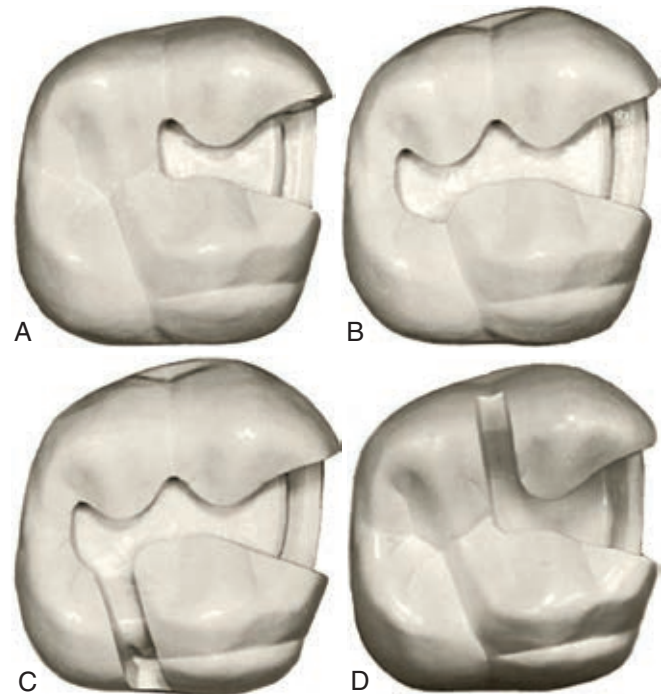
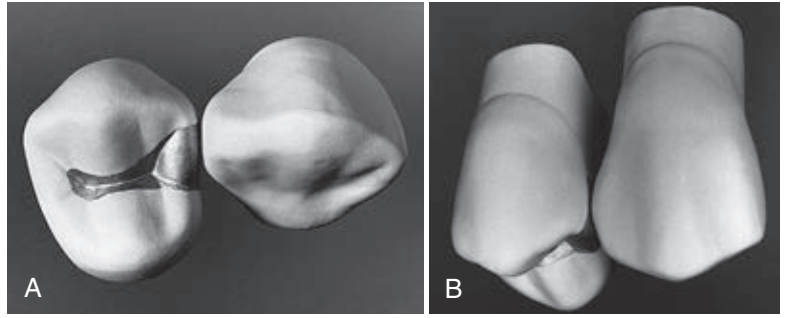


Fig. 14-57 Maxillary first molar. **A**, Conventional mesioocclusal preparation. **B**, Mesioocclusal preparation extended to include the distal pit. **C**, Mesiooccluso-lingual preparation, including the distal pit and the distal oblique and lingual fissures. **D**, Mesioocclusal preparation with facial fissure extension.

The disto-occlusal tooth preparation may take one of several outlines, depending on the occlusal anatomy. The occlusal outline is determined by the pit-and-fissure pattern and by the amount and extension of caries. An extension onto the lingual surface to include a lingual fissure should be prepared only after the distolingual proximal margin is established. This approach may allow conservation of more tooth structure between the distolingual wall and the lingual fissure extension, resulting in more strength of the distolingual cusps.

Fig. 14-58 To produce an inconspicuous margin on the maxillary first premolar, the mesiofacial wall does not diverge gingivally, and facial extension with a No. 245 bur should be minimal so that the mesiofacial proximal margin of the preparation minimally clears the contact as the margin is finished. **A**, Occlusal view. **B**, Facial view.



It is accomplished by preparing the lingual fissure extension more at the expense of the mesiolingual cusp than the distolingual cusp. Nevertheless, the distolingual cusp on many maxillary molars (particularly the maxillary second molars) may be weakened during such a disto-occluso-lingual tooth preparation because of the small cuspal portion remaining between the lingual fissure preparation and the distolingual proximal wall. In addition, caries excavation may weaken the cusp. Capping of the distolingual cusp is often necessary to provide the proper resistance form.

Maxillary First Premolar

A Class II amalgam tooth preparation involving the mesial surface of a maxillary first premolar requires special attention because the mesiofacial embrasure is esthetically prominent. The occlusogingival preparation of the facial wall of the mesial box should be parallel to the long axis of the tooth instead of converging occlusally to minimize an unesthetic display of amalgam in the faciogingival corner of the restoration. In addition, the facial extension of the mesiofacial proximal wall should be minimal so that the mesiofacial proximal margin of the preparation only minimally clears the contact as the margin is finished with an appropriate enamel hatchet or chisel (Fig. 14-58).

If the mesial proximal involvement (1) is limited to a fissure in the marginal ridge that is at risk for caries, (2) is not treatable by enameloplasty, and (3) does not involve the proximal contact, the proximal portion of the tooth preparation is prepared by extending through the fault with the No. 245 bur so that the margins are lingual to the contact. Often, this means that the proximal box is the faciolingual width of the bur, and the gingival floor may be at the same depth as the pulpal floor. The retention form for this extension is provided by the slight occlusal convergence of the facial and lingual walls (see Fig. 14-9).

If the proximal caries is limited to the mesiolingual embrasure, the mesial proximal contact should not be included in the tooth preparation. If only the lingual aspect of the mesial proximal contact is carious, the mesiofacial wall may be left in contact with the adjacent tooth (reducing the display of amalgam). A Class II tooth preparation involving the distal surface of the maxillary first premolar is similar to the preparation of the mandibular second premolar described earlier.

Box-Only Preparation

When restoring a small, cavitated proximal lesion in a tooth with neither occlusal fissures nor a previously inserted occlusal restoration, a proximal box preparation without an occlusal step has been recommended.^{18,19} To maximize retention,

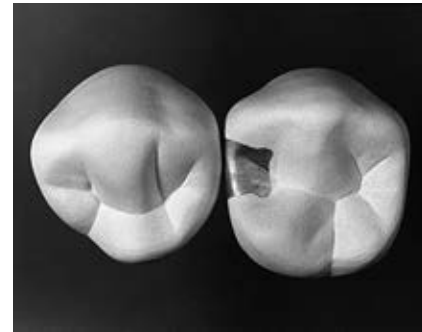


Fig. 14-59 A simple box restoration without the occlusal step is permissible when restoring a small proximal lesion in the tooth without either occlusal fissures or previously inserted occlusal restoration and when the involved marginal ridge does not support occlusal contact. The proximal grooves extend to the occlusal surface.

preparations with facial and lingual walls that almost oppose each other are recommended. This type of preparation should be limited to a proximal surface with a narrow proximal contact (allowing minimal facial and lingual extensions). As in the typical preparation, the facial and lingual proximal walls converge occlusally. Retention grooves are necessary in box-only preparations.⁸² The proximal retention grooves should have a 0.5-mm depth at the gingival point angle, tapering to a depth of 0.3 mm at the occlusal surface (Fig. 14-59).

MODIFICATIONS IN TOOTH PREPARATION

Slot Preparation for Root Caries

Older patients who have gingival recession that exposes cementum may experience caries on the proximal root surface that is appreciably gingival to the proximal contact (Fig. 14-60, A). Assuming that the contact does not need restoring, the tooth preparation usually is approached from the facial direction and has the form of a slot (see Fig. 14-60, B). A lingual approach is used when the caries is limited to the linguoproximal surface. Amalgam is particularly indicated for slot preparations if isolation is difficult.¹³

The initial outline form is prepared from a facial approach with a No. 2 or No. 4 bur using high speed and air-water spray. Outline form extension to sound tooth structure is at a limited depth axially (i.e., 0.75–1 mm at the gingival aspect [if no enamel is present], increasing to 1–1.25 mm at the occlusal wall [if margin is in enamel]) (see Fig. 14-60, B). If the occlusal margin is in enamel, the axial depth should be 0.5 mm inside the DEJ. During this extension, the bur should not remove any infected carious dentin from the axial wall deeper than the

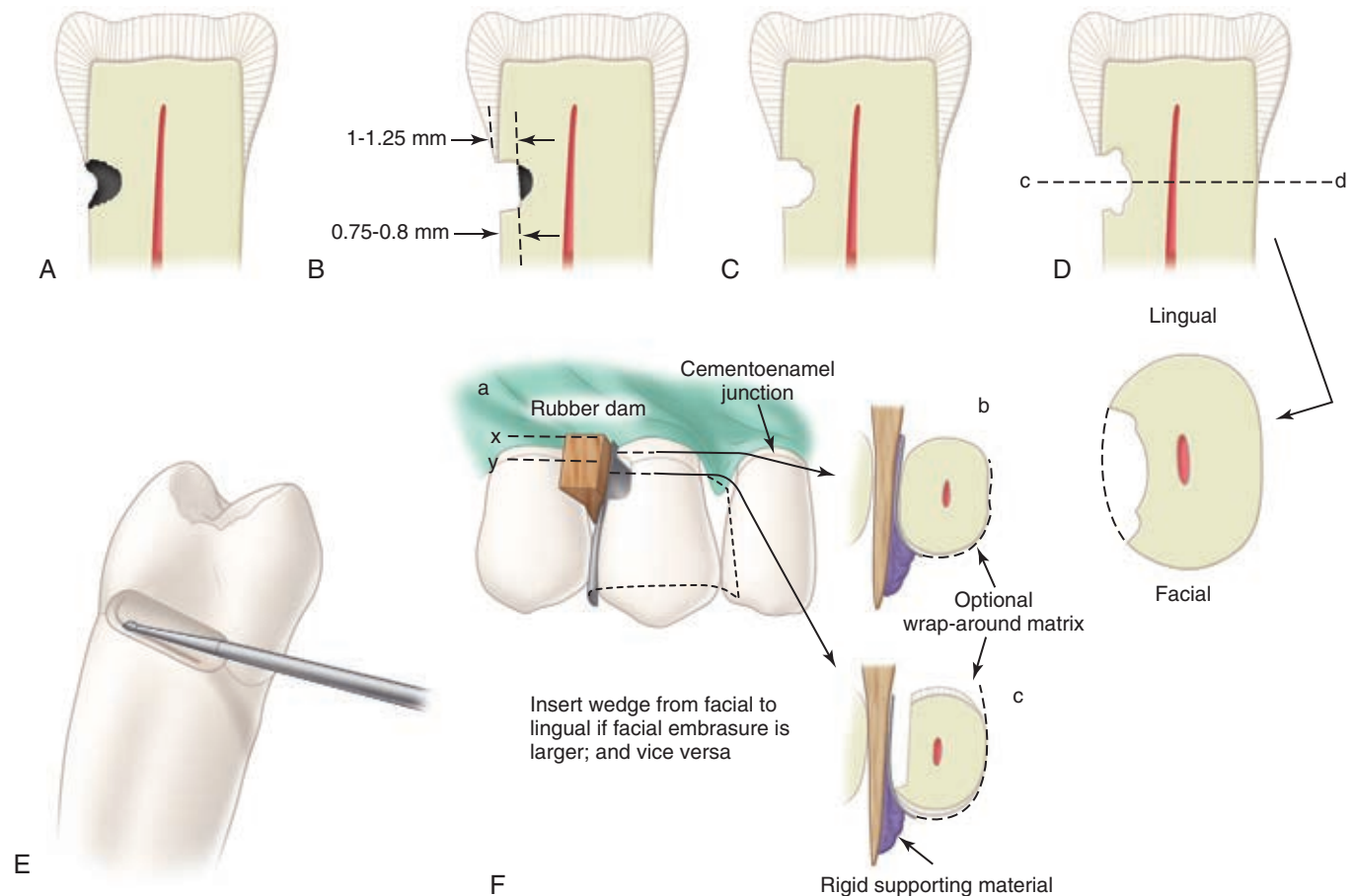


Fig. 14-60 Slot preparation. **A**, Mesiodistal longitudinal section illustrating a carious lesion. The proximal contact is not involved. **B**, Initial tooth preparation. **C**, Tooth preparation with infected carious dentin removed. **D**, The retention grooves are shown in longitudinal section, and the transverse section through plane *cd* illustrates the contour of the axial wall and the direction of the facial and lingual walls. **E**, Preparing the retention form to complete the tooth preparation. **F**, Matrix for slot preparation: *a*, facial view of wedged matrix; *b*, wedged matrix as viewed in transverse cross-section (*x*), gingival to gingival floor; *c*, wedged matrix as viewed in transverse cross-section (*y*), occlusal to gingival floor.

outline form initial depth. The remaining infected carious dentin (if any) is removed during final tooth preparation (see Fig. 14-60, *C*). The external walls should form a 90-degree cavosurface angle. With a facial approach, the lingual wall should face facially as much as possible; this aids condensation of amalgam during its insertion. The facial wall must be extended to provide access and visibility (convenience form) (see Fig. 14-60, *D*). In the final tooth preparation, the No. 2 or No. 4 bur should be used to remove any remaining infected carious dentin on the axial wall. A liner or base (or both) is applied, if indicated.

A No. $\frac{1}{4}$ bur is used to create retention grooves in the occlusoaxial and gingivoaxial line angles, 0.2 mm inside the DEJ or 0.3 to 0.5 mm inside the cemental cavosurface margin (see Fig. 14-60, *E*). The depth of these grooves is one-half the diameter of the bur head (i.e., 0.25 mm), and the bur is directed to bisect the angle formed by the junction of the occlusal (or gingival) and axial walls. Ideally, the direction of the occlusal groove is slightly more occlusal than axial, and the direction of the gingival groove would be slightly more gingival than axial (as in the Class III amalgam preparation). Before application of the matrix, a dentin desensitizer should be placed. The matrix for inserting amalgam in a slot

preparation for root caries is similar to that illustrated in Figure 14-60, *F*.

For instances in which root caries encircles the tooth, the proximal areas can be restored as described previously. Subsequently, Class V preparations are prepared and abutted with the proximal restorations. The amalgam used to restore the proximals should be fully set (to avoid dislocation during preparation and during insertion of the Class V restorations). Alternatively, the Class V portions can be restored first. When the proximals are restored first, the mesial and distal walls of the Class V preparations would be in amalgam. Doing a circumferential restoration in segments allows proper condensation of amalgam. A full-coverage restoration usually is preferred if caries encircles the tooth cervically.

Rotated Teeth

Tooth preparation for rotated teeth follows the same principles as for normally aligned teeth. The outline form for a mesio-occlusal tooth preparation on the rotated mandibular second premolar (Fig. 14-61, *A*) differs from normal in that its proximal box is displaced facially because the proximal caries involves the mesiofacial line angle of the tooth crown. When the tooth is rotated 90 degrees and the “proximal” lesion

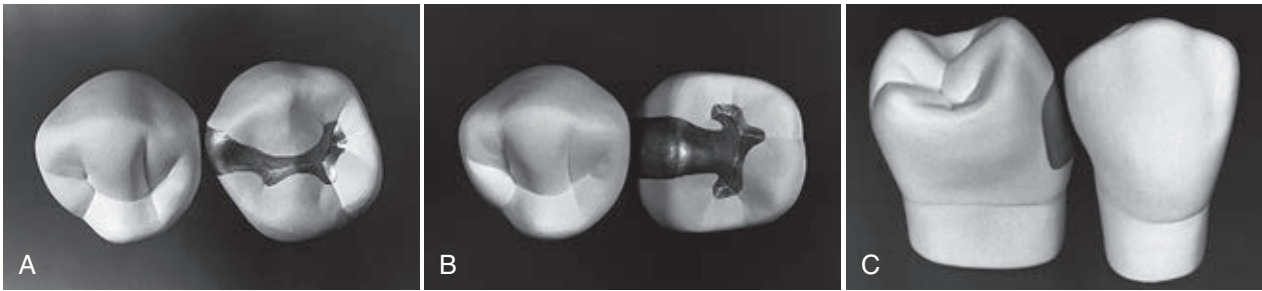


Fig. 14-61 Restoration outlines for rotated teeth. **A**, Mesio-occlusal outline for the mandibular premolar with 45-degree rotation. **B**, Mesio-occlusal outline for the mandibular premolar with 90-degree rotation. **C**, Slot preparation outline for the restoration of a small mesial lesion involving the proximal contact of the mandibular premolar with 90-degree rotation.



Fig. 14-62 Restoration of the mesio-occlusal tooth preparation, with the central fissure segmented by coalesced enamel.

is on the facial or lingual surface, or orthodontic correction is declined or ruled out, the preparation may require an isthmus that includes the cuspal eminence (see Fig. 14-61, *B*). If the lesion is small, consideration should be given to slot preparation. In this instance, the occlusal margin may be in the contact area or slightly occlusal to it (see Fig. 14-61, *C*).

Unusual Outline Forms

Outline forms should conform to the restoration requirements of the tooth and not to the classic example of a Class II tooth preparation. As mentioned earlier, a dovetail feature is not required in the occlusal step of a single proximal surface preparation unless a fissure emanating from the occlusal step is involved in the preparation. Another example is an occlusal fissure that is segmented by coalesced enamel (as illustrated previously for mandibular premolars and the maxillary first molars). This condition should be treated with individual amalgam restorations if the preparations are separated by approximately 0.5 mm or more of sound tooth structure (Fig. 14-62).^{18,68}

Adjoining Restorations

It is permissible to repair or replace a defective portion of an existing amalgam restoration if the remaining portion of the original restoration retains adequate resistance and retention forms. Adjoining restorations on the occlusal surface occur more often in molars because the dovetail of the new restoration usually can be prepared without eliminating the dovetail of the existing restoration. Where the two restorations adjoin, care should be taken to ensure that the outline of the second restoration does not weaken the amalgam margin of the

first (Fig. 14-63, *A*). The intersecting margins of the two restorations should be at a 90-degree angle as much as possible. The decision to adjoin two restorations is based on the assumption that the first restoration, or a part of it, does not need to be replaced and that the procedure for the single proximal restoration (compared with a mesio-occluso-distal restoration) is less complicated, especially in matrix application.

Occasionally, preparing an amalgam restoration in two or more phases is indicated, such as for a Class II lesion that is contiguous with a Class V lesion. Preparing both lesions before placing amalgam introduces condensation problems that can be eliminated by preparing and restoring the Class II lesion before preparing and restoring the Class V lesion (see Fig. 14-63, *B*). It is better to condense amalgam against a carious wall of the first preparation than to attempt condensation where no wall exists.

Abutment Teeth for Removable Partial Denture

When the tooth is an abutment for a planned removable partial denture, the occlusoproximal outline form adjacent to the edentulous region may need additional extension if a rest seat is planned, such as for the tooth-borne partial denture. This additional extension must be sufficient facially, lingually, and axially to allow for preparing the rest seat in the restoration without jeopardizing its strength. The facial and lingual proximal walls and the respective occlusal margins must be extended so that the entire rest seat can be prepared in amalgam without encroaching on the occlusal margins. If the rest seat is to be within the amalgam margins, it is recommended that a minimum of 0.5 mm of amalgam be present between the rest seat and the margins (Fig. 14-64, *A*). The portion of the pulpal wall apical to the planned rest seat is deepened 0.5 mm so that the total depth of the axiopulpal line angle measured on the faciolingual wall is 2.5 mm (see Fig. 14-64, *B*). A rest seat used for a tissue-borne (i.e., distal extension) partial denture may involve amalgam and enamel (see Fig. 14-64, *C*). In this case, no modification of the outline form of the tooth preparation is indicated (see Fig. 14-64, *C*). Figure 14-64, *D*, illustrates the relationship of the tissue-borne removable partial denture with the abutment tooth (see Fig. 14-64, *C*).

Class II Amalgam Restorations Involving Both Proximal Surfaces

Perhaps the best indications for the use of amalgam restorations are moderate and large Class II defects that include both

Fig. 14-63 Adjoining restorations. **A**, Adjoining mesio-occlusal tooth preparation with disto-occlusal restoration so that the new preparation does not weaken the amalgam margin of the existing restoration. **B**, Preparing and restoring a Class II lesion before preparing and restoring a Class V lesion contiguous with it eliminates condensation problems that occur when both lesions are prepared before either is restored.

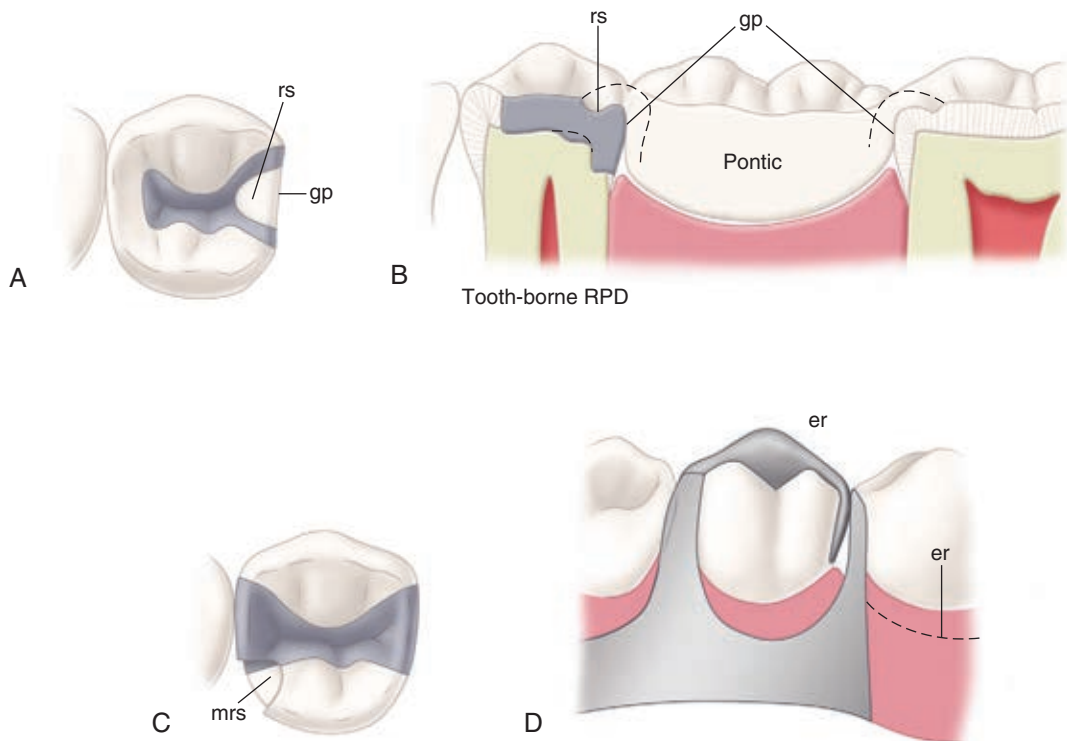
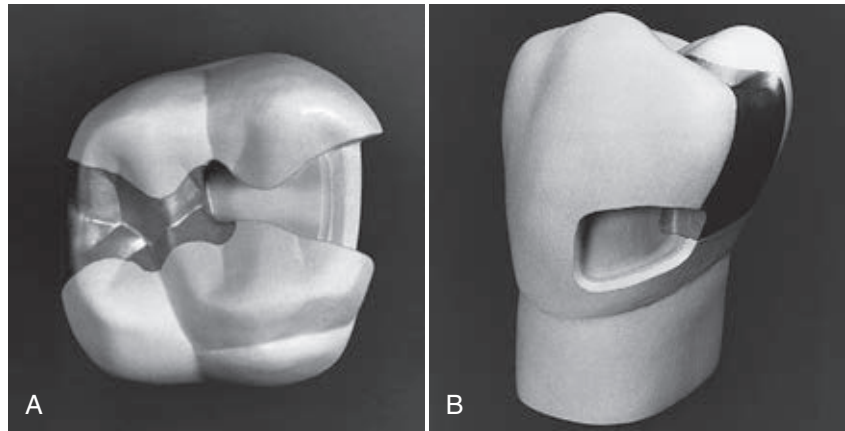


Fig. 14-64 Abutment teeth with Class II restorations designed for a removable partial denture (RPD). **A**, Occlusal view showing the location of the rest seat (*rs*) and the guiding plane (*gp*) for a tooth-borne RPD. **B**, Cross-sectional view illustrating deepened pulpal wall in the area of the rest seat (*rs*) to provide adequate thickness of amalgam. Note the relationship of the guiding planes (*gp*) to the tooth-borne RPD. **C**, Occlusal view showing the mesial rest seat (*mrs*) for the tissue-borne (i.e., distal extension) RPD. **D**, Lingual view of the tissue-borne RPD showing the relationship of the RPD to the Class II restoration and the edentulous ridge (*er*).

proximal surfaces and much of the occlusal surface. This section describes factors to consider when amalgam is used for moderate and large Class II restorations. The principles of tooth preparation are the same for all amalgam restorations and are as follows:

- A cavosurface marginal design that results in an approximate 90-degree amalgam margin
- Appropriate removal of tooth structure to provide for adequate strength of the amalgam
- Appropriate retention features

The tooth preparation techniques presented for a two-surface Class II restoration apply to larger Class II restorations as well. When the defect is large, however, certain modifications in tooth preparation may be necessary.

Occlusal Extensions

Often, a larger Class II defect requires greater extension of the occlusal surface outline form. This may require extending the grooves that are fissured, capping the cusps that are undermined, or extending the outline form up the cuspal inclines. These alterations can be accomplished easily by following the

principles presented previously. Groove extension occurs at the same initial pulpal floor depth (i.e., at the level of the DEJ), and follows the DEJ as the groove is extended in a facial or lingual direction. The pulpal floor of an extended groove usually rises slightly occlusally as it is extended toward the cusp ridge. If it is necessary to extend through the cusp ridge onto the facial or lingual surface, the preparation is accomplished as described for the occlusolingual Class I restoration.

If an occlusal outline form extends up a cuspal incline, the extension also should maintain the pulpal floor at the level of the DEJ. This extension (as well as the groove extension) usually requires some alteration in the orientation of the No. 245 bur—a slight lingual tilt when extending in a facial direction and a slight facial tilt when extending in a lingual direction. Maintaining the correct pulpal floor depth preserves tooth structure and reduces the potential for pulpal encroachment. The prepared facial (or lingual) cavosurface margin still should result in a 90-degree amalgam margin.

When the occlusal outline form extends from a primary groove to within two-thirds of the distance to a cusp tip, that cusp is usually sufficiently weakened so as to require replacement. Leaving the cusp in a weakened state may be acceptable if the cusp is very large or, occasionally, if the amalgam is to be bonded (which provides some reinforcement of the strength of the remaining cuspal structure). Routine preparations in some teeth may predispose some cusps for capping (i.e., reduction). The small distal cusp of the mandibular first molars, the distolingual cusp of maxillary molars, and the lingual cusp of some mandibular premolars (especially first premolars) may be weakened when normal preparations of surrounding areas of the tooth are included.

Cusp reduction for an amalgam restoration should result in a uniform amalgam thickness over the reduced cusp of 1.5 to 2 mm. The thicker amount is necessary for functional cusps. These dimensions provide adequate strength for amalgam by limiting flexure during loading. The cusp reduction should occur as early in the preparation as can be determined to provide better access and visibility for completing the preparation. To reduce the cusp, the dentist orients the No. 245 bur parallel to the cuspal incline (lingual incline for facial cusp reductions and facial inclines for lingual cusp reduction) and makes several depth cuts in the cusp (to a depth of 1.5 or 2 mm). The depth cuts provide guides for the correct amount of cusp reduction. Without depth cuts, after the beginning reduction of the cusp, the operator may no longer know how much more reduction is necessary. The operator uses the bur to reduce the cusp, following the mesiodistal inclines of the cusp; this results in a uniform reduction. If only one of two facial (or lingual) cusps is to be capped, the cusp reduction should extend slightly beyond the facial (or lingual) groove area, provide the correct amount of tooth structure removal, and meet the adjacent, unreduced cusp to create a 90-degree cavosurface margin. This approach results in adequate thickness and edge strength of the amalgam. Cusp capping reduces the amount of vertical preparation wall heights and increases the need for the use of secondary retention features. An increased retention form may be provided by the proximal box retention grooves but may require the use of pins or slots (as described in Chapter 16). If indicated, cusp capping increases the resistance form of the tooth.^{83,84} It has been reported that the survival rate of cusp-covered amalgam restorations is 72% at 15 years.⁸⁵

Proximal Extensions

Larger Class II restorations often require larger proximal box preparations. These may include not only increased faciolingual or gingival extensions but also extension around a facial or lingual line angle. Large proximal box preparations also need secondary retention features (i.e., retention grooves, pins, slots) for an adequate retention form. Extensive proximal boxes are usually prepared the same as a more conservative proximal box but may require modifications. For increased faciolingual extensions, it may be necessary to tilt the No. 245 bur to include proximal faults that are extensive gingival to the contact area. Tilting the bur lingually when extending a facial proximal wall, or facially when extending a lingual proximal wall, conserves more of the marginal ridge and cuspal tooth structure. Although this action enhances preservation of some tooth structure strength, it results in a more occlusally convergent wall, which increases the difficulty of amalgam condensation in the gingival corners of the preparation.

When proximal extension around a line angle is necessary, it usually is associated with a reduction of the involved cusp. Such proximal extension usually is necessitated by a severely defective (or fractured) cusp or a cervical lesion that extends from the facial (or lingual) surface into the proximal area. Often, these areas are included in the preparation by extending the gingival floor of the proximal box around the line angle, using the same criteria for preparation as the typical proximal box: (1) Facial (or lingual) extension results in an occlusogingival wall that has a 90-degree cavosurface margin, and (2) the axial depth is 0.5 mm inside the DEJ.

The increased dimensions of a large proximal box usually require the use of retention grooves or other secondary retention form features (i.e., pins or slots). Secondary retention form features better ensure the retention of amalgam within the preparation by resisting displacement of amalgam in a proximal direction (and occasionally in an occlusal direction). Placement of retention grooves may be more difficult because of the extent of the preparation and the amount of caries excavation that may be necessary. If the outline form is developed correctly, however, the axiofacial and axiolingual line angles are correctly positioned and can be used as the location for retention groove placement.

When the proximal defect is extensive gingivally, isolation of the area, tooth preparation, matrix placement, and condensation and carving of amalgam are more difficult. If the proximal box is extended onto the root surface, the axial wall depth is no longer dictated by the DEJ. Any root surface preparation for amalgam should result in an initial axial wall depth of approximately 0.8 mm. This axial depth provides appropriate strength for amalgam, preserves pulp integrity, and creates enough dimension for the placement of retention grooves of 0.5 mm depth while preserving the strength of the adjacent, remaining marginal dentin and cementum. The extent of the preparation onto the root surface, the contour of the tooth, or both may require that the bur be tilted toward the adjacent tooth when preparing the gingival floor of the proximal box. This tilting may result in an axial wall that has two planes, the more gingival plane angled slightly internally. It also may cause more difficulty in retention groove placement. The more occlusal part of the axial wall may be over-reduced if the bur is not tilted.

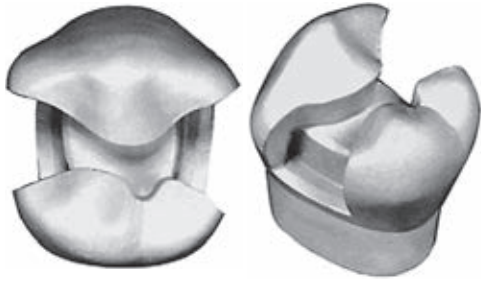


Fig. 14-65 Mesio-occluso-distal preparation on the mandibular second premolar.

Caries Excavation and Pulp Protection

Larger Class II restorations often require more extensive caries excavation and pulp protection procedures during tooth preparation. Deep excavations indicate the increased need for pulp protection with a liner, a base, or both.

Matrix Placement

When a tooth preparation is extensive, matrix placement is more difficult. This is especially true for preparations that extend onto the root surface. Use of modified matrix bands and wedging techniques may be required. Different types of matrix systems are presented in Chapter 16.

Condensation and Carving of the Amalgam

Larger Class II preparations that extend around line angles or cap cusps or onto the root surface require careful amalgam condensation and carving techniques. Condensation of amalgam is more difficult in areas where cusps have been capped, where slots or pins have been placed, where vertical walls are more convergent occlusally, and where the root surface is involved. For larger restorations, lateral condensation is important to produce a properly condensed restoration in the gingival corners; also, carving cusps and gingival areas is more difficult.

EXAMPLES OF MODERATE CLASS II AMALGAM TOOTH PREPARATIONS THAT INVOLVE BOTH PROXIMAL SURFACES

Mandibular Second Premolar

A moderate mesio-occluso-distal tooth preparation in a mandibular second premolar is illustrated in Figure 14-65. Note the similarity with the two-surface mesio-occlusal preparation.

Mandibular First Premolar

When a mesio-occluso-distal amalgam tooth preparation is needed for the mandibular first premolar, the support of the small lingual cusp may be conserved by preparing the occlusal step more at the expense of tooth structure facial to the central groove than lingual. In addition, the bur is tilted slightly lingually to establish the correct pulpal wall direction. Despite these precautions, the lingual cusp may need to be reduced for capping if the lingual margin of the occlusal step extends more than two-thirds the distance from the central fissure to the cuspal eminence (Fig. 14-66). Special attention is given to such cusp reduction because retention is severely diminished when the cusp is reduced, eliminating the lingual wall of the occlusal



Fig. 14-66 Mandibular first premolar with the lingual cusp reduced for capping.

portion. Depth cuts of 1.5 mm aid the operator in establishing the correct amount of cusp reduction and in conserving a small portion of the lingual wall in the occlusal step. It is acceptable when restoring diminutive nonfunctional cusps, such as the lingual cusp of a mandibular first premolar, to reduce the cusp only 0.5 to 1 mm and restore the cusp to achieve an amalgam thickness of 1.5 mm. This procedure conserves more of the lingual wall of the isthmus for added retention form.

Maxillary First Molar

The mesio-occluso-distal tooth preparation of the maxillary first molar may require extending through the oblique ridge to unite the proximal preparations with the occlusal step. Cutting through the oblique ridge is indicated only if (1) the ridge is undermined by caries, (2) it is crossed by a deep fissure, or (3) occlusal portions of the separate mesio-occlusal and disto-occlusal outline forms leave less than 0.5 mm of the tooth structure between them. The remainder of the outline form is similar to the two-surface outline forms described previously in this chapter. Figure 14-67 illustrates typical three-surface and four-surface restorations for this tooth. The procedure for reducing the distolingual cusp of a maxillary first molar for capping is illustrated in Figure 14-68. Extending the facial or lingual wall of a proximal box to include the entire cusp is done (if necessary) to include weak or carious tooth structure or existing restorative material (Figs. 14-69 and 14-70).

Maxillary Second Molar with Caries on the Distal Portion of the Facial Surface

Close examination of the distal portion of the facial surface of the maxillary second molar may reveal decalcification or cavitation or both. When enamel is only slightly cavitated (i.e., softened and rough), polishing with sandpaper disks may eliminate the fault. Careful brushing technique, daily use of fluoride (i.e., rinses, toothpaste), and periodic applications of a fluoride varnish may prevent further breakdown. When decalcification is as deep as the DEJ and distal proximal caries is also present, however, the entire distofacial cusp may need to be included in a mesio-occluso-disto-facial tooth preparation. The facial lesion may be restored separately, if it is judged that the distofacial cusp would not be significantly weakened if left unrestored (i.e., uncapped) by amalgam. In that case, the mesio-occluso-distal preparation would be restored first, followed by preparation and restoration of the facial lesion. When such sequential preparations are contraindicated, the

Fig. 14-67 Typical three- and four-surface restorations for the maxillary first molar. (See Fig. 14-68 for preparation of the distolingual cusp for capping.)

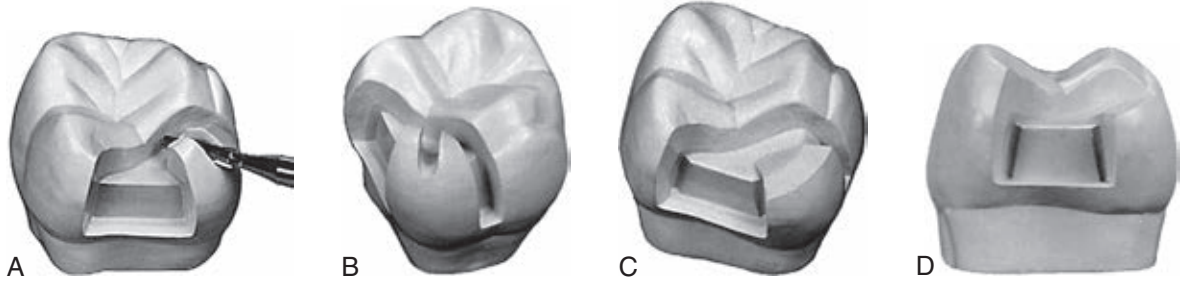


Fig. 14-68 Reduction of the distolingual cusp of the maxillary molar. **A**, Cutting a depth gauge groove with the side of the bur. **B**, Completed depth gauge groove. **C** and **D**, Completed cusp reduction.

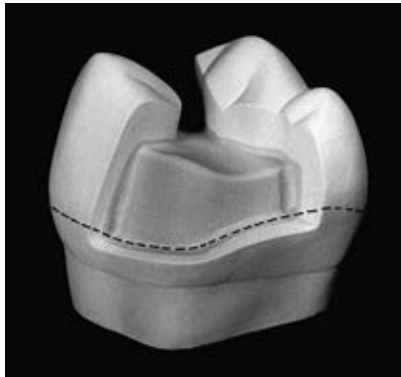


Fig. 14-69 Mesio-occluso-distofacial preparation of the maxillary second molar showing extension to include moderate to extensive caries in the distal half of the facial surface. The outline includes the distofacial cusp and the facial groove. The dotted line represents the soft tissue level.

preparation outline is extended gingivally to include the distofacial cusp (just beyond the caries) and mesially to include the facial groove (see Fig. 14-69). The No. 245 bur should be used to create a gingival floor (i.e., shoulder) perpendicular to the occlusal force when extending the distal gingival floor to include the affected facial surface. Inclusion of distofacial caries often indicates a gingival margin that follows the gingival tissue level. The width of the shoulder should be approximately 1 or 0.5 mm inside the DEJ, whichever is greater. Some resistance form is provided by the shoulder. A retention groove should be placed in the axiofacial line angle of this distofacial extension, similar to the grooves placed in the proximal boxes. For additional retention, a slot may be placed (see Chapter 16).

Mandibular First Molar

The distal cusp on the mandibular first molar may be weakened when positioning the distofacial wall and margin. Facial extension of the distofacial margin to clear the distal contact often places the occlusal outline in the center of the cusp; this dictates relocation of the margin to provide a sound enamel wall and 90-degree amalgam that is not on a cuspal eminence. When the distal cusp is small or weakened or both, extension of the distal gingival floor and distofacial wall to include the distal cusp places the margin just mesial to the distofacial groove. Figure 14-70 illustrates the ideal distofacial extension and a preparation design that includes the distal cusp.

Capping the distal cusp is an alternative to extending the entire distofacial wall when the occlusal margin crosses the cuspal eminence (see Fig. 14-70, C). A minimal reduction of 2 mm should result in a 2-mm thickness of amalgam over the capped cusp (see Fig. 14-70, D). The cusp reduction should result in a butt joint between the tooth structure and amalgam. Whenever possible, capping the distal cusp is more desirable than extending the distofacial margin because this conserves the tooth structure, and the remaining portion of the cusp helps in applying the matrix for the development of proper embrasure form. The plane of the reduced cusp should parallel the facial (or lingual) outline of the unreduced cusp mesio-distally and the cuspal incline emanating from the central groove faciolingually.

Restorative Technique for Class II Amalgam Preparations Desensitizer Placement

A dentin desensitizer is placed in the completed cavity preparation.

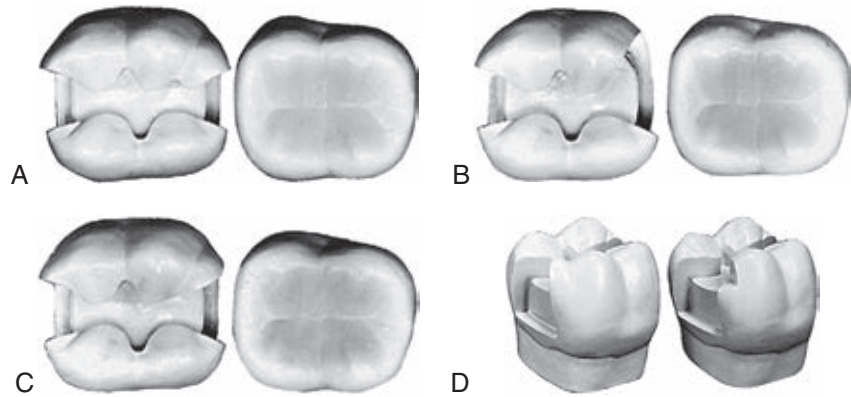


Fig. 14-70 Mandibular first molar. **A**, Ideal distofacial extension. **B**, Entire distal cusp included in preparation outline form. **C**, Capping of the distal cusp is indicated when the occlusal margin crosses the cuspal eminence. **D**, Distofacial view of the distal cusp shown in **C** before reduction for capping (*left*); the distal cusp after reduction (*right*). A reduction of 2 mm is necessary to provide for minimal 2-mm thickness of amalgam.

Matrix Placement

The primary function of the matrix is to restore anatomic contours and contact areas. The qualities of a good matrix include (1) rigidity, (2) establishment of proper anatomic contour, (3) restoration of correct proximal contact relation, (4) prevention of gingival excess, (5) convenient application, and (6) ease of removal. The following information presents the technique of placement for the universal (Tofflemire), and precontoured matrix systems.

UNIVERSAL MATRIX

The universal matrix system (designed by B.R. Tofflemire) is ideally indicated when three surfaces (i.e., mesial, occlusal, distal) of a posterior tooth have been prepared (Fig. 14-71). It also is commonly used for the two-surface Class II restoration. A definite advantage of the Tofflemire matrix retainer is that it may be positioned on the facial or lingual aspect of the tooth. However, lingual positioning requires the contra-angled design of the retainer (which can be used on the facial aspect as well) (Fig. 14-72). The retainer and the band are generally stable when in place. The retainer is separated easily from the band to expedite removal of the band. Matrix bands of various occlusogingival widths are available (see Fig. 14-71). A small Tofflemire retainer is available for use with the primary dentition.

Precontoured bands for the universal retainer are commercially available and need little or no adjustment before being placed in the retainer or after being positioned around the tooth (Fig. 14-73). Although precontoured bands are more expensive, they generally are preferred over the uncountoured bands. The difference in cost is justified because they require less chair time. When cotton roll isolation is used, the Tofflemire retainer helps hold the cotton roll in place (Fig. 14-74).

Although the universal retainer is a versatile instrument, it still does not meet all the requirements of the ideal retainer and band. The conventional, flat Tofflemire matrix band must be shaped (i.e., burnished) to achieve proper contour and contact. The uncountoured bands are available in two thicknesses, 0.002 inch (0.05 mm) and 0.0015 inch (0.038 mm). Burnishing the thinner band to contour is more difficult, and the band is less likely to retain its contour when tightened around the tooth. The uncountoured band must be burnished before assembling the matrix band and the retainer. Burnishing must occur in the areas corresponding to the proximal

surface to be restored after the band is positioned around the tooth.

Burnishing means that the metal band has been deformed occlusogingivally with a suitable hand instrument to produce a rounded or convex surface that (when in place around the tooth) produces a restoration that is symmetric in contour with the adjacent proximal surface (Fig. 14-75). The No. 26-28 burnisher is generally recommended for burnishing the band. The band should be placed on a resilient paper pad because contouring cannot occur on a hard, nonresilient surface. The smaller round burnisher tip should be used with firm pressure in back-and-forth, overlapping strokes along the length of the band until the band is deformed occlusogingivally in the appropriate areas. When the band is deformed, the larger egg-shaped end may be used to smooth the burnished band. If a convex surface is not obvious in the burnished areas when the band is removed from the pad, it has not been adequately burnished. The band can be burnished with the larger egg-shaped burnisher only, but more work is required to do so. It is not necessary to burnish the entire length of the band. To prepare the retainer to receive the band, the larger of the knurled nuts is turned counterclockwise until the locking vise is a short distance ($\frac{1}{4}$ inch [6 mm]) from the end of the retainer (Fig. 14-76, A). Next, while holding the large nut, the dentist turns the smaller knurled nut counterclockwise until the pointed spindle is free of the slot in the locking vise (see Fig. 14-76, B). The matrix band is folded end to end, forming a loop (see Fig. 14-76, C). When the band is folded, the gingival edge has a smaller circumference than does the occlusal edge. The band design accommodates the difference in tooth circumferences at the contact and gingival levels. The band is positioned in the retainer so that the slotted side of the retainer is directed gingivally to permit easy separation of the retainer from the band in an occlusal direction (later procedure). This is accomplished by placing the occlusal edge of the band in the correct guide channel (i.e., right, left, or parallel to the long axis of the retainer), depending on the location of the tooth. The two ends of the band are placed in the slot of the locking vise, and the smaller of the knurled nuts is turned clockwise to tighten the pointed spindle against the band (see Fig. 14-76, D). If proximal wedges were used during tooth preparation, the wedges are removed now, and the matrix band is fitted around the tooth (allowing the gingival edge of the band to be positioned at least 1 mm apical to the gingival margin). Damaging the gingival attachment should be avoided. If needed, the larger of the knurled nuts may be turned



Fig. 14-71 Straight and contra-angled Universal (Tofflemire) retainers. Bands with varying occlusogingival measurements are available.



Fig. 14-72 Lingual positioning requires a contra-angled Universal retainer.



Fig. 14-73 Precontoured bands for a Universal retainer. Pictured: Waterpik Getz Contour Matrix Bands (Courtesy of Water Pik Inc., Fort Collins, CO).

counterclockwise to obtain a larger loop to fit around the tooth. Care should be taken not to trap the rubber dam between the band and the gingival margin. If the dam material is trapped between the band and the tooth, the septum of the dam should be stretched and depressed gingivally to reposition the dam material. Next, the larger knurled nut is rotated clockwise to tighten the band slightly. Exploration along the



Fig. 14-74 Tofflemire retainer maintaining a cotton roll in the maxillary vestibule during condensation.

gingival margin is accomplished to determine that the gingival edge of the band extends beyond the preparation margins. When the band is correctly positioned, the band is securely tightened around the tooth.

When one of the proximal margins is deeper gingivally, the Tofflemire mesio-occluso-distal band may be modified to prevent damage to the gingival tissue or attachment on the more shallow side. A band may be trimmed for the shallow gingival margin, permitting the matrix to extend farther gingivally for the deeper gingival margin (**Fig. 14-77**).

The mouth mirror is positioned to observe the proximal contours of the matrix through the interproximal space (**Fig. 14-78**). The occlusogingival contour should be convex, with the height of contour at proper contact level and contacting the adjacent tooth. The matrix is also observed from an occlusal aspect allowing evaluation of the position of the contact area in a faciolingual direction. It may be necessary to remove the retainer and reburnish the band for additional contouring. Minor alterations in contour and contact may be accomplished without removal from the tooth. The backside of the blade of the 15-8-14 spoon excavator (i.e., Black spoon) is an excellent instrument for improving contour and contact. If a smaller burnishing instrument is used, the dentist should take care not to create a grooved or bumpy surface that would result in a restoration with an irregular proximal surface. Ideally, the band should be positioned 1 mm apical to the gingival margin or deep enough to be engaged by the wedge

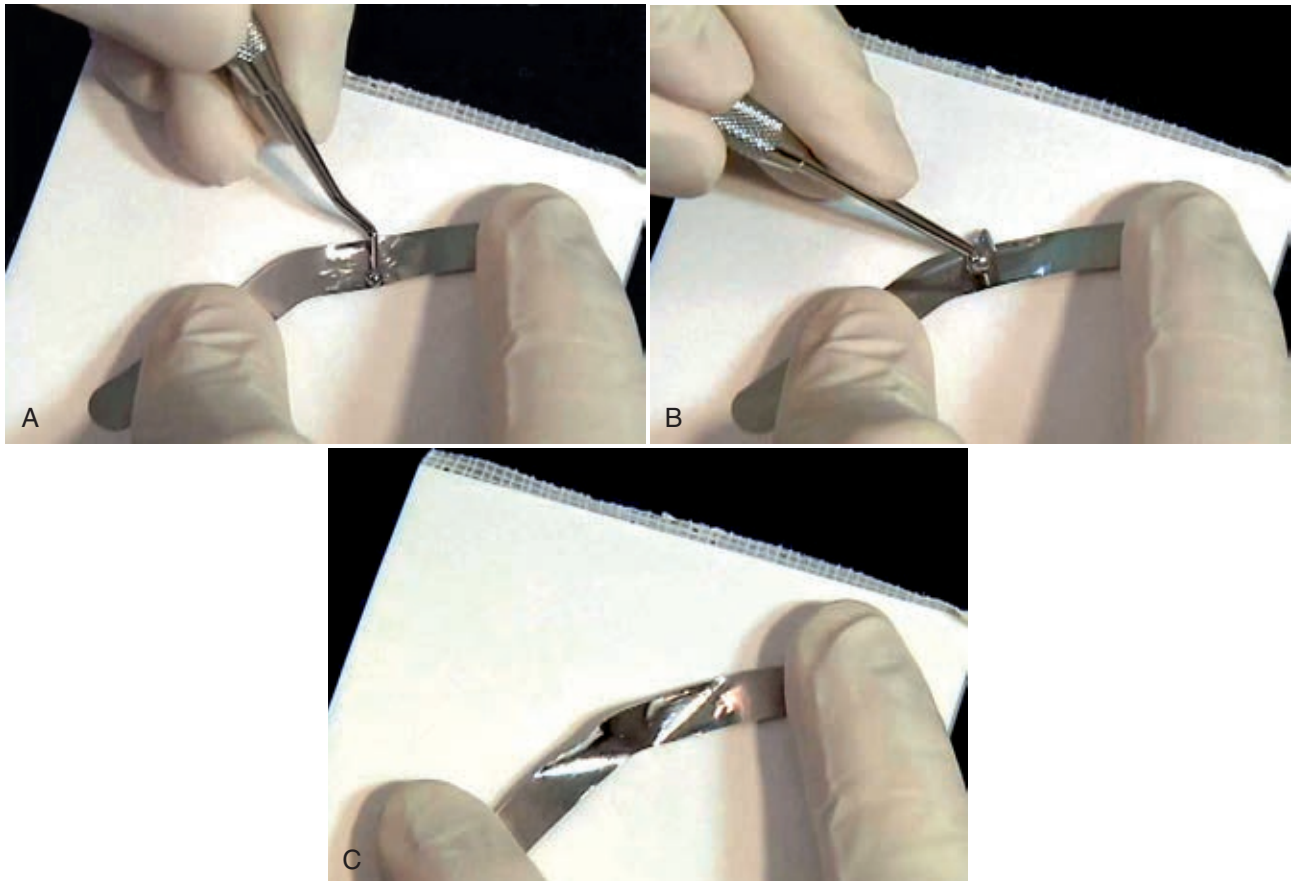


Fig. 14-75 Burnishing the matrix band. **A**, With the band on the pad, a small burnisher is used to deform the band. **B**, A large burnisher to smooth the band contour. **C**, Burnished matrix band for mesio-occluso-distal tooth preparation. (Courtesy of Aldridge D. Wilder, DDS.)

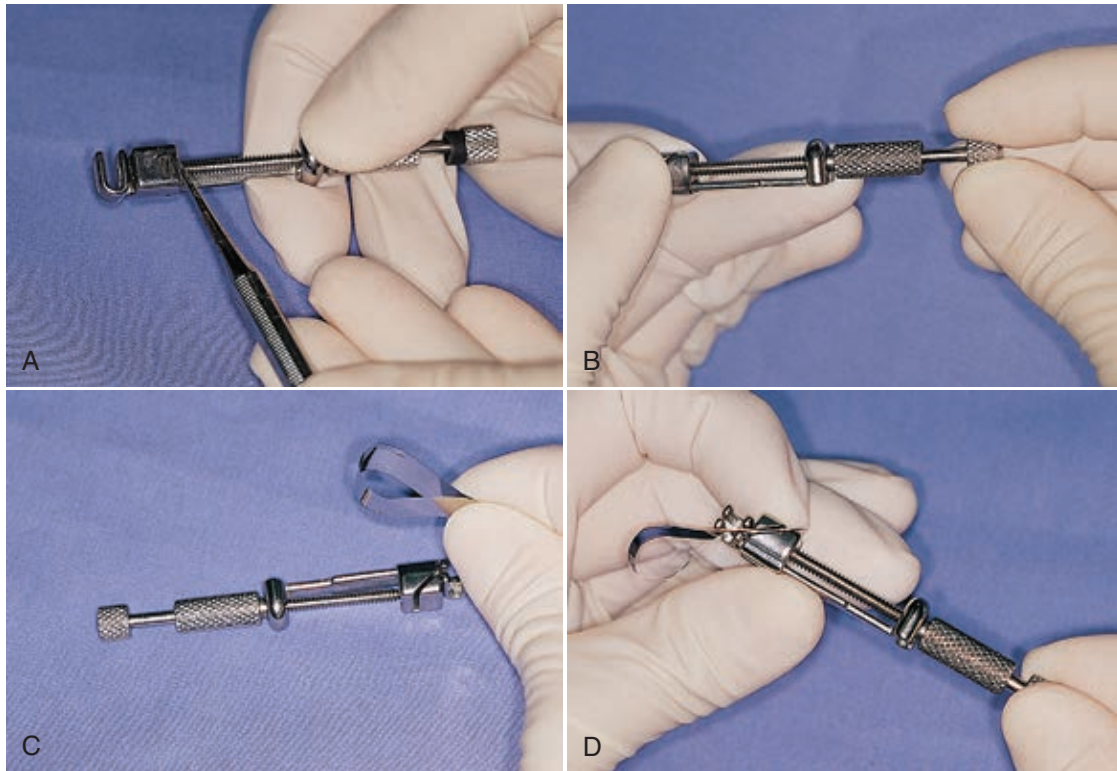


Fig. 14-76 Positioning the band in a Universal retainer. **A**, Explorer pointing to the locking vise. The gingival aspect of the vise is shown in this view. **B**, The pointed spindle is released from the locking vise when the small knurled nut is turned counterclockwise. **C**, The band is folded to form a loop and to be positioned in the retainer (occlusal edge of band first). **D**, The spindle is tightened against the band in the locking vise. (From Daniel SJ, Harfst SA, Wilder RS: Mosby's dental hygiene: Concepts, cases, and competencies, ed 2, St. Louis, Mosby, 2008.)



Fig. 14-77 The band may be trimmed for the shallower gingival margin, permitting the matrix to extend farther gingivally for the deeper gingival margin on the other proximal surface.

(whichever is less) and 1 to 2 mm above the adjacent marginal ridge or ridges.

A minor modification of the matrix may be indicated for restoring the proximal surface that is planned for a guide plane for a removable partial denture. Abutment teeth for a tooth-supported removable partial denture must provide amalgam contour to allow defining (by carving or [later] disking) a guide plane extending from the marginal ridge 2.5 mm gingivally. Normal proximal contouring, rather than



Fig. 14-78 Using a mirror from the facial or lingual position to evaluate the proximal contour of the matrix band.

over-contouring, is usually sufficient, however, and best for the development of a guide plane. Guide plane development results in a gingival embrasure between the natural tooth and denture teeth that is less open and less likely to trap food (see Fig. 14-64, B).

Abutment teeth adjacent to the residual ridge for a tissue-supported (i.e., distal extension) removable partial denture are carved to provide normal morphology. Sufficient gingival embrasure should be provided to allow for the difference between the compression under the load of the ridge soft tissue and that of the periodontal membrane (although a small area guide plane may be provided).

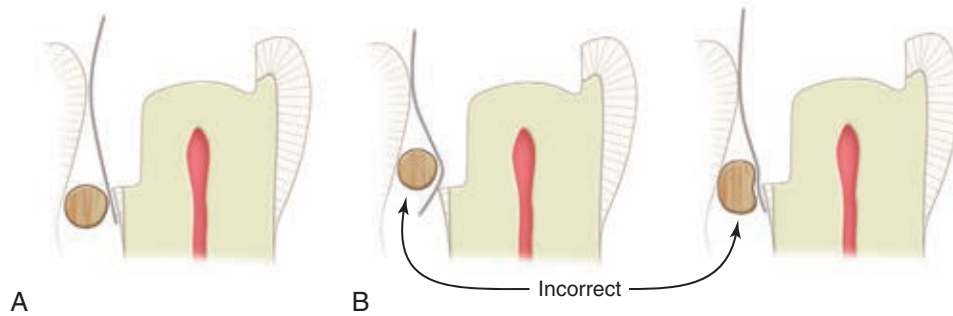


Fig. 14-79 A, Correct wedge position. B, Incorrect wedge positions.

After the matrix contour and extension are evaluated, a wedge is placed in the gingival embrasure or embrasures using the following technique: (1) Break off approximately 0.5 inch (1.2 cm) of a round toothpick. (2) Grasp the broken end of the wedge with the No. 110 pliers. (3) Insert the pointed tip from the lingual or facial embrasure (whichever is larger), slightly gingival to the gingival margin. (4) Wedge the band tightly against the tooth and margin (Fig. 14-79, A). If necessary, the gingival aspect of the wedge may be lightly moistened with lubricant to facilitate its placement. If the wedge is placed occlusal to the gingival margin, the band is pressed into the preparation, creating an abnormal concavity in the proximal surface of the restoration (see Fig. 14-79, B). The wedge should not be so far apical to the gingival margin that the band will not be held tightly against the gingival margin. This improper wedge placement results in gingival excess (i.e., “overhang”) caused by the band moving slightly away from the margin during condensation of the amalgam. Such an overhang often goes undetected and may result in irritation of the gingiva or an area of plaque accumulation, which may increase the risk of secondary caries. To be effective, a wedge should be positioned as close to the gingival margin as possible without being occlusal to it. If the wedge is significantly apical of the gingival margin, a second (usually smaller) wedge may be placed on top of the first to wedge adequately the matrix against the margin (Fig. 14-80). This type of wedging is particularly useful for patients whose interproximal tissue level has receded.

The gingival wedge should be tight enough to prevent any possibility of an overhang of amalgam in at least the middle two-thirds of the gingival margin (see Fig. 14-80, A and B). Occasionally, double wedging is permitted (if access allows), securing the matrix when the proximal box is wide faciolingually. *Double wedging* refers to using two wedges: one from the lingual embrasure and one from the facial embrasure (see Fig. 14-80, E and F). Two wedges help ensure that the gingival corners of a wide proximal box can be properly condensed; they also help minimize gingival excess. Double wedging should be used only if the middle two-thirds of the proximal margins can be adequately wedged, however. Because the facial and lingual corners are accessible to carving, proper wedging is important to prevent gingival excess of amalgam in the middle two-thirds of the proximal box (see Fig. 14-80, B).

Occasionally, a concavity may be present on the proximal surface that is apparent in the gingival margin. This may occur on a surface with a fluted root, such as the mesial surface of

the maxillary first premolar (see Fig. 14-80, G1). A gingival margin located in this area may be concave (see Fig. 14-80, G2). To wedge a matrix band tightly against such a margin, a second pointed wedge can be inserted between the first wedge and the band (see Fig. 14-80, G3 and G4).

The wedging action between teeth should provide enough separation to compensate for the thickness of the matrix band. This ensures a positive contact relationship after the matrix is removed (after the condensation and initial carving of amalgam). If a Tofflemire retainer is used to restore a two-surface Class II preparation, the single wedge must provide enough separation to compensate for two thicknesses of band material. The tightness of the wedge is tested by pressing the tip of an explorer firmly at several points along the middle two-thirds of the gingival margin (against the matrix band) to verify that it cannot be moved away from the gingival margin (Fig. 14-81). As an additional test, the dentist attempts to remove the wedge (using the explorer with moderate pressure) after first having set the explorer tip into the wood near the broken end. Moderate pulling should not cause dislodgment. Often, the rubber dam has a tendency to loosen the wedge. Rebounding of the dam stretched during wedge placement may loosen the wedge. Stretching the interproximal dam septa before and during wedge placement in the direction opposite to the wedge (and lubricating the wedge) can prevent this. The stretched dam is released after the wedge is inserted.

Some situations may require a triangular wedge that can be modified (by knife or scalpel blade) to conform to the approximating tooth contours (Fig. 14-82). The round toothpick wedge is usually the wedge of choice with conservative proximal boxes, however, because its wedging action is more occlusal (i.e., nearer the gingival margin) than with the triangular wedge (Fig. 14-83, A and B).

The triangular (i.e., anatomic) wedge is recommended for a preparation with a deep gingival margin. The triangular wedge usually is indicated with the Tofflemire mesio-occluso-distal matrix band. The triangular wedge is positioned similarly to the round wedge, and the goal is the same. When the gingival margin is deep (cervically), the base of the triangular wedge more readily engages the tooth gingival to the margin without causing excessive soft tissue displacement. The anatomic wedge is preferred for deeply extended gingival margins because its greatest cross-sectional dimension is at its base (see Fig. 14-83, C and D).

To maintain gingival isolation attained by an anatomic wedge placed before the preparation of a deeply extended gingival margin, it may be appropriate to withdraw the wedge

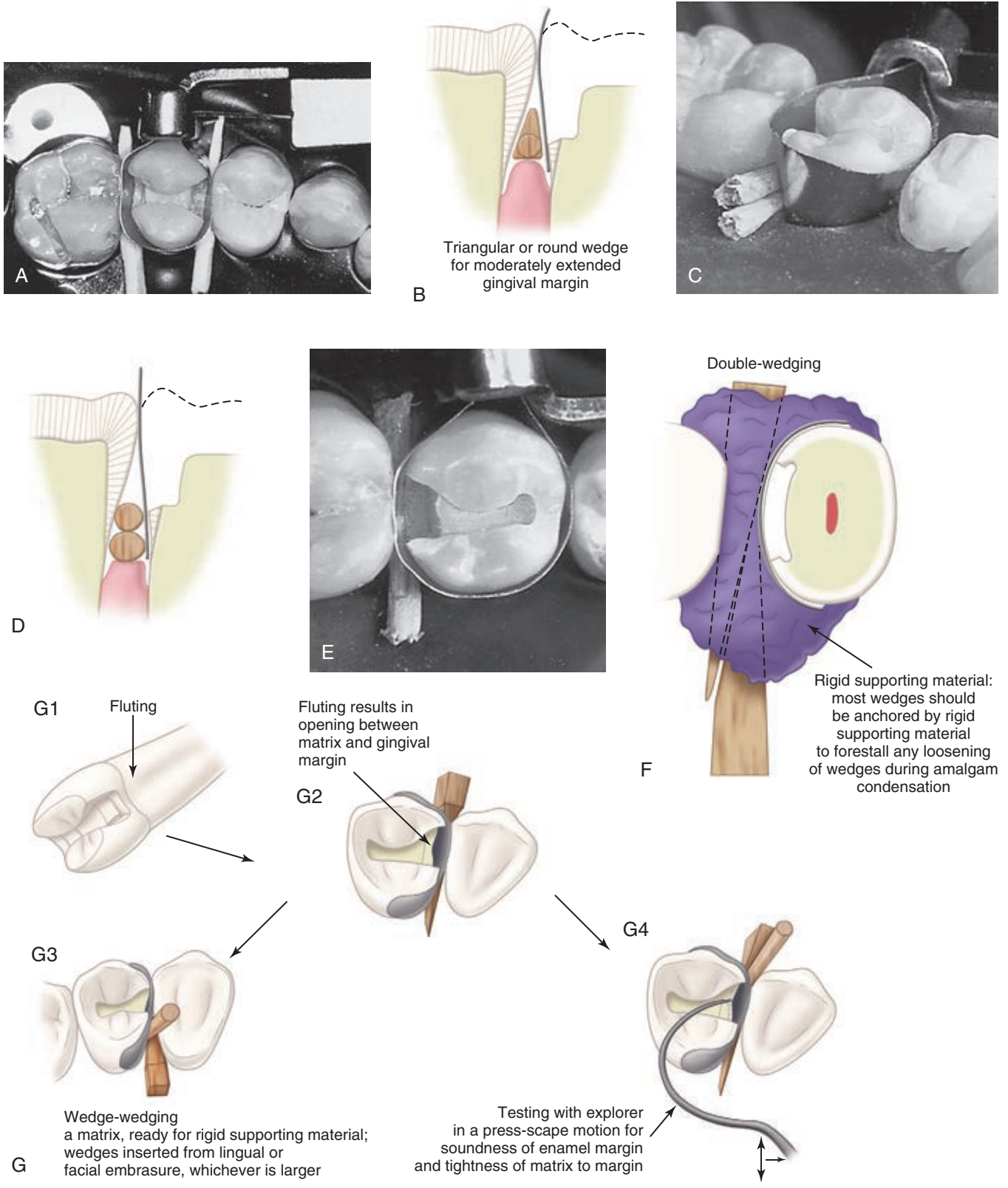


Fig. 14-80 Various double-wedging techniques. **A** and **B**, Proper wedging for the matrix for a typical mesio-occluso-distal preparation. **C** and **D**, Technique to allow wedging near the gingival margin of the preparation when the proximal box is shallow gingivally, the interproximal tissue level has receded, or both. **E** and **F**, Double wedging may be used with faciolingually wide proximal boxes to provide maximal closure of the band along the gingival margin. **G**, Another technique may be used on the mesial aspect of the maxillary first premolars to adapt the matrix to the fluted (i.e., concave) area of the gingival margin (**G1**, **G2**); a second wedge inserted from the lingual embrasure (**G3**); testing the adaptation of the band after insertion of the wedges from the facial aspect (**G4**).

a small distance to allow passage of the band between the loosened wedge and the gingival margin. Tilting (i.e., canting) the matrix into place helps the gingival edge of the band slide between the loosened wedge and the gingival margin. The band is tightened, and the same wedge is firmly re-inserted.

Supporting the matrix material with the blade of a Hollenback carver during the insertion of the wedge for the difficult deep gingival restoration may be helpful.¹⁹ The tip of the blade is placed between the matrix and the gingival margin,

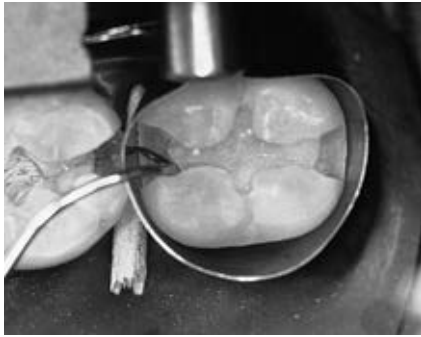


Fig. 14-81 Use of the explorer tip (with pressure) to ensure proper adaptation of the band to the gingival margin. In addition, the tip is pressed and dragged along the gingival margin in both directions to ensure removal of any friable enamel.

and then the “heel” of the blade is leaned against the matrix and adjacent tooth (Fig. 14-84). In this position, the blade supports the matrix to help in positioning the wedge sufficiently gingivally and preventing the wedge from pushing the matrix into the preparation. After the wedge is properly inserted, the blade is gently removed.

All aspects of the band are assessed and any desired final corrections are made after the wedge is placed. The matrix band must be touching the adjacent contact area (see Fig. 14-78). If the band does not reach the adjacent contact area after contouring and wedging, the tension of the band is released by turning the larger knurled nut of the Tofflemire retainer slightly (quarter turn) counterclockwise. If loosening the loop of a Tofflemire band still does not allow for contact with an adjacent tooth, a custom-made band with a smaller angle can be used. Reducing the angle of the band increases the difference in length (i.e., circumferences) of the gingival and occlusal edges. To reduce the angle of the band, the operator folds it as shown in Figure 14-85. Next, the operator burnishes for appropriate occlusogingival contour (in the contact areas) and inserts the band into the Tofflemire retainer.

A suitably trimmed tongue blade can wedge a matrix where the interproximal spacing between teeth is large (Fig. 14-86). Occasionally, however, it is impossible to use a wedge to secure the matrix band. In this case, the band must be sufficiently tight to minimize the gingival excess of amalgam. Because the

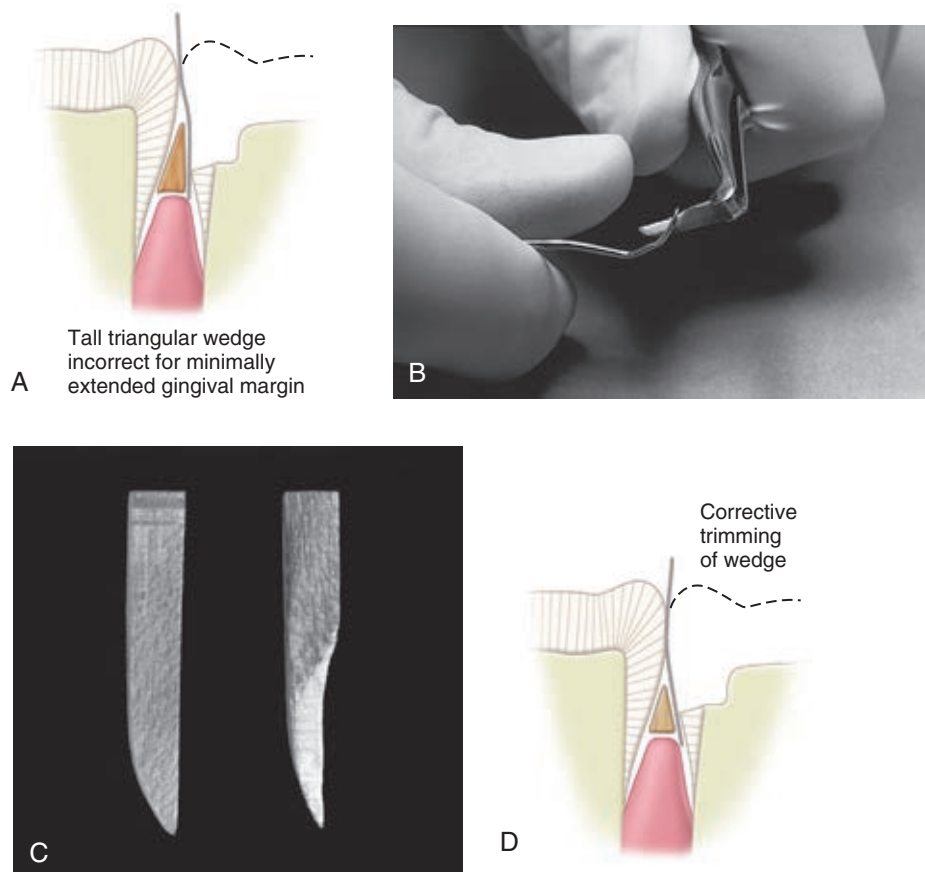


Fig. 14-82 Modified triangular (i.e., anatomic) wedge. **A**, Depending on the proximal convexity, a triangular wedge may distort the matrix contour. **B**, A sharp-bladed instrument may be used to modify the triangular steepness of the wedge. **C**, Modified and unmodified wedges are compared. **D**, Properly modified triangular wedge prevents distortion of the matrix contour.

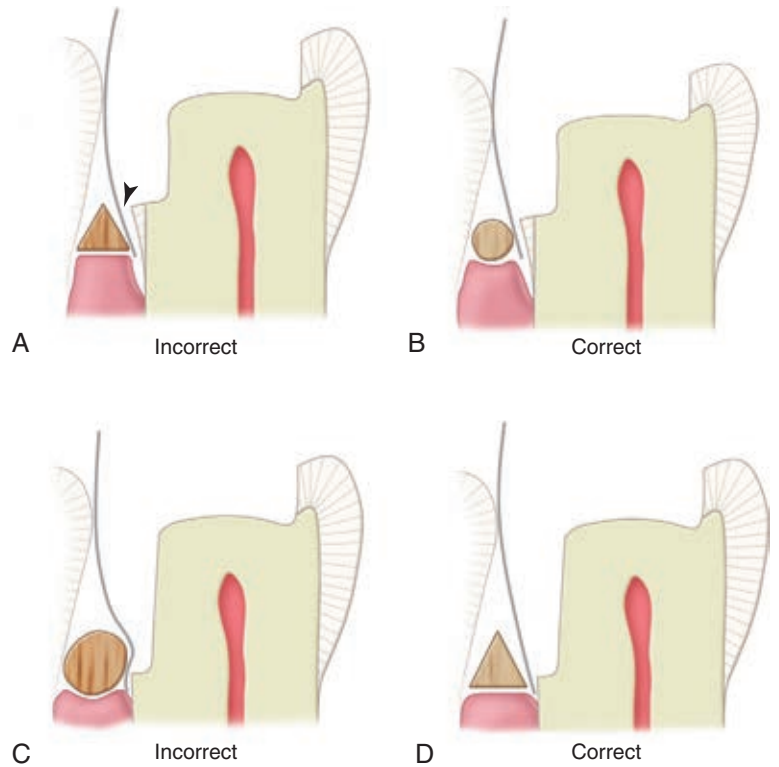


Fig. 14-83 Indications for the use of a round toothpick wedge versus a triangular (i.e., anatomic) wedge. **A**, As a rule, the triangular wedge does not firmly support the matrix band against the gingival margin in conservative Class II preparations (*arrowhead*). **B**, The round toothpick wedge is preferred for these preparations because its wedging action is nearer the gingival margin. **C**, In Class II preparations with deep gingival margins, the round toothpick wedge crimps the matrix band contour if it is placed occlusal to the gingival margin. **D**, The triangular wedge is preferred with these preparations because its greatest width is at its base.

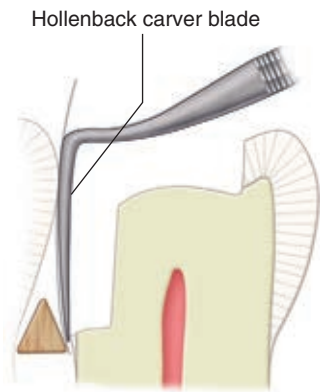


Fig. 14-84 Supporting the matrix with the blade of a Hollenback carver during wedge insertion.



Fig. 14-86 A custom-made tongue blade wedge may be used when excessive space exists between adjacent teeth.

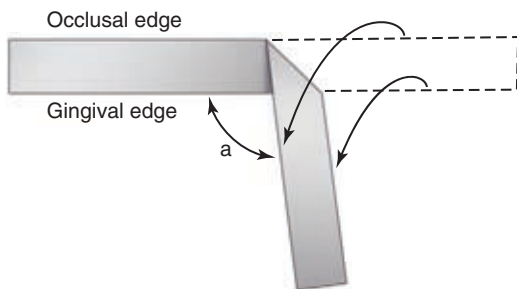


Fig. 14-85 The custom-made matrix strip is folded, as indicated by arrows. The smaller angle (*a*) compared with the angle of the commercial strip increases the difference between the lengths of the gingival and occlusal edges.

band is not wedged, special care must be exercised by placing small amounts of amalgam in the gingival floor and condensing the first 1 mm of amalgam lightly, but thoroughly, in a gingival direction. The condensation is then carefully continued in a gingival direction using a larger condenser with firm pressure. Condensation against an unwedged matrix may cause the amalgam to extrude grossly beyond the gingival margin. Without a wedge, some excess amalgam that is overcontoured remains at the proximal margins, requiring correction by a suitable carver immediately after matrix removal.

The matrix is removed after insertion of the amalgam, carving of the occlusal portion (including the occlusal embrasure or embrasures), and hardening of the amalgam to avoid fracture of the marginal ridge during band removal. The retainer is removed from the band after turning the small knurled nut counterclockwise to retract the pointed spindle.

The end of the index finger may be placed on the occlusal surface of the tooth to stabilize the band as the retainer is removed. Any rigid supporting material applied to support the matrix is then removed. The No. 110 pliers are used to tease the band free from one contact area at a time by pushing or pulling the band in a linguo-occlusal (or facio-occlusal) direction and, if possible, in the direction of wedge insertion (Fig. 14-87). The wedge may be left in place to provide separation of teeth while the matrix band is removed, and then it (the wedge) is removed. By maintaining slight interdental separation, the wedge reduces the risk of fracturing of amalgam. A straight occlusal direction should be avoided during matrix removal to prevent breaking of the marginal ridges.

RIGID-MATERIAL SUPPORTED SECTIONAL MATRIX

An alternative to the universal matrix is the use of a properly contoured sectional matrix that is wedged and supported by a material that is rigid enough to resist condensation pressure. The supporting material selected must be easy to place and to remove. Examples include light-cured, thermoplastic and quick-setting rigid polyvinyl siloxane (PVS) materials (Fig. 14-88). The gingival wedge is positioned interproximally to secure the band tightly at the gingival margin to prevent any excess of amalgam (i.e., overhang). The wedge also separates teeth slightly to compensate for the thickness of the band material.

The proximal surface contour of the matrix should allow the normal slight convexity between the occlusal and middle thirds of the proximal surface when viewed from the lingual (or facial) aspect. Proximal surface restorations often display an occlusogingival proximal contour that is too straight, thereby causing the contact relationship to be located too far



Fig. 14-87 Using No. 110 pliers, the matrix band should be removed in a linguo-occlusal (arrow) or facio-occlusal direction (not just in an occlusal direction).

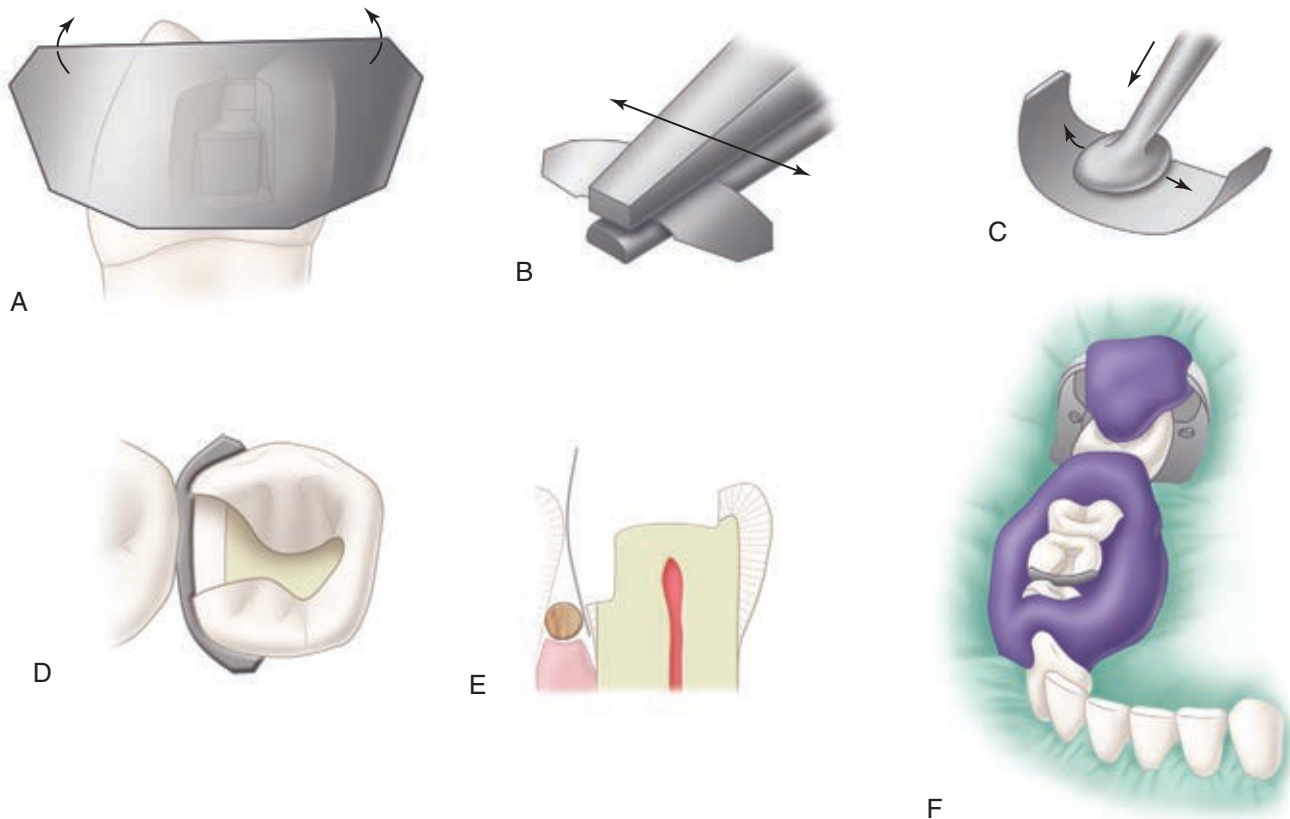


Fig. 14-88 Rigid material-supported sectional matrix. **A**, The shape of the stainless steel strip after trimming. **B**, The strip contoured to the circumferential contour of the tooth (fingers can be used). **C**, Burnishing the strip to produce occlusogingival contact contour (left and right arrows indicate the short, back-and-forth motion of the burnisher). **D**, Contoured strip in position. **E**, Matrix strip properly wedged. **F**, Completed rigid material-supported sectional matrix.



Fig. 14-89 Alteration of the matrix contour to provide the correct form to the proximofacial line angle region.

occlusally (with little or no occlusal embrasure). This condition allows food impaction between teeth, with resultant injury to the interproximal gingiva and supporting tissues, and invites caries. The proximal surface contour of the matrix should also provide the correct form to the proximofacial line angle region. If this contour is not present, the facial embrasure of the restoration is too open, inviting food impaction and injury to underlying supporting tissues. Correct and incorrect contours and matrix correction steps are illustrated in Figures 14-89 and 14-90.

The matrix should be tight against the facial and lingual margins on the proximal surface so that the amalgam can be well condensed at the preparation margins. In addition, when the matrix is tight against the tooth, minimal carving is necessary on the proximal margins after the matrix is removed. A matrix that is tight against the margins requires thorough condensation of the amalgam into the matrix and tooth corners to prevent amalgam voids at the proximal margins.

PRECONTOURED MATRIX STRIPS

Commercially available sectional metal strips (e.g., Palodent System; DENTSPLY Caulk, Milford, DE) are precontoured and ready for application to the tooth (Fig. 14-91). These strips have limited application when used for amalgam because of their rounded contour. They usually are most suitable for mandibular first premolars and the distal surface of maxillary canines. The contact area of the adjacent tooth occasionally is too close to allow placement of the contoured Palodent strip without causing a dent in the strip's contact area, making it unusable.

INSERTION AND CARVING OF THE AMALGAM

The principal objectives during the insertion of amalgam are as follows:

- Condensation to adapt the amalgam to the preparation walls and the matrix and to produce a restoration free of voids
- Keeping the mercury content in the restoration as low as possible to improve strength and decrease corrosion

Care should be taken to choose condensers that are best suited for use in each part of the tooth preparation and that can be used without binding.

The amount of amalgam initially transferred is the amount that (when condensed) will fill the gingival 1 mm (approximately) of the proximal box. It is condensed in a gingival

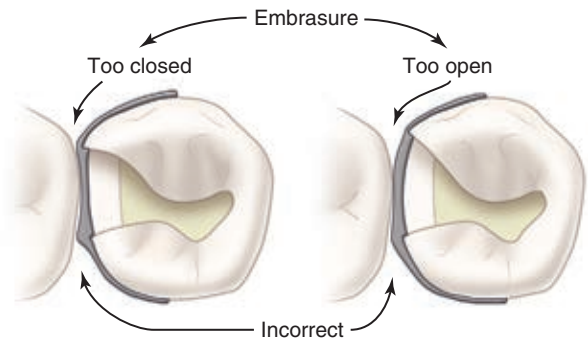


Fig. 14-90 Correct or incorrect facial and lingual embrasure form is determined by the shape of the matrix strip.



Fig. 14-91 Pre-contoured metal strips. (The Palodent System; courtesy of DENTSPLY Caulk, Milford, DE.)

direction with sufficient force to adapt amalgam to the gingival floor. Additional amalgam is carefully condensed against the proximal margins of the preparation and into the proximal retention grooves. Firm, facially and lingually directed pressure (i.e., lateral condensation) of the condenser accomplishes this at the same time as exertion of gingivally directed force (Fig. 14-92). Mesial (or distal) condensation of the amalgam in the proximal box is accomplished to ensure proximal contact with the adjacent tooth. Lateral condensation should be a routine step for Class II amalgams.⁸⁶ An advantage of amalgam over direct composite is that amalgam is condensed into place rather than being placed. Condensation strokes in a gingival direction help ensure that no voids occur internally or along the margins. Lateral condensation helps ensure that sufficient proximal contact and proximal contour

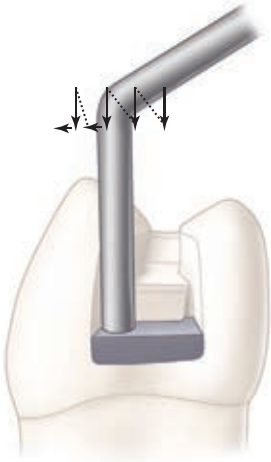


Fig. 14-92 Lateral and occlusogingival force is necessary to condense amalgam properly into the proximal grooves and into the angles at the junction of the matrix band and the margins of the preparation.

are achieved. Placement of composite resin materials will not allow distortion of the matrix band laterally into an optimal contact with the adjacent proximal surface. This results in a greater likelihood of restoration proximal undercontour and an open contact. Proximal contact and contour of the matrix band must be ensured prior to composite resin restoration placement.

The procedure of adding and condensing continues until amalgam reaches the level of the pulpal wall. The size of the condenser is changed (usually to a larger one), if indicated, and amalgam is condensed in the remaining proximal portion of the preparation concurrently with the occlusal portion. It may be necessary to return to a smaller condenser when condensing in a narrow extension of the preparation or near the proximal margins. A smaller condenser face is more effective at condensing, provided it does not significantly penetrate amalgam. The occlusal margins are covered and over-packed by at least 1 mm using a large condenser, ensuring that the margins are well condensed, especially in the area of the marginal ridge.⁸⁷ This step significantly reduces the risk of marginal ridge fracture during matrix removal.

Condensation should be completed within the working time for the alloy being used, as indicated by the manufacturer's recommendations. Condensation that occurs within this time frame will result in the following:

- Proper coherence and homogeneity, with minimal voids in the restoration
- Desired adaptation of the material to the walls of the preparation and matrix during condensation
- Development of the maximal strength and minimal flow (i.e., creep) in the completed restoration
- Proper intermingling of the adhesive and amalgam, if a bonding system is used

The plasticity and wetness of the amalgam mass should be monitored during condensation. Proper condensation requires that the mix should be neither wet (i.e., mercury-rich) nor dry and crumbly (i.e., mercury-poor). Amalgam that is beginning to set should be discarded and a new mix obtained to complete any condensation.

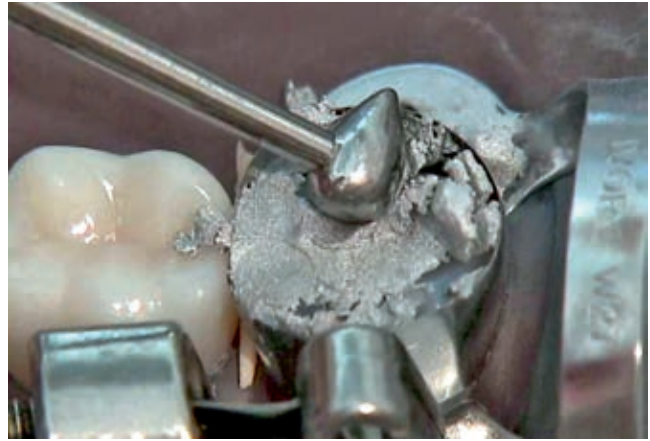


Fig. 14-93 Precurve burnishing with a large burnisher. (Courtesy of Aldridge D. Wilder, DDS.)



Fig. 14-94 Defining the marginal ridge and the occlusal embrasure with an explorer.

CARVING THE OCCLUSAL PORTION

Before carving procedures are initiated, precurve burnishing of the occlusal portion with a large egg-shaped or ball burnisher should be done (Fig. 14-93).⁵²

With the matrix band still in place, careful carving of the occlusal portion should begin immediately after condensation and burnishing. Sharp discoid instruments of suitable size are the recommended carvers. The larger discoid is used first, followed by the smaller one in regions not accessible to the larger instrument.

While the matrix is in place, the marginal ridge is carved confluent with the tooth's anatomy such that it duplicates the height and shape of the adjacent marginal ridge (Fig. 14-94). An explorer or small Hollenback carver may be used to carefully define the occlusal embrasure. Occlusal contacts were evaluated before tooth preparation. Remembering the pattern of occlusal contacts, observing the height of the adjacent marginal ridge, and knowing where the preparation cavosurface margins are located all aid in completing the carving of the occlusal surface, including the marginal ridge and occlusal embrasure.

If the restoration has extensive axial involvement of the tooth, the occlusal carving should be accomplished quickly. The objectives would be to develop the general occlusal contour and, most importantly, to develop the correct marginal ridge height and occlusal embrasure form (see Fig.

14-94). Then, the matrix is removed, and access is gained to carve the axial portions of the restoration. This permits these areas (usually more inaccessible) to be carved while amalgam is carvable. When the axial carving is completed, the occlusal surface contouring is completed. Occasionally, this occlusal contouring may require the use of an abrasive stone or finishing bur if the setting of the amalgam is nearing completion.

REMOVAL OF THE MATRIX BAND AND COMPLETION OF CARVING

The matrix band (or sectional matrix) and any wedges are gently removed. The proximal surface should be nearly completed, with proper contact evident and minimal carving required except to remove a possible small amount of excess amalgam at the proximal facial and lingual margins, at the faciogingival and linguogingival corners, and along the gingival margin. Amalgam knives (scalars, No. 34 and No. 35) are ideal for removing gingival excess to prevent gingival overhangs (Fig. 14-95 and 14-96). They also are ideal for refining the embrasure form around the proximal contacts (Fig. 14-97). The secondary (or “back”) edges of amalgam knives are occasionally helpful while either a pull stroke or a push stroke is used. The Hollenback carver No. 3 and (occasionally) the side of the explorer may be suitable instruments for carving these areas. The explorer cannot refine the margins and contour as accurately as amalgam knives can.

When carving the margins, the cutting surface of the carving instrument is held perpendicular to them. Carving should be parallel to the margins, however, with the adjacent

tooth surface being used to guide the carver. The existence of the proximal contact is verified visually by using the mouth mirror. If an amalgam adhesive was used, any thin layers of set resin near the margin that formed between the matrix and the tooth should be removed. When carving is completed, the rubber dam is removed, and the occlusion is assessed and adjusted, as needed.

Before the patient is dismissed, thin unwaxed dental floss may be passed through the proximal contacts once to remove any amalgam shavings on the proximal surface of the restoration and to assess the gingival margin. Passing the floss through

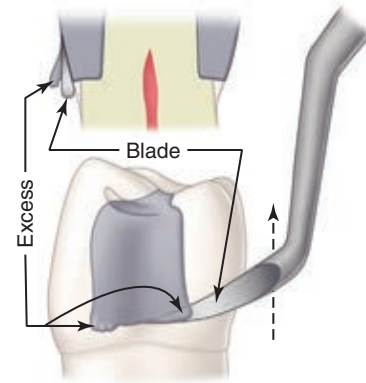


Fig. 14-95 Gingival excess may be removed with amalgam knives.

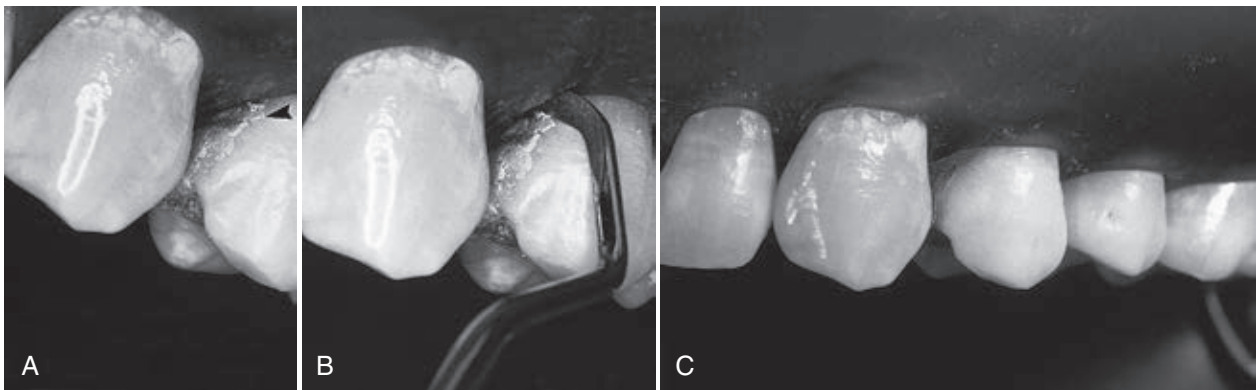


Fig. 14-96 Removal of gingival excess of amalgam. **A**, Excess of amalgam (arrowhead) at the gingival corner of the restoration. **B**, Use of the amalgam knife for removal of gingival excess. **C**, Gingival corner of restoration with excess removed.

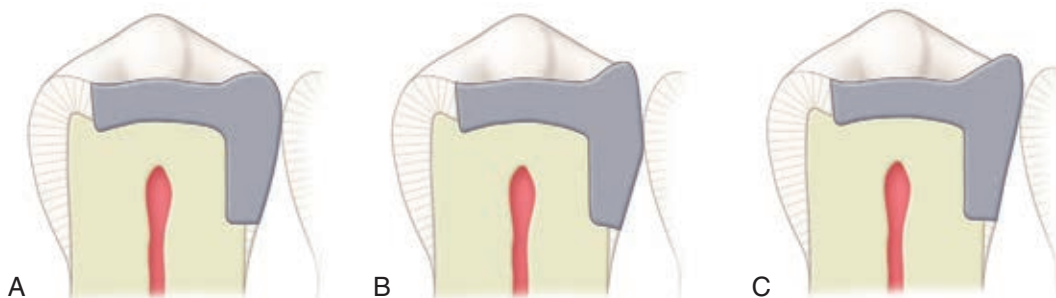


Fig. 14-97 Proximal contour. **A**, Correct proximal contour. **B**, Incorrect marginal ridge height and occlusal embrasure form. **C**, The occlusogingival proximal contour is too straight, the contact is too high, and the occlusal embrasure form is incorrect.

a contact more than once may weaken it. Wrapping the floss around the adjacent tooth when the floss is passed through the contact minimizes the pressure exerted on amalgam. When positioned in the gingival embrasure, the floss is wrapped around the restored tooth and positioned apical to the gingival margin of the restoration. The floss is moved in a faciolingual direction while extended occlusally. The floss not only removes amalgam shavings but also smooths the proximal amalgam and detects any gingival overhang of amalgam. If an overhang is detected, further use of an amalgam knife is necessary.⁸⁸ Floss also can be used to verify that the weight of the contact is similar to that of neighboring teeth. Final rinsing of the oral cavity is then accomplished. The patient is advised to avoid chewing with the restored tooth for 24 hours.

Finishing and Polishing of the Amalgam

Finishing of amalgam restorations may be necessary to correct a marginal discrepancy or to improve the contour. Polishing of high-copper amalgams is unnecessary.⁵⁷ Although they are less prone to corrosion and marginal deterioration than are their low-copper predecessors, some operators still prefer to polish amalgam restorations. Finishing (and polishing) usually is delayed until all proposed restorations have been placed, rather than being done periodically during the course of treatment. Polishing an amalgam restoration is not attempted within 24 hours after insertion because crystallization is incomplete.

Finishing and polishing the occlusal portion is similar to the procedures described for Class I amalgam restoration. Finishing and polishing of the proximal surface is indicated where the proximal amalgam is accessible. This area usually includes the facial and lingual margins and amalgam that is occlusal to the contact. The remainder of the proximal surface is often inaccessible; however, the matrix band should have imparted sufficient smoothness to it.

If amalgam along the facial and lingual proximal margins was slightly over-carved, the enamel margin can be felt as the explorer tip passes from amalgam across the margin onto the external enamel surface. Finishing burs or sandpaper disks, rotating at slow speed, may be used to smooth the enamel–amalgam margin. Sandpaper disks also can be used to smooth

and contour the marginal ridge. Inappropriate use of sandpaper disks may “ledge” the restoration around the contact, however, resulting in inappropriate proximal contours.

In conservative preparations, the facial and lingual proximal margins are generally inaccessible for finishing and polishing. Fine abrasive disks or the tip of a sharpened rubber polishing point should be used to polish the proximal portion that is accessible. When proximal margins are inaccessible to finishing and polishing with disks or rubber polishing points, and some excess amalgam remains (e.g., at the gingival corners and margins), amalgam knives occasionally may be used to trim amalgam back to the margin and to improve the contour. Accessible facial and lingual proximal margins also may be polished using the edge of an abrasive rubber polishing cup.

Final polishing of the occlusal surface and the accessible areas of the proximal surface may be accomplished with a fine-grit rubber polishing point or by the rubber cup with flour of pumice followed by a high-luster agent such as precipitated chalk. [Figure 14-98](#) provides examples of properly finished and polished amalgam restorations.

Quadrant Dentistry

When several teeth are to be restored, they are usually treated by quadrants rather than individually. Quadrant dentistry increases efficiency and reduces chairtime for the patient. The use of the rubber dam is particularly important in quadrant dentistry. For maximal efficiency, when a quadrant of amalgam tooth preparations is planned, each rotary or hand instrument should be used on every tooth where it is needed before being exchanged.

When restoring a quadrant of Class II amalgam tooth preparations, it is permissible to apply matrix bands on alternate preparations in the quadrant and restore teeth two at a time. Banding adjacent preparations requires excessive wedging to compensate for a double thickness of band material and makes the control of proximal contours and interproximal contacts difficult. Extensive tooth preparations may need to be restored one at a time. If proximal boxes differ in size, teeth with smaller boxes should be restored first because often the proximal margins are inaccessible to carving if the larger adjacent box is restored first. In addition, smaller boxes can be

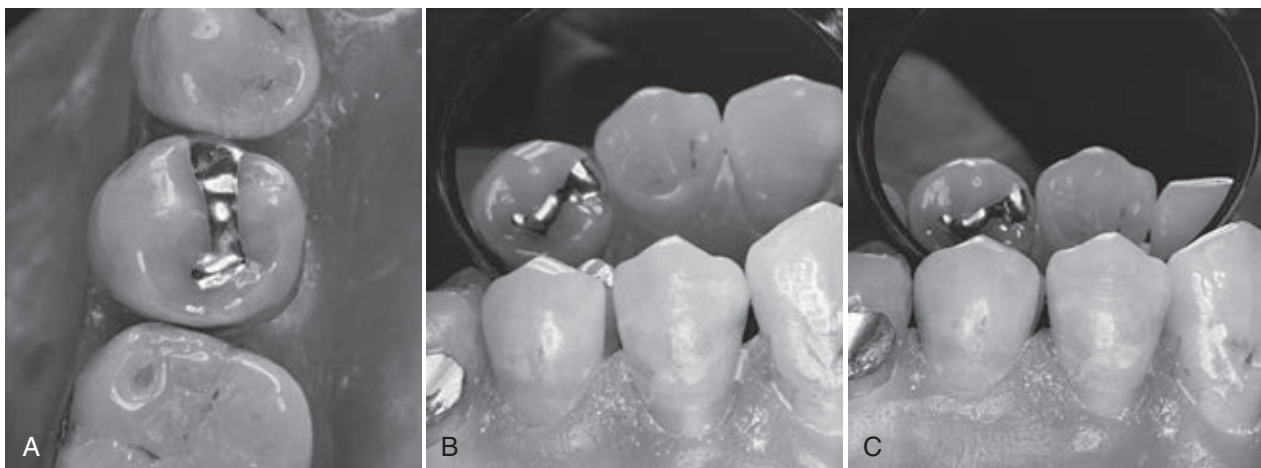


Fig. 14-98 Polished mesio-occlusal amalgam restoration. Note the conservative extension. **A**, Occlusal view. **B**, Mesiofacial and occlusal views of the mesiofacial margin. **C**, Facial and occlusal views of the proximal surface contour and the location of the proximal contact.

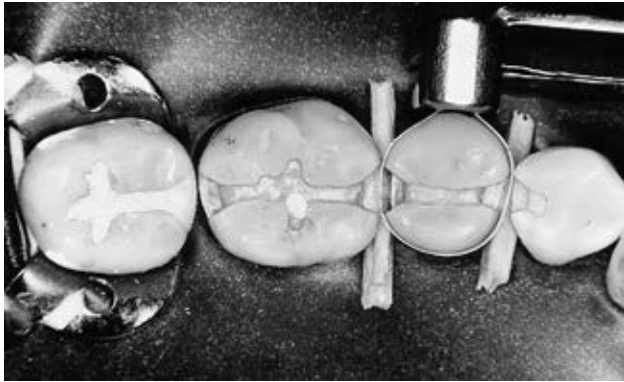


Fig. 14-99 Quadrant dentistry. Unless otherwise indicated, a quadrant of Class II preparations with similarly sized proximal boxes can be restored using two bands simultaneously if they are placed on every other prepared tooth. It is recommended that the posterior most tooth be restored first.

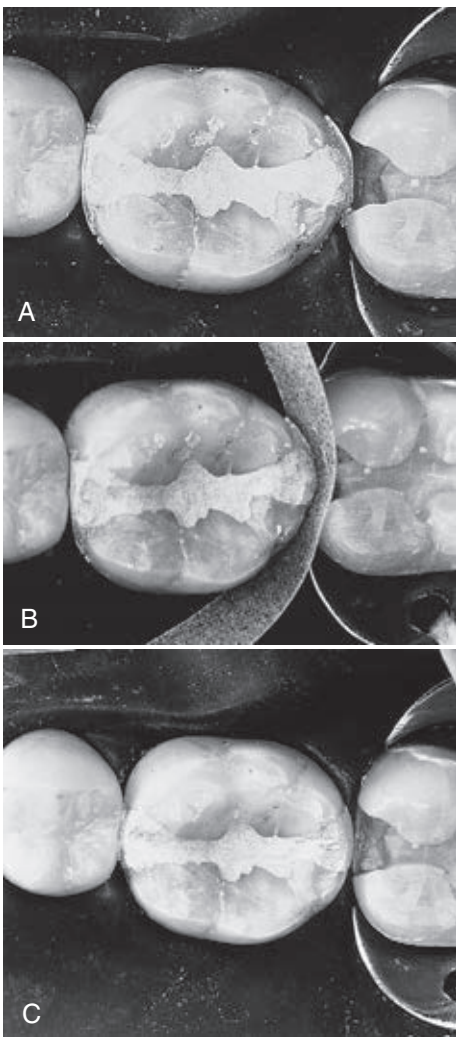


Fig. 14-100 When the first of two adjacent Class II preparations is restored, proper contour can be established by using a finishing and contouring strip before the second is restored. **A**, Before using the strip. **B**, Applying the strip. **C**, Verification of proper contouring can be done by viewing the restoration with a mirror from the occlusal, facial, and lingual positions. The proximal contour also can be evaluated after matrix placement by noting the symmetry between the restored surface and the burnished matrix band.

restored more quickly and accurately because more tooth structure remains to guide the carver. If the larger proximal box is restored first, the gingival contour of the restoration could be damaged when the wedge is inserted to secure the matrix band for the second, smaller restoration. If the adjacent proximal boxes are similar in size, the banding of alternate preparations should be started with the most posterior preparation because this allows the patient to close slightly as subsequent restorations are inserted (Fig. 14-99).

Before restoring the second of two adjacent teeth, the proximal contour of the first restoration should be carefully established. Its anatomy serves as the guide to establish proper contact size and location of the second restoration; it also serves as good embrasure form. If necessary, a finishing strip can be used to refine the contour of the first proximal amalgam (Fig. 14-100). The finishing strip is indicated, however, only where the proximal contact is open. Using a finishing strip between contacting amalgam restorations may lighten or eliminate the proximal contact.

Class VI Amalgam Restorations

The Class VI tooth preparation is used to restore the incisal edge of anterior teeth or the cusp tip regions of posterior teeth.

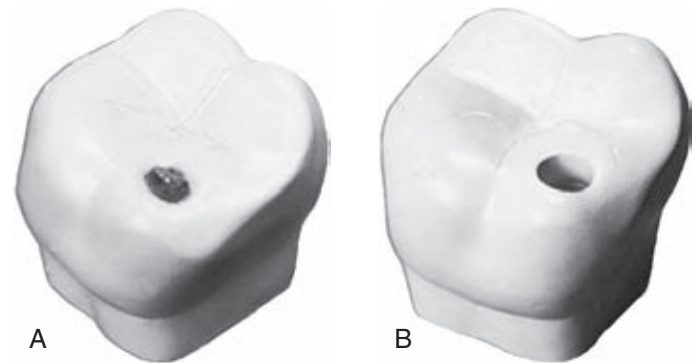


Fig. 14-101 Class VI preparation. **A**, Exposed dentin on the mesiofacial cusp. **B**, Tooth preparation necessary to restore the involved area.

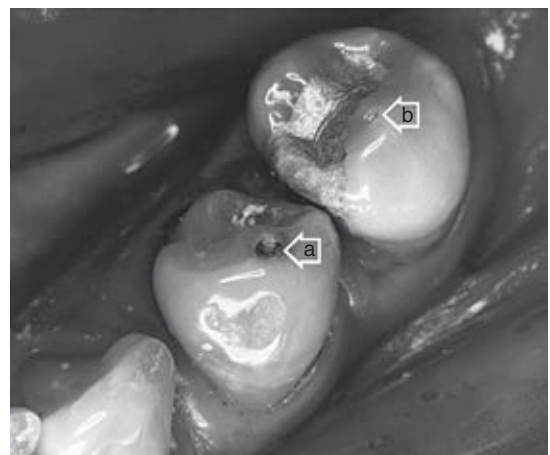


Fig. 14-102 Class VI lesions. Carious cusp tip fault on the first premolar (a). Noncarious fault on the second premolar (b).

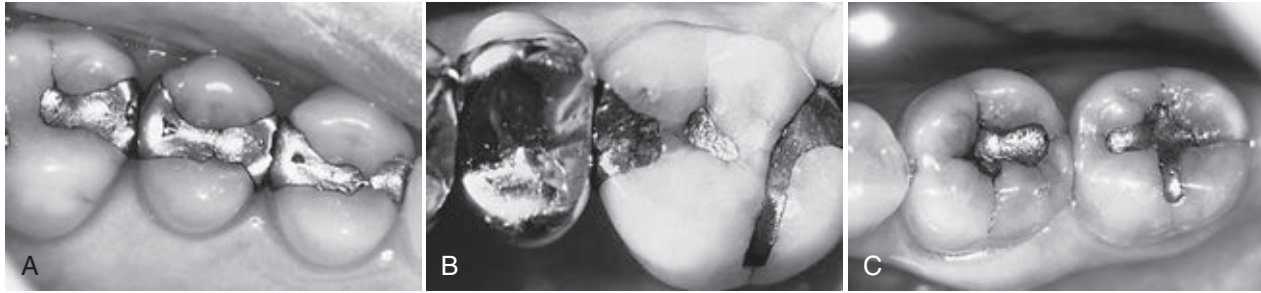


Fig. 14-103 Clinical examples of long-term amalgam restorations. **A**, 44-year-old amalgams. **B**, 58-year-old amalgams in the first molar. **C**, 65-year-old amalgams in molars. (**A** and **B**, courtesy of Drs. John Osborne and James Summitt.)

Such tooth preparations are frequently indicated where attrition (loss of tooth substance from the occluding of food, abrasives, and opposing teeth) has removed enamel to expose the underlying dentin on those areas (Fig. 14-101). This occurs more frequently in older patients. When the softer dentin is exposed, it wears faster than the surrounding enamel, resulting in “cupped-out” areas. As the dentin support is lost, enamel begins to fracture away, exposing more dentin and often causing sensitivity. Sensitivity to hot and cold is a frequent complaint with Class VI lesions, and some patients are bothered by food impaction in the deeper depressions. Enamel edges may become jagged and sharp to the tongue, lips, or cheek. Lip, tongue, or cheek biting is occasionally a complaint. Rounding and smoothing such incisioaxial (or occlusoaxial) edges is an excellent service to the patient. Early recognition and restoration of these lesions is recommended to limit the loss of dentin and the subsequent loss of enamel supported by this dentin.

The Class VI tooth preparation also is indicated to restore the hypoplastic pit occasionally found on cusp tips (Fig. 14-102). Such developmental faults are vulnerable to caries, especially in high-risk patients, and should be restored as soon as they are detected. Caries are rarely found in dentin where attritional wear has removed the overlying enamel.

Composite is generally used to restore Class VI preparations. Amalgam may be selected for posterior class VI preparations because of its wear resistance and longevity. Moisture control for Class VI restorations is usually achieved with cotton roll isolation. Class VI amalgam preparations may be accomplished with a small tapered fissure bur (e.g., No. 169 L or 271) and involves extension to place the cavosurface margin on enamel that has sound dentin support (see Fig. 14-101). The preparation walls may need to diverge occlusally to ensure a 90-degree cavosurface margin. A depth of 1.5 mm is sufficient to provide bulk of material for strength. Retention of the restoration is ensured by the creation of small undercuts along the internal line angles. Do not remove dentin that is immediately supporting enamel. Conservative tooth preparation is particularly important with Class VI preparations because it is easy to undermine the enamel on incisal edges and cusp tips. Inserting, carving, and polishing are similar to procedures described for Class I tooth preparations for amalgam.

Some older patients have excessive occlusal wear of most of their teeth in the form of large concave areas with much exposed dentin. Teeth with excessive wear may require indirect restorations.

Summary

Class I and II amalgam restorations are still common procedures performed by general dentists. Class VI amalgam restorations are done infrequently. It is important for practitioners to understand the indications, advantages, techniques, and limitations of these restorations. When used correctly and in properly selected cases, these restorations have the potential to serve for many years (Fig. 14-103).

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Class III and V Amalgam Restorations

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This chapter presents information about Class III and V amalgam restorations. Class III restorations are indicated for defects located on the proximal surface of anterior teeth that do not affect the incisal edge. Part of the facial or the lingual surfaces also may be involved in Class III restorations. Class V restorations are indicated to restore defects on the facial or lingual cervical one third of any tooth.

The Class III amalgam restoration is rarely used. Its use has been supplanted by tooth-colored restorations (primarily composite), which have become increasingly wear-resistant and color-stable. Because indications exist for Class III amalgam restorations, however, practitioners should be familiar with this restorative technique.

The Class V amalgam restoration can be especially technique-sensitive because of location, extent of caries, and limited access and visibility. Cervical caries usually develops because of the chronic presence of acidogenic plaque located in the non-self-cleansing area just beneath the coronal height of contour. Patients with gingival recession are predisposed to cervical caries because dentin is more susceptible to demineralization than enamel. Patients with a reduced salivary flow caused by certain medical conditions (e.g., Sjögren's syndrome), medications, or head and neck radiation therapy also are predisposed to cervical caries. These patients usually have less saliva to buffer the acids produced by oral bacteria. Patients with gingival recession that has exposed the root surface have a predisposition to *root caries* because dentin is more susceptible to demineralization than enamel. Class V restorations may be used to treat both cervical and root caries lesions.

Incipient, smooth-surface enamel caries appears as a chalky white line just occlusal or incisal to the crest of the marginal gingiva (usually on the facial surface) (Fig. 15-1). These areas often are overlooked in the oral examination, unless teeth are free of debris, isolated with cotton rolls, and dried gently with the air syringe. When incipient cervical caries has not decalcified the enamel sufficiently to result in cavitation (i.e., a break in the continuity of the surface), the lesion may be remineralized by appropriate techniques, including patient motivation

toward proper diet and hygiene. Occasionally, an enamel surface that is only slightly cavitated may be treated successfully by smoothing with sandpaper disks, polishing, and treating with a fluoride varnish or a dentin adhesive in an attempt to prevent further caries that may require treatment. This prophylactic, preventive treatment cannot be instituted if caries has progressed to decalcify and soften enamel to an appreciable depth. In this instance, a Class V tooth preparation and restoration is indicated, particularly if caries has penetrated to the dentinoenamel junction (DEJ) (Fig. 15-2, A). When numerous cervical lesions are present (see Fig. 15-2, B), a relatively high caries index is obvious. In addition to the restorative treatment, the patient should be instructed and encouraged to implement an aggressive prevention program to avoid recurrent decay.

Pertinent Material Qualities and Properties

Material qualities and properties important for Class III and V amalgam restorations are strength, longevity, ease of use, and past success. See Chapter 13 for a discussion of the pertinent material qualities and properties of amalgam.

Indications

Few indications exist for a Class III amalgam restoration. It is generally reserved for the distal surface of maxillary and mandibular canines if (1) the preparation is extensive with only minimal facial involvement, (2) the gingival margin primarily involves cementum, or (3) moisture control is difficult. For esthetic reasons, amalgam rarely is indicated for the proximal surfaces of incisors and the mesial surface of canines.

Class V amalgam restorations may be used anywhere in the mouth. As with Class III amalgam restorations, they generally are reserved for non-esthetic areas, for areas where access and visibility are limited and where moisture control is difficult, and for areas that are significantly deep gingivally. Because of

limited access and visibility, many Class V restorations are difficult and present special problems during the preparation and restorative procedures.

One measure of clinical success of cervical amalgam restorations is the length of time the restoration serves without failing (Fig. 15-3). Properly placed Class V amalgams have the



Fig. 15-1 Incipient caries lesions of enamel appear as white spots. The affected surface may be smooth (i.e., non-cavitated). White spots are more visible when dried. (From Cobourne MT, DiBiase AT: Handbook of orthodontics, Edinburgh, 2010, Mosby.)



Fig. 15-2 Cervical caries. **A**, Cavitation involving enamel and dentin in several teeth. **B**, Relatively high caries index is obvious when numerous cervical lesions are present. (From Perry DA, Beemsterboer PL: Periodontology for the dental hygienist, ed 3, St. Louis, 2007, Saunders.)

potential to be clinically acceptable for many years. Some cervical amalgam restorations show evidence of failure, however, even after a short period. Inattention to tooth preparation principles, improper manipulation of the restorative material, and moisture contamination contribute to early failure. Extended service depends on the operator's care in following accepted treatment techniques and proper care by the patient.

Amalgam may be used on partial denture abutment teeth because amalgam resists wear as clasps move over the restoration. Contours prepared in the restoration to retentive areas for the clasp tips may be achieved relatively easily and maintained when an amalgam restoration is used. Occasionally, amalgam is preferred when the caries lesion extends gingivally enough that a mucoperiosteal flap must be reflected for adequate access and visibility (Fig. 15-4). Proper surgical procedures must be followed, including sterile technique, careful soft tissue management, and complete debridement of the surgical and operative site before closure.

Contraindications

Class III and V amalgam restorations usually are contraindicated in esthetically important areas because many patients object to metal restorations that are visible (Fig. 15-5). Generally, Class V amalgams placed on the facial surface of mandibular canines, premolars, and molars are not readily visible. Amalgams placed on maxillary premolars and first molars may be visible. The patient's esthetic demands should be considered when planning treatment.

Advantages

Amalgam restorations are stronger than other Class III and V direct restorations. In addition, they are generally easier to place and may be less expensive to the patient. Because of its metallic color, amalgam is easily distinguished from the surrounding tooth structure. Amalgam restorations are usually easier to finish and polish without damage to the adjacent surfaces.

Disadvantages

The primary disadvantage of Class III and V amalgam restorations is that they are metallic and unesthetic. In addition, the preparation for an amalgam restoration typically requires



Fig. 15-3 **A**, 6-year-old cervical amalgam restorations. **B**, After 16 years, some abrasion and erosion are evident at the gingival margin of the lateral incisor and canine restorations. **C**, 20-year-old cervical amalgam restorations.

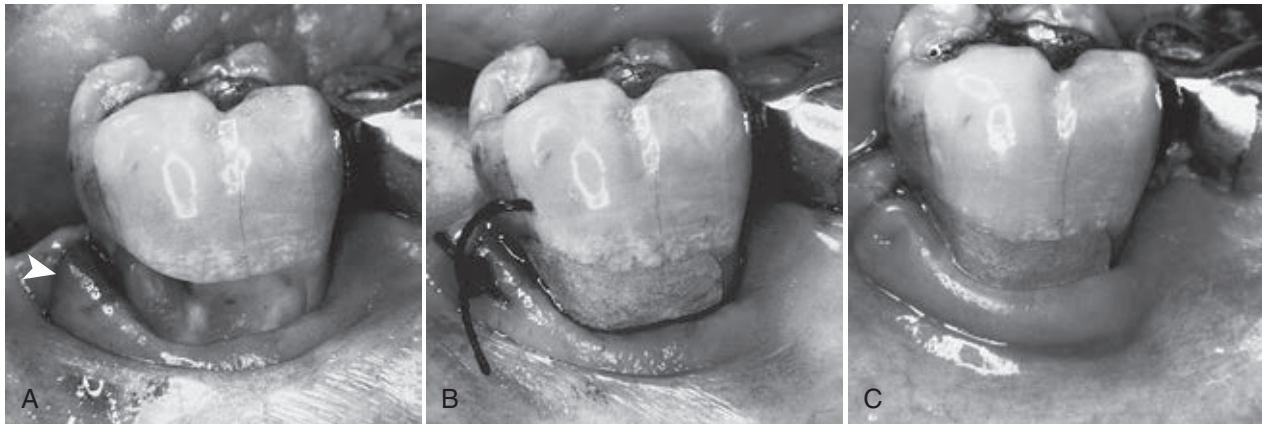


Fig. 15-4 Surgical access. **A**, Class V preparation requiring mucoperiosteal flap reflection with a releasing incision (*arrowhead*). **B**, Completed restoration with suture in place. **C**, Suture removed 1-week after the procedure.



Fig. 15-5 Patients may object to metal restorations that are visible during conversation.

90-degree cavosurface margins and specific axial depths that allow incorporation of secondary retentive features. These features result in a less conservative preparation than that required for most esthetic restorative materials.

Clinical Technique for Class III Amalgam Restorations

Initial Procedures

After appropriate review of the patient records (including medical history), treatment plan, and radiographs, the gingival extension of the preparation should be anticipated. Anesthesia is usually necessary when a vital tooth is to be restored. Pre-wedging in the gingival embrasure of the proximal site to be restored provides (1) better protection of soft tissue and the rubber dam, (2) better access because of the slight separation of teeth, and (3) better re-establishment of the proximal contact. The use of a rubber dam is generally recommended; however, cotton roll isolation is acceptable if moisture can be adequately controlled.

Tooth Preparation

A lingual access preparation on the distal surface of the maxillary canine is described here because the use of amalgam in



Fig. 15-6 Restoration for Class III tooth preparation using facial approach on mandibular canine. Restoration is 5 years old. (Courtesy of Dr. C. L. Sockwell.)

that location is more likely. For esthetic reasons, use of amalgam is best suited for caries that can be accessed from the lingual rather than the facial. A facial approach for a mandibular canine may be indicated, however, if the lesion is more facial than lingual. The mandibular restoration is often not visible at conversational distance (*Fig. 15-6*).

The outline form of the Class III amalgam preparation may include only the proximal surface. A lingual dovetail may be indicated if one existed previously or if additional retention is needed for a larger restoration.

Initial Tooth Preparation

Bur size selection depends on the anticipated size of the lesion. Bur options may include a No. 2 (or smaller) round bur or No. 330 bur. The bur is positioned so that the entry cut penetrates into the caries lesion, which is usually apical to (and slightly into) the contact area. Ideally, the bur is positioned so that its long axis is perpendicular to the lingual surface of the tooth, but directed at a mesial angle as close to the adjacent tooth as possible. (The bur position may be described as perpendicular to the distolingual line angle of the tooth.) This position conserves the marginal ridge enamel (*Fig. 15-7, A*

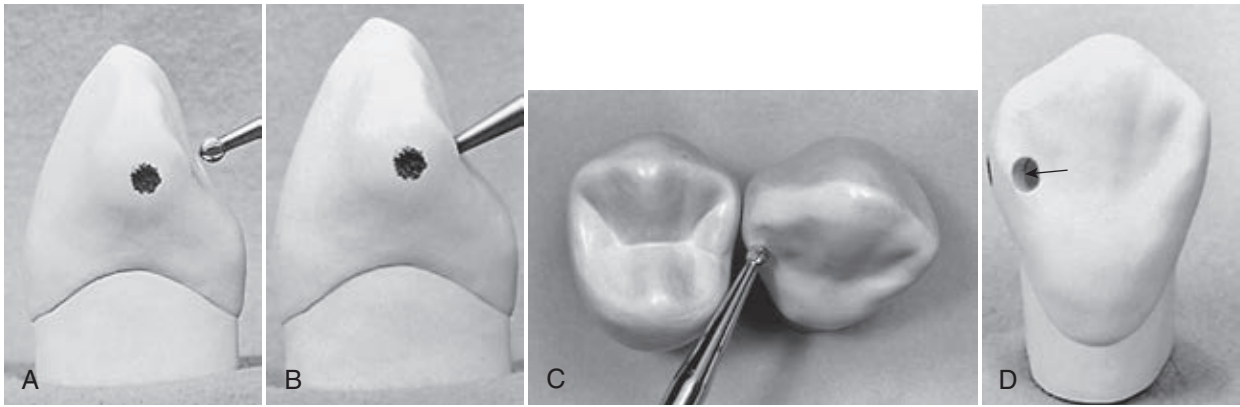


Fig. 15-7 Entry for Class III tooth preparation on maxillary canine. **A**, Bur position is perpendicular to the enamel surface at the point of entry. **B**, Initial penetration through enamel is directed toward cavitated, caries lesion. **C**, Initial entry should isolate the proximal enamel, while preserving as much of the marginal ridge as possible. **D**, Initial cutting reveals the dentinoenamel junction (DEJ) (arrow).

through C). Penetration through enamel positions the bur so that additional cutting isolates the proximal enamel affected by caries and removes some or all of the infected dentin. In addition, penetration should be at a limited initial axial depth (i.e., 0.5–0.6 mm) inside the DEJ (see Fig. 15-7, C and D) or at a 0.75–0.8-mm axial depth when the gingival margin is on the root surface (in cementum) (Fig. 15-8). This 0.75-mm axial depth on the root surface allows a 0.25-mm distance (the diameter of the No. $\frac{1}{4}$ bur is 0.5 mm) between the retention groove (which is placed later) and the gingival cavosurface margin. Infected dentin that is deeper than this limited initial axial depth is removed later during final tooth preparation.

For a small lesion, the facial margin is extended 0.2–0.3 mm into the facial embrasure (if necessary), with a curved outline from the incisal to the gingival margin (resulting in a less visible margin). The lingual outline blends with the incisal and gingival margins in a smooth curve, creating a preparation with little or no lingual wall. The cavosurface angle should be 90 degrees at all margins. The facial, incisal, and gingival walls should meet the axial wall at approximately right angles (although the lingual wall meets the axial wall at an obtuse angle or may be continuous with the axial wall) (Fig. 15-9). If a large round bur is used, the internal angles are more rounded. The axial wall should be uniformly deep into dentin and follow the faciolingual contour of the external tooth surface (Fig. 15-10). The initial axial wall depth may be in sound dentin (i.e., shallow lesion), in infected dentin (i.e., moderate to deep lesion), or in existing restorative material, if a restoration is being replaced.

Incisal extension to remove carious tooth structure may eliminate the proximal contact (Fig. 15-11). It is important to conserve as much of the distoincisor tooth structure as possible to reduce the risk for subsequent fracture. When possible, it is best to leave the incisal margin in contact with the adjacent tooth.

When preparing a gingival wall that is near the level of the rubber dam or apical to it, it is beneficial to place a wedge in the gingival embrasure earlier to depress and protect soft tissue and the rubber dam. As the bur is preparing the gingival wall, it may lightly shave the wedge. A triangular (i.e., anatomic) wedge, rather than a round wedge, is used for a deep gingival margin.

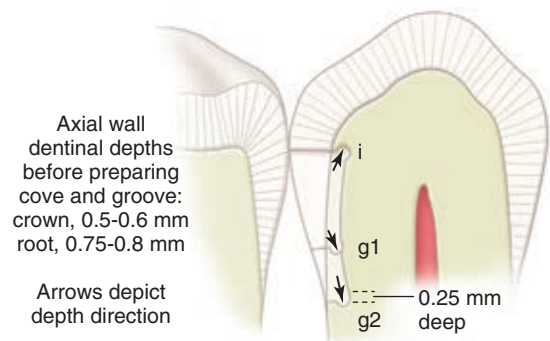


Fig. 15-8 Mesiodistal vertical section showing location, depth direction (arrows), and direction depth of the retention form in Class III tooth preparations of different gingival depths. *i*, incisal cove; *g1*, gingival groove, enamel margin; *g2*, gingival groove, root surface margin. Distance from outer aspect of *g2* groove to margin is approximately 0.3 mm; bur head diameter is 0.5 mm; direction depth of groove is half this diameter (or approximately 0.25 mm).

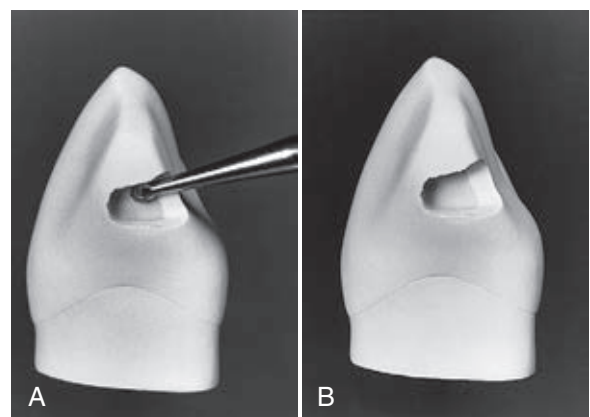


Fig. 15-9 Class III tooth preparation on maxillary canine. **A**, Round bur shaping the incisal area. The incisal angle remains. **B**, Initial shape of the preparation accomplished with a round bur.

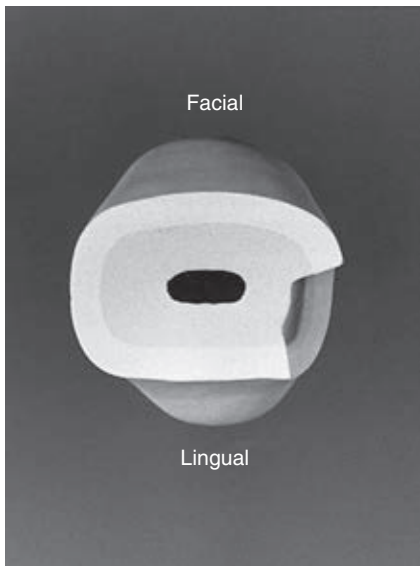


Fig. 15-10 Transverse section of mandibular lateral incisor illustrating that the lingual wall of a Class III tooth preparation may meet the axial wall at an obtuse angle and that the axial wall is a uniform depth into dentin and follows the faciolingual contour of the external tooth surface.

The initial tooth preparation is completed by using a No. $\frac{1}{2}$ round bur to accentuate the axial line angles (Fig. 15-12, *A and B*), particularly the axiokingival angle. This facilitates the subsequent placement of retention grooves and leaves the internal line angles slightly rounded. Rounded internal preparation angles permit more complete condensation of the amalgam. The No. $\frac{1}{2}$ round bur also may be used to smooth any roughened, undermined enamel produced at the gingival and facial cavosurface margins (see Fig. 15-12, *C*). The incisal margin of the minimally extended preparation is often not accessible to the larger round bur without marring the adjacent tooth (see Fig. 15-12, *D*). Further finishing of the incisal margin is presented later. At this point, the initial tooth preparation is completed.

Final Tooth Preparation

Final tooth preparation involves removing any remaining infected dentin; protecting the pulp; developing secondary resistance and retention forms; finishing external walls; and cleaning, inspecting, and desensitizing or bonding. Any remaining infected carious dentin on the axial wall is removed by using a slowly revolving round bur (No. 2 or No. 4),

Fig. 15-11 Distofacial (*A*) and incisal (*B*) views of the canine to show the curved proximal outline necessary to preserve the distoincisor corner of the tooth. The incisal margin of this preparation example is located slightly incisally of the proximal contact (but whenever possible, the margin may be in the contact area).

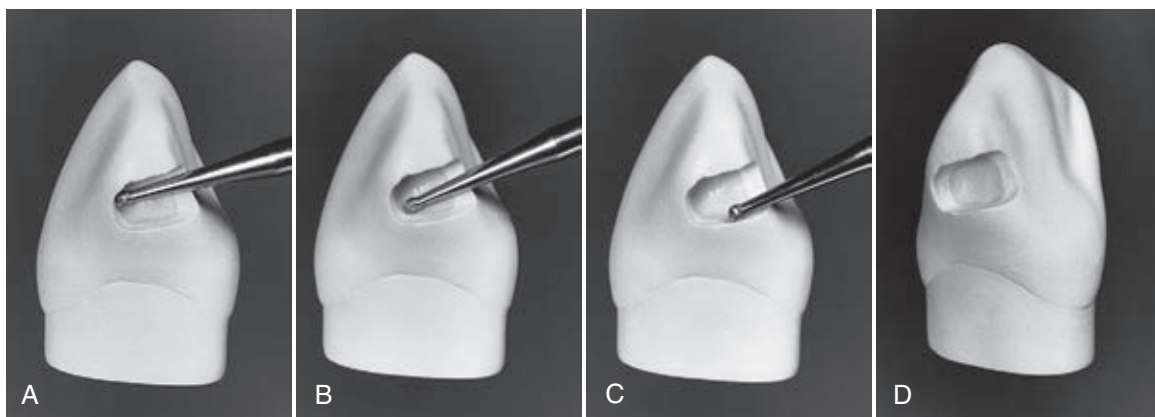
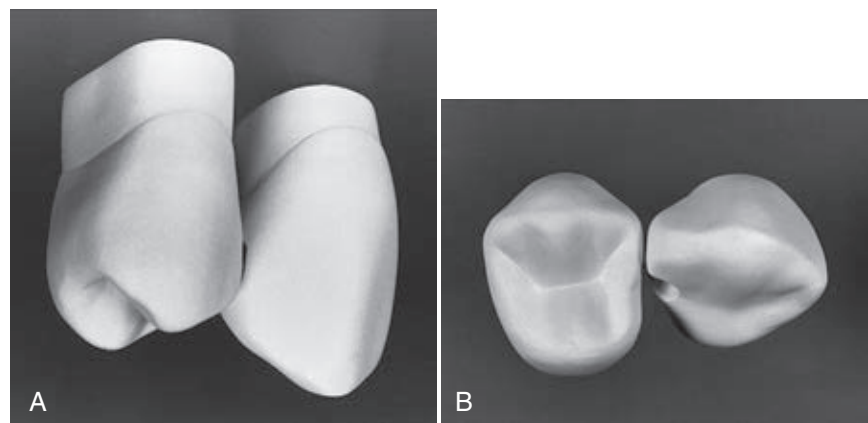
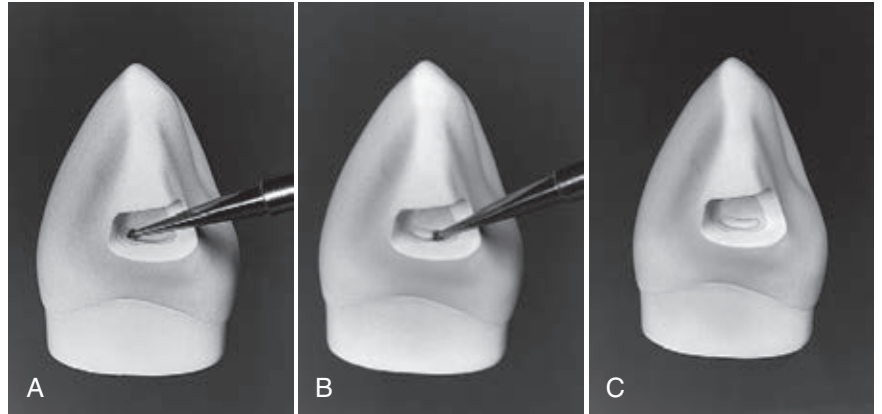


Fig. 15-12 Refining proximal portion. **A–C**, A small, round bur is used to shape the preparation walls, define line angles, and initiate removal of any undermined enamel along the gingival and facial margins. **D**, Tooth preparation completed, except for the final finishing of the enamel margins and placing the retention form.

Fig. 15-13 Preparing the gingival retention form. **A**, Position of No. $\frac{1}{4}$ round bur in axio-facio-gingival point angle. **B**, Advancing the bur lingually to prepare the groove along the axiokingival line angle. (See Fig. 15-8 regarding location, depth direction, and direction depth of groove.) **C**, Completed gingival retention groove.



appropriate spoon excavators, or both. (See Chapter 5 for the indications and technique for placing a liner.)

For the Class III amalgam restoration, resistance form against post-restorative fracture is provided by (1) cavosurface and amalgam margins of 90 degrees, (2) enamel walls supported by sound dentin, (3) sufficient bulk of amalgam (minimal 1-mm thickness), and (4) no sharp preparation internal angles. The box-like preparation form provides primary retention form. Secondary retention form is provided by a gingival groove, an incisal cove, and sometimes a lingual dovetail.

The gingival retention groove is prepared by placing a No. $\frac{1}{4}$ round bur (rotating at low speed) in the axio-facio-gingival point angle. It is positioned in the dentin to maintain 0.2 mm of dentin between the groove and the DEJ. The rotating bur is moved lingually along the axiokingival line angle, with the angle of cutting generally bisecting the angle between the gingival and axial walls. Ideally, the direction of the gingival groove is slightly more gingival than axial (and the direction of an incisal [i.e., occlusal] groove would be slightly more incisal [i.e., occlusal] than axial) (Fig. 15-13; see also Fig. 15-8).

Alternatively, if less retention form is needed, two gingival coves may be used, as opposed to a continuous groove. One each may be placed in the axio-gingivo-facial and axio-gingivo-lingual point angles. The diameter of the $\frac{1}{4}$ round bur is 0.5 mm, and the depth of the groove should be half this diameter (0.25 mm). (See the location and depthwise direction of the groove, where the gingival wall remains in enamel, in Fig. 15-18.) When preparing a retention groove on the root surface (gingival wall in cementum or dentin), the angle of cutting is more gingival, resulting in the distance from the gingival cavosurface margin to the groove being approximately 0.3 mm (see Fig. 15-8). Careful technique is necessary in preparing the gingival retention groove. If the dentin that supports gingival enamel is removed, enamel is subject to fracture. In addition, if the groove is placed only in the axial wall, no effective retention form is developed, and a risk of pulpal involvement is possible.

An incisal retention cove is prepared at the axio-facio-incisal point angle with a No. $\frac{1}{4}$ round bur in dentin, being careful not to undermine enamel. It is directed similarly into the incisal point angle and prepared to half the diameter of the bur (Fig. 15-14). Undermining the incisal enamel should

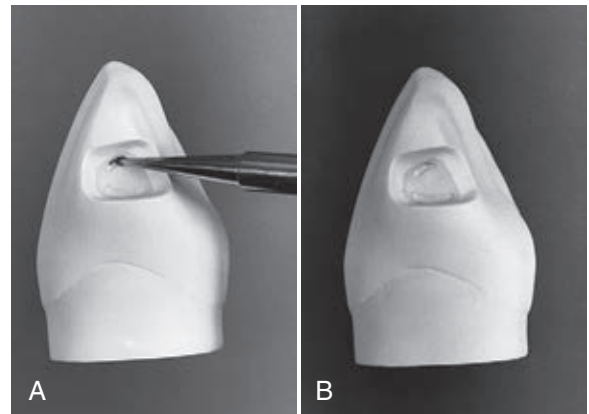


Fig. 15-14 Preparing the incisal retention cove. **A**, Position of No. $\frac{1}{4}$ round bur in the axioincisal point angle. **B**, Completed incisal cove.

be avoided. For the maxillary canine, the palm-and-thumb grasp may be used to direct the bur incisally (Fig. 15-15). This completes the typical Class III amalgam tooth preparation (Fig. 15-16). Similar to Class I and II amalgams, it is recommended that the clinician prepare mechanical retention.

A lingual dovetail is not required in small or moderately sized Class III amalgam restorations. It may be used in large preparations, especially preparations with excessive incisal extension in which additional retention form is needed. The dovetail may not be necessary (even in large preparations), however, if an incisal secondary retention form can be accomplished (Fig. 15-17).

If a lingual dovetail is needed, it is prepared only after initial preparation of the proximal portion has been completed. Otherwise, the tooth structure needed for the isthmus between the proximal portion and the dovetail may be removed when the proximal outline form is prepared. The lingual dovetail should be conservative, generally not extending beyond the mesiodistal midpoint of the lingual surface; this varies according to the extent of the proximal caries. The axial depth of the dovetail should approximate 1 mm, and the axial wall should be parallel to the lingual surface of the tooth. This wall may or may not be in dentin. The No. 245 bur is positioned in the proximal portion at the correct depth and angulation and moved in a

mesial direction (Fig. 15-18, *A and B*). The correct angulation places the long axis of the bur perpendicular to the lingual surface. The bur is moved to the point that corresponds to the most mesial extent of the dovetail (see Fig. 15-18, *C and D*). The bur is then moved incisally and gingivally to create sufficient incisogingival dimension to the dovetail (approximately 2.5 mm) (see Fig. 15-18, *E and F*). The incisal and gingival walls of the isthmus are prepared in smooth curves connecting the dovetail to the proximal outline form (see Fig. 15-18, *G and H*).

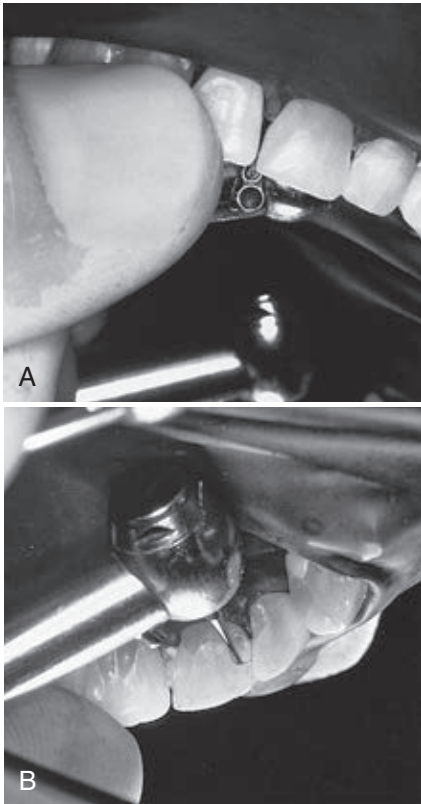


Fig. 15-15 Use of the palm-and-thumb grasp to place the incisal retention cove. **A**, Hand position showing thumb rest. **B**, Handpiece position for preparing the incisal retention.

The gingival margin trimmer can be used to bevel (or round) the axiopulpal line angle (i.e., the junction of the proximal and dovetail preparation). This increases the strength of the restoration at the junction of the proximal and lingual portions by providing bulk and reducing stress concentration. The lingual convergence of the dovetail's external walls (prepared with the No. 245 bur) usually provides a sufficient retention form. Retention coves, one in the incisal corner and one in the gingival corner (Fig. 15-19), may be placed in the dovetail to enhance retention if the axial wall of the dovetail is in dentin. The coves are prepared with the No. $\frac{1}{4}$ round bur in dentin that does not immediately support the lingual enamel. This preparation may require deepening of the axial wall. Unsupported enamel is removed, the walls or margins are smoothed, and the cavosurface angles are refined, where indicated. The 8-3-22 hoe is recommended for finishing minimally extended margins (Fig. 15-20). If the gingival margin is in enamel, a slight bevel (approximately 20 degrees) is necessary to ensure full-length enamel rods forming the cavosurface margin. All the walls of the preparation should meet the external tooth surface to form a right angle (i.e., butt joint) (Fig. 15-21; see also Fig. 15-16). The various steps involved in the clinical procedure with the dovetail are shown in Figure 15-22. The completed tooth



Fig. 15-16 Completed Class III tooth preparation for amalgam restoration.

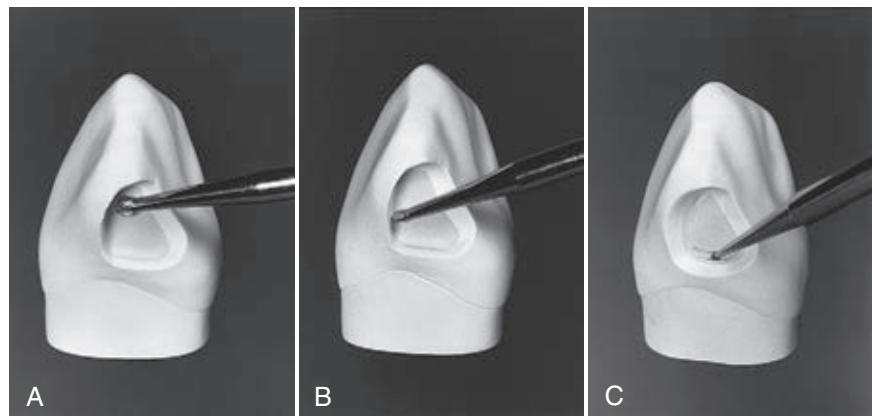


Fig. 15-17 Extensive Class III tooth preparation. **A**, Initial tooth preparation with No. 2 round bur. **B**, Defining line angles and removing undermined enamel with No. $\frac{1}{2}$ round bur. **C**, Placing the retention groove using No. $\frac{1}{4}$ round bur. Note the completed incisal cove.

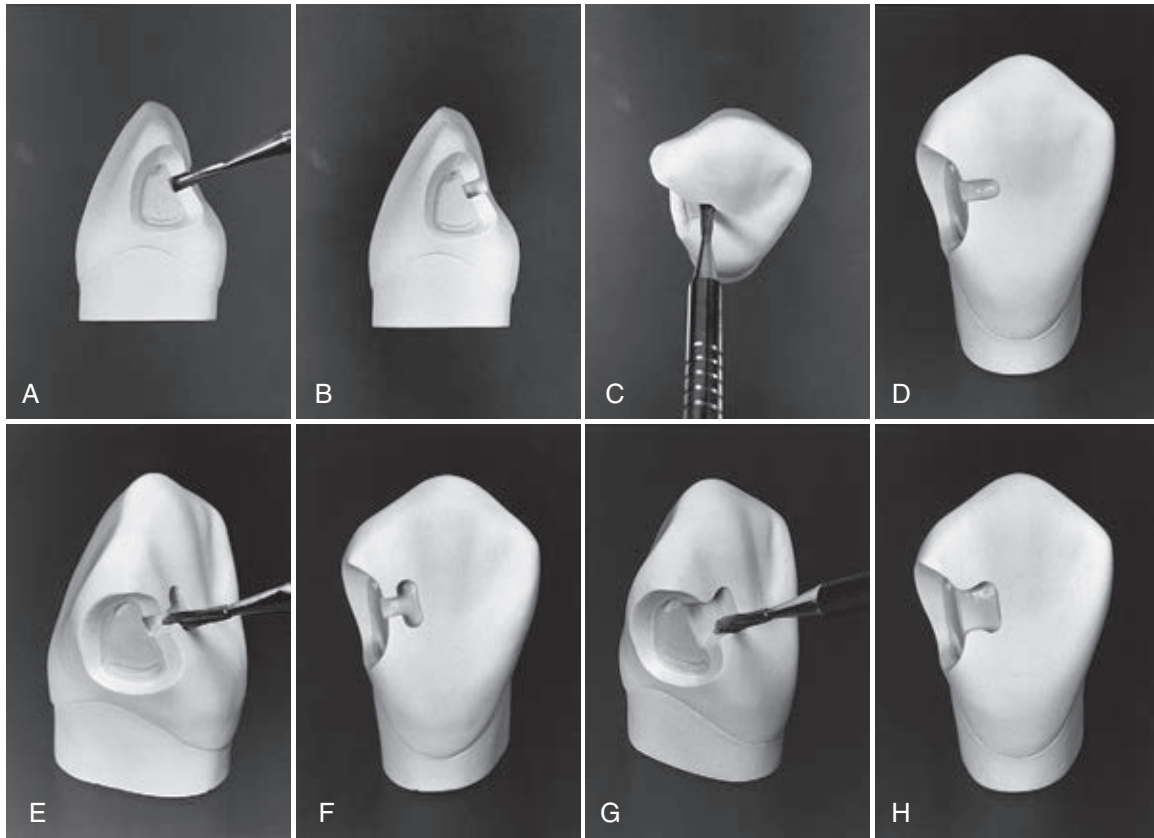


Fig. 15-18 Lingual dovetail providing additional retention for extensive amalgam restoration. **A**, Bur position at correct depth and angulation to begin cutting. **B**, Initial cut in beginning dovetail. **C**, Bur moved to most mesial extent of dovetail. **D**, If possible, cutting should not extend beyond the midlingual position. **E**, Bur cutting gingival extension of the dovetail. **F**, Incisal and gingival extensions of the dovetail. **G**, Completing the isthmus. The proximal and lingual portions are connected by the incisal and gingival walls in smooth curves. **H**, Completed lingual dovetail.

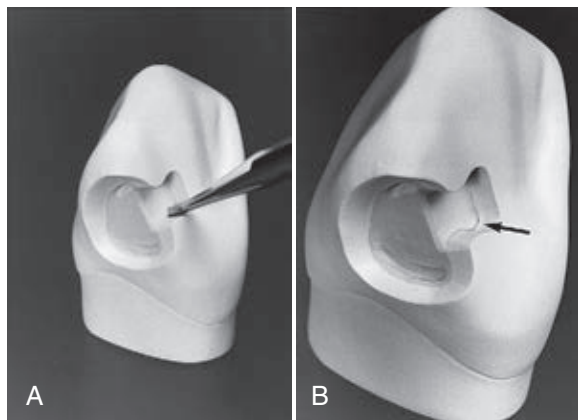


Fig. 15-19 Ensuring retention in lingual dovetail (often optional). **A**, Position of No. 33½ bur for cutting the retention cove. **B**, Preparation of the cove should not remove the dentinal support of the lingual enamel (arrow).

preparation should be cleaned of any residual debris and inspected. Careful assessment should be made to see that all of the caries has been removed, that the depth and retention are appropriate, and that cavosurface margins provide for the amalgam bulk.

Restorative Technique *Desensitizer Placement*

The use of a dentin desensitizer over the prepared tooth structure before placing amalgam is generally recommended. The dentin desensitizer is rubbed onto the prepared tooth surface for 30 seconds and excess moisture is removed without desiccating the dentin.

Matrix Placement

The wedged, rigid material-supported sectional matrix may be used for the Class III amalgam restoration. Insertion of amalgam into the Class III tooth preparation is usually from the lingual aspect. It is essential to trim the lingual portion of the sectional matrix material correctly to avoid covering the preparation and blocking access for insertion of the amalgam. A length of 5/6 inch (8 mm) wide, 0.002 inch (0.05 mm) thick stainless steel matrix material that covers one-third of the facial surface and extends through the proximal to the lingual surface is obtained. The lingual portion is trimmed at an angle that corresponds approximately to the slope of the lingual surface of the tooth (Fig. 15-23). The section of matrix is burnished on a resilient paper pad to create the desired contact and contour form. The sectional matrix is placed in position and wedged from the facial or lingual embrasure, whichever

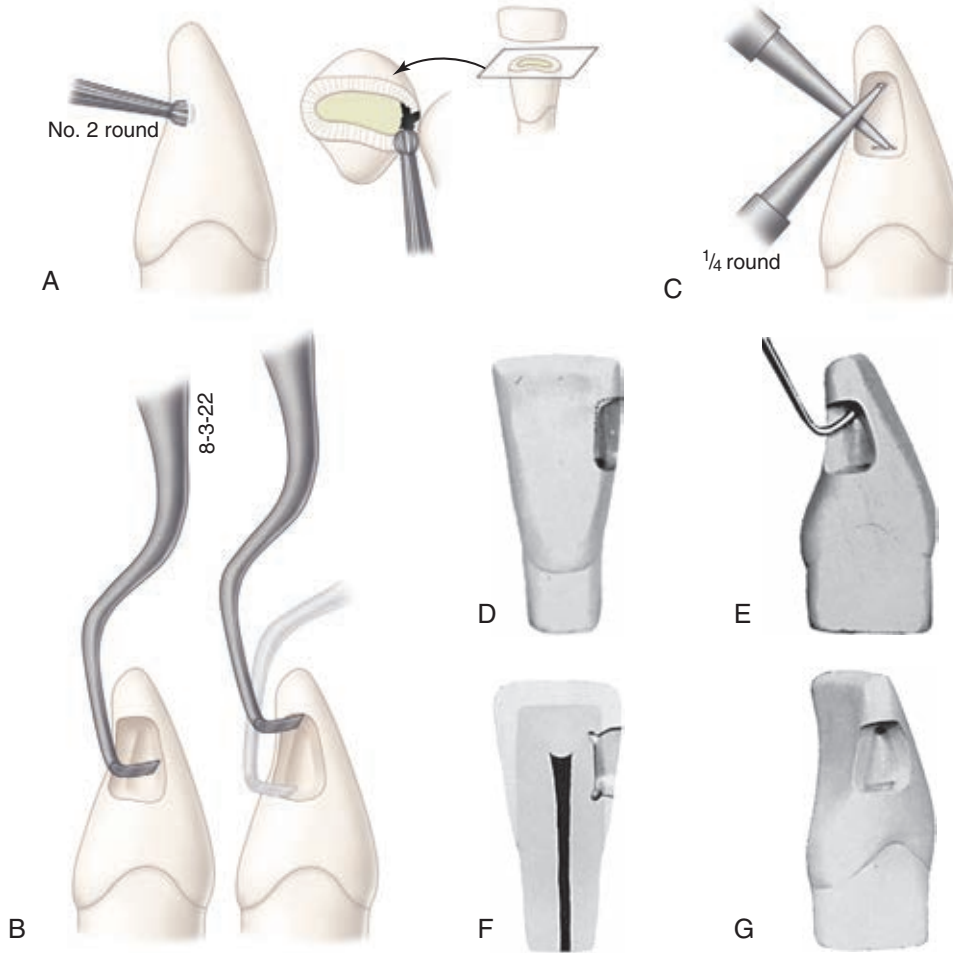


Fig. 15-20 Class III tooth preparation for amalgam restoration on the mandibular incisor. **A**, Entering the tooth from the lingual approach. **B**, Finishing the facial, incisal, and gingival enamel margins with an 8-3-22 triple angle hoe. Note how the reverse bevel blade is used on the gingival enamel. **C**, Placing incisal and gingival retention forms with No. $\frac{1}{4}$ round bur. **D**, Dotted line indicates the outline of the additional extension that is sometimes necessary for access in placing the incisal retention cove. **E**, Position of a bi-beveled hatchet to place the incisal retention cove. **F**, The axial wall forms a convex surface over the pulp. **G**, Completed tooth preparation. Note the gingival retention groove.



Fig. 15-21 Completed distolingual Class III tooth preparation for amalgam.

is greater. The facial and lingual portions of the matrix are stabilized with a rigid material (see Fig. 15-22, G). Precontoured metallic matrices may be used (instead of custom-made matrices) if the contour of the precontoured matrix coincides with that of the proximal surface being restored. If the preparation is small and the matrix is sufficiently rigid, additional rigid material to support the matrix may not be required.

Condensation and Carving

Insertion of the amalgam, initial carving, matrix removal, wedge removal, and final carving are similar to the techniques for posterior teeth (see Chapter 14). When properly placed, conservative restorations in incisors and canines are relatively inconspicuous (Fig. 15-24). Figure 15-25 illustrates a Class III amalgam restoration in a mandibular incisor.

Finishing and Polishing

The finishing and polishing techniques and procedures are the same as those presented in Chapters 13 and 14.

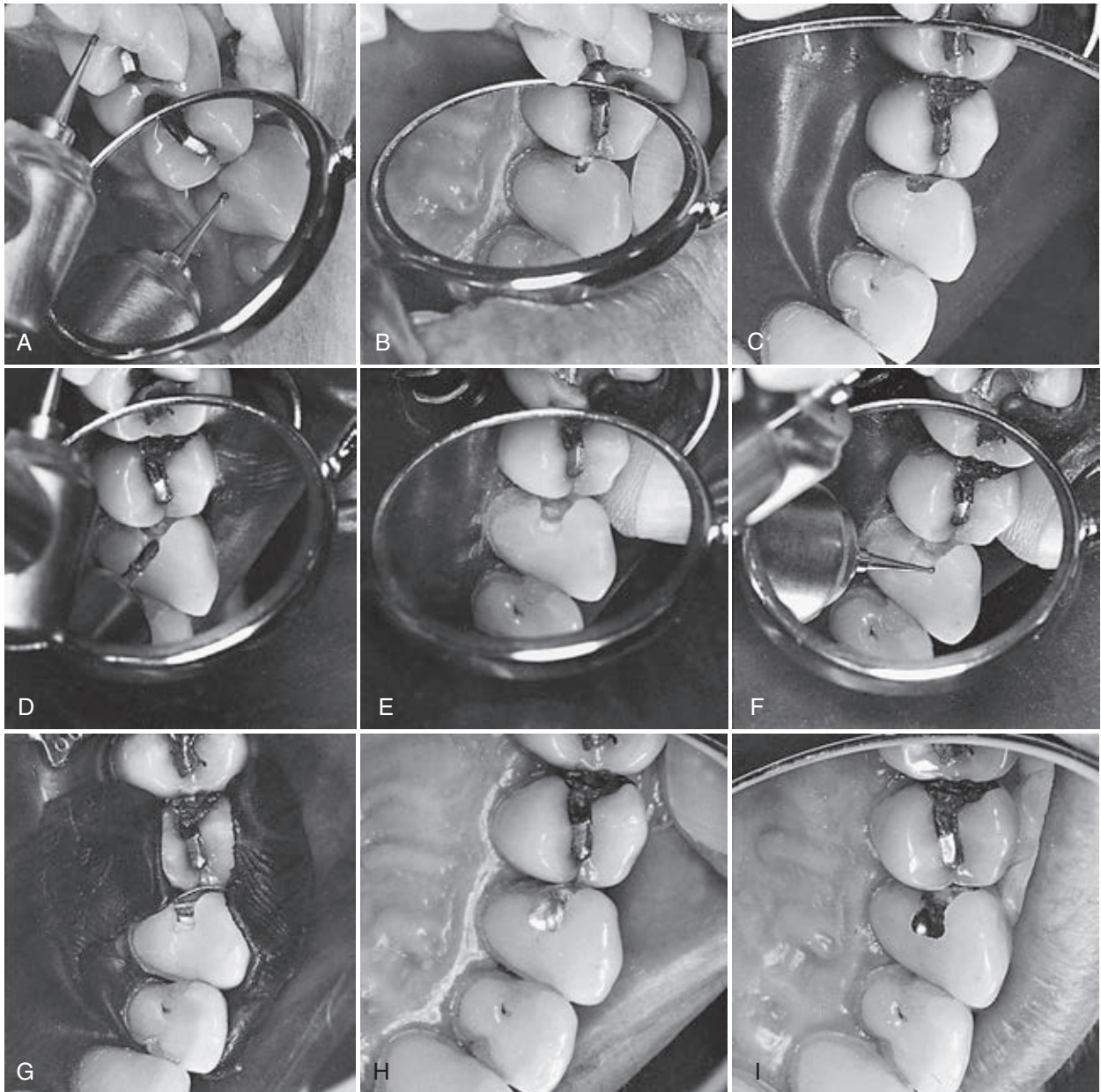


Fig. 15-22 Distolingual tooth preparation and restoration. **A**, Bur position for entry. **B**, Penetration made through the lingual enamel to the caries. **C**, Proximal portion completed, except for the retention form. **D**, Preparing the dovetail. **E**, Completed preparation, except for the retention groove and the coves. **F**, Bur position for the incisal cove in the dovetail. **G**, Rigid material-supported matrix ready for the insertion of amalgam. **H**, Carving completed and rubber dam removed. **I**, Polished restoration.

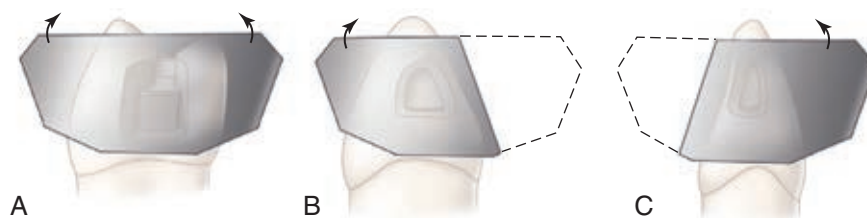


Fig. 15-23 Matrix strip design. **A**, Design required for rigid material-supported matrix for Class II tooth preparations. **B**, Alteration necessary for Class III preparation on the maxillary canine. **C**, Alteration necessary for the mandibular incisor. The strip material is cut to approximate the slope of the lingual surface.



Fig. 15-24 Inconspicuous facial margin (arrow) of Class III amalgam restoration on the maxillary canine.



Fig. 15-25 Class III amalgam restoration on the mandibular incisor (arrowhead).

Clinical Technique for Class V Amalgam Restorations

Initial Procedures

Proper isolation prevents moisture contamination of the operating site, enhances asepsis, and facilitates access and visibility. Moisture in the form of saliva, gingival sulcular fluid, or gingival hemorrhage must be excluded during caries removal, liner application, and insertion and carving of amalgam. Moisture impairs visual assessment, may contaminate the pulp during caries removal (especially with a pulpal exposure), and negatively affects the physical properties of restorative materials. The gingival margin of Class V tooth preparations is often apical to the gingival crest. Such a gingival margin necessitates retraction of the free gingiva with a retraction cord or appropriate rubber dam and retainer to protect it and to provide access, while eliminating seepage of sulcular fluid into the tooth preparation or restorative materials.

These isolation objectives are met by local anesthesia and isolation by (1) a cotton roll and a retraction cord or (2) a rubber dam and a suitable cervical retainer (Fig. 15-26). Isolation with a cotton roll and a retraction cord is satisfactory when properly performed. This type of isolation is practical and probably the approach most often used. The retraction cord should be placed in the sulcus before initial tooth preparation to reduce the possibility of cutting instruments damaging the free gingiva. The cord should produce a temporary,

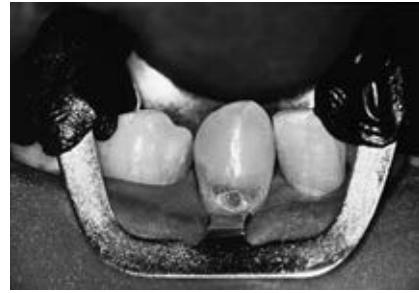


Fig. 15-26 A rubber dam and a No. 212 retainer may be required to isolate the carious area properly.

adequate, a traumatic apical retraction and lateral deflection of the free gingiva. The cord may be treated with hemostatic preparations containing aluminum chloride or ferrous sulfate. Alternatively, the cord may be treated with epinephrine. However, caution must be used as epinephrine on abraded gingiva can be absorbed rapidly into the circulatory system, causing an increase in blood pressure, elevated heart rate, and possible dysrhythmia. The retraction cord may be braided, twisted, or woven. The diameter of the cord should be easily accommodated in the gingival sulcus. An appropriate amount is cut to a length $\frac{1}{4}$ inch (6 mm) longer than the gingival margin. Some operators prefer to place the cord in a Dappen dish, wet it with a drop of hemostatic solution and blot it with a 2×2 inch (5×5 cm) gauze to remove excess liquid. A braided or woven cord is usually easier to use because it does not unravel during placement. A larger cord can be inserted over the first cord if the sulcus is large enough to accommodate two cords. A thin, blunt-edged instrument blade or the side of an explorer tine may be used to gently insert the cord progressively into place. A slight backward direction of the instrument as it steps along the cord helps prevent dislodgment of previously inserted cord (Fig. 15-27). In addition, using a second instrument stepping along behind the first instrument can help prevent dislodgment of cord. Additionally, using the air syringe or cotton pellets to reduce or absorb the sulcular fluid in the cord already placed is helpful during cord placement. The cord results in adequate retraction in a short time. If significant blanching of the free gingiva is observed (or if too much pressure has to be applied to place the cord), it means that an oversized cord has been selected, and it should therefore be exchanged with a cord of smaller diameter. The cord can be moistened before or after placement with the hemostatic solution if slight hemorrhage is anticipated or observed. Alternatively, the cord can be used dry.

The cord usually remains in place throughout tooth preparation as well as insertion and initial carving of amalgam. While carving amalgam at the gingival margin, the presence of the cord may cause difficulty in feeling the unprepared tooth surface apical to the margin to prevent under-carving of the margin; this results in over-contouring and marginal excess. In this instance, after carving gross excess, the cord can be teased from its place before the carving is completed.

Tooth Preparation

Proper outline form for Class V amalgam tooth preparations results in extending the cavosurface margins to sound tooth structure while maintaining a limited axial depth of 0.5 mm

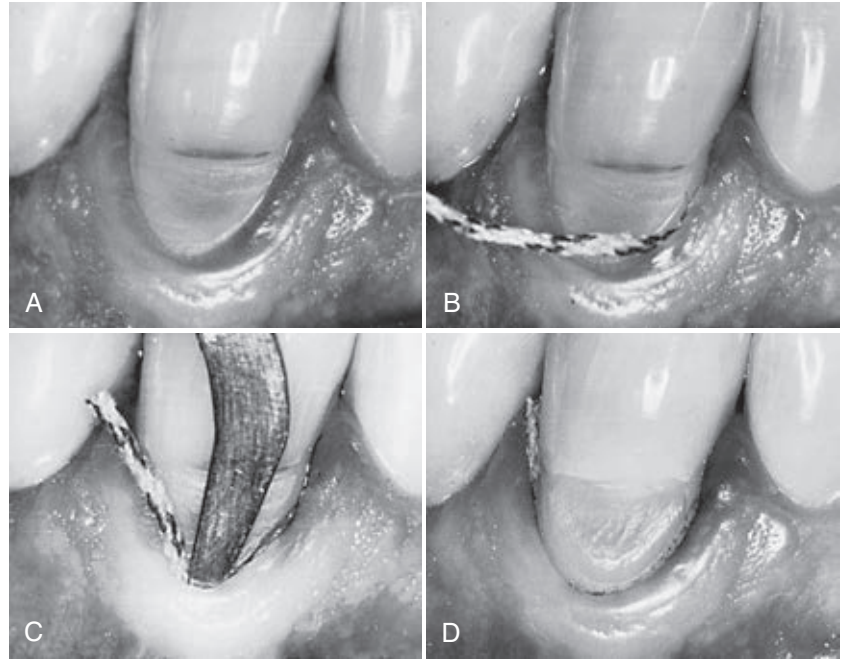


Fig. 15-27 Use of the retraction cord for isolation of a Class V lesion. **A**, Pre-operative view. **B**, Cord placement initiated. **C**, Cord placement using a thin, flat-bladed instrument. **D**, Cord placement completed.

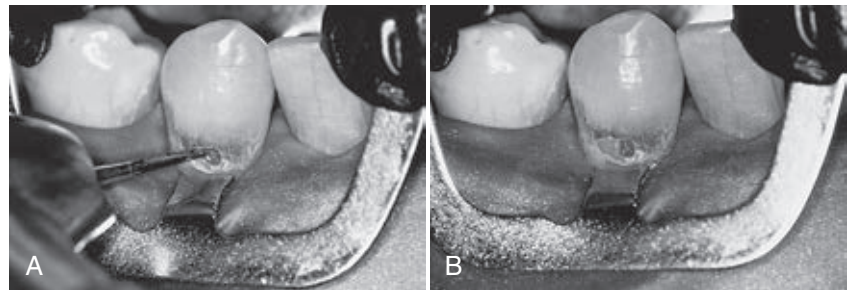


Fig. 15-28 Starting Class V tooth preparation. **A**, Bur positioned for entry into caries lesion. **B**, The entry cut is the beginning of the outline form having a limited axial depth. (The end of the bur in the center of the lesion may be in the carious tooth structure or in the air.)

inside the DEJ and 0.75 mm inside cementum (when on the root surface). The outline form for the Class V amalgam tooth preparation is determined primarily by the location and size of the caries or old restorative material. Clinical judgment determines final preparation outline, especially when the cavosurface margins approach or extend into areas of enamel decalcification. The operator must observe the prepared enamel wall to evaluate the depth of the decalcified enamel and to determine if cavitation exists peripheral to the wall. When no cavitation has occurred and when the decalcification does not extend appreciably into the enamel, extension of the outline form often should cease. In some cases, if all decalcification were included in the outline form, the preparation would extend into the proximal cervical areas (if not circumferentially around the tooth). Such a preparation would be difficult and perhaps unrestorable. A full-coverage restoration should be considered for teeth with extensive cervical decalcification.

Initial Tooth Preparation

A Class V amalgam restoration is not used often in a mandibular canine, but it is presented here for illustration. The

same general principles for tooth preparation apply for all other tooth locations. A tapered fissure bur of suitable size (e.g., No. 271) is used to enter the caries lesion (or existing restoration) to a limited initial axial depth of 0.5 mm inside the DEJ (Fig. 15-28). This depth is usually 1 to 1.25 mm total axial depth, depending on the incisogingival (i.e., occlusogingival) location. The enamel is considerably thicker occlusally and incisally than cervically. If the preparation is on the root surface, however, the axial depth is approximately 0.75 mm. The end of the bur at the initial depth is in dentin, in infected carious dentin, or in old restorative material. The edge of the end of the bur can be used to penetrate the area; this is more efficient than using the flat end of the bur, reducing the possibility of the bur's "crawling." When the entry is made, the bur orientation is adjusted to ensure that all external walls are perpendicular to the external tooth surface and parallel to the enamel rods (Fig. 15-29). Often, this requires changing the orientation of the handpiece to accommodate the cervical mesiodistal and incisogingival (i.e., occlusogingival) convexity of the tooth. The preparation is extended incisally, gingivally, mesially, and distally until the cavosurface margins are positioned in sound tooth structure such that an initial axial depth of 0.5 mm inside the DEJ (if on the root surface, the axial

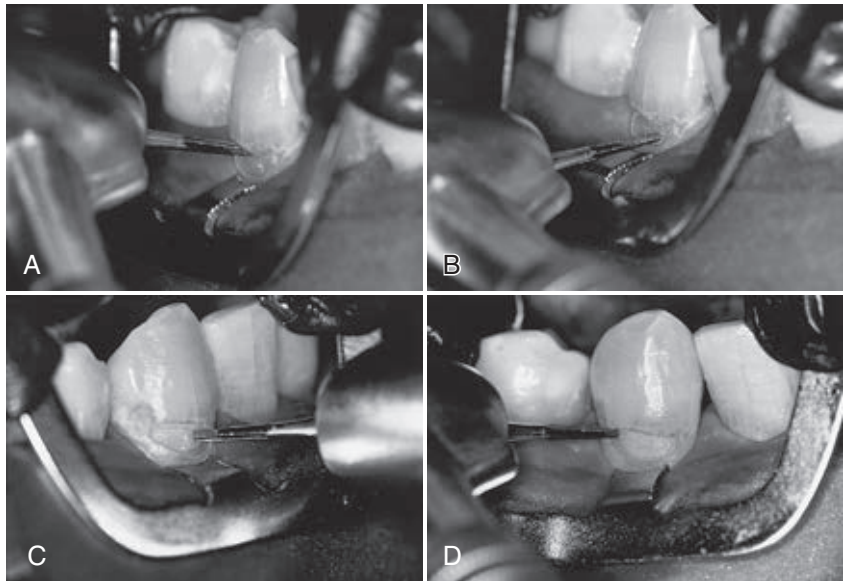


Fig. 15-29 When extending incisally (A), gingivally (B), mesially (C), and distally (D), the bur is positioned to prepare these walls perpendicular to the external tooth surface.



Fig. 15-30 The flat-bladed instrument protects the rubber dam from the bur.

depth is 0.75 mm) is established. When extending mesially and distally, it may be necessary to protect the rubber dam from the bur by placing a flat-bladed instrument over the dam (Fig. 15-30). Because the axial wall follows the mesiodistal and incisogingival (i.e., occlusogingival) contours of the facial surface of the tooth, it usually is convex in both directions. In addition, the axial wall usually is slightly deeper at the incisal wall, where more enamel (i.e., approximately 1-1.25 mm in depth) is present than at the gingival wall, where little or no enamel (i.e., approximately 0.75-1 mm in depth) may be present. A depth of 0.5 mm inside the DEJ permits placement of necessary retention grooves without undermining enamel. This subtle difference in depth serves also to increase the thickness of the remaining dentin (between the axial wall and the pulp) in the gingival aspect of the preparation to aid in protecting the pulp. For the tooth preparation that is extended incisogingivally, the axial wall should be more convex (because it follows the contour of the DEJ).

Alternatively, an appropriate carbide bur (usually No. 2 or No. 4) may be used for the initial tooth preparation. Round burs are indicated in areas inaccessible to a fissure bur that is held perpendicular to the tooth surface. If needed, smaller round burs may also be used to define the internal angles in these preparations, enhancing proper placement of the retention grooves.

Final Tooth Preparation

Final tooth preparation involves removing any remaining infected dentin; pulp protection; retention form; finishing external walls; and cleaning, inspecting, and desensitizing. Any remaining infected axial wall dentin is removed with a No. 2 or No. 4 round bur. Any old restorative material (including base and liner) remaining may be left if (1) no clinical or radiographic evidence of recurrent caries exists, (2) the periphery of the base and liner is intact, and (3) the tooth is asymptomatic. With proper outline form, the axial line angles are already in sound dentin. If needed, an appropriate liner or base is applied.

Because the mesial, distal, gingival, and incisal walls of the tooth preparation are perpendicular to the external tooth surface, they usually diverge facially. Consequently, this form provides no inherent retention, and retention form must be provided because the primary retention form for an amalgam restoration is macromechanical. A No. $\frac{1}{4}$ round bur is used to prepare two retention grooves, one along the incis axial line angle and the other along the gingivoaxial line angle (Fig. 15-31). The handpiece is positioned so that the No. $\frac{1}{4}$ round bur is directed generally to bisect the angle formed at the junction of the axial wall and the incisal (i.e., occlusal) wall. Ideally, the direction of the incisal (i.e., occlusal) groove is slightly more incisal (i.e., occlusal) than axial, and the direction of the gingival groove is slightly more gingival than axial. Alternatively, four retention grooves may be prepared, one in each of the four axial point angles of the preparation (Fig. 15-32).

Using four grooves instead of two full-length grooves conserves the dentin near the pulp, reducing the possibility of a mechanical pulp exposure. The depth of the grooves should be approximately 0.25 mm, which is half the diameter of the bur. It is important that the retention grooves be adequate because they provide the only retention form to the preparation. Regardless, the grooves should not remove dentin immediately supporting enamel. In a large Class V amalgam preparation, extending the retention groove circumferentially

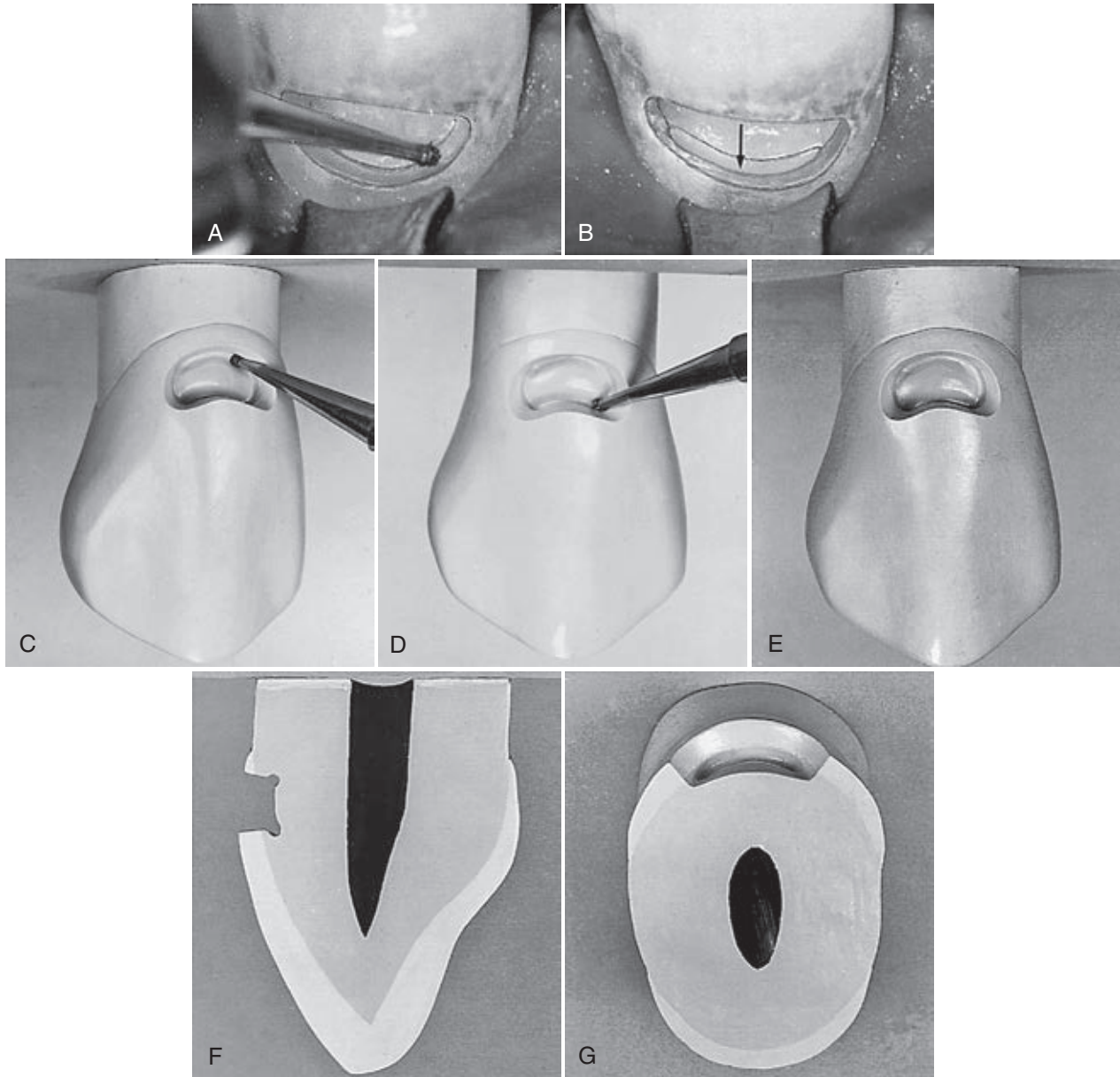


Fig. 15-31 Retention form. **A**, A No. $\frac{1}{4}$ round bur positioned to prepare the gingival retention groove. **B**, Gingival retention groove (arrow) prepared along the gingivoaxial line angle generally to bisect the angle formed by the gingival and axial walls. Ideally, the direction of preparation is slightly more gingival than pulpal. An incisal retention groove is prepared along the incisoaxial line angle and directed similarly. **C** and **D**, A groove is placed with a No. $\frac{1}{4}$ round bur along the gingivoaxial and incisoaxial line angles 0.2 mm inside the dentinoenamel junction (DEJ) and 0.25 mm deep. Note the slight pulpal inclination of the shank of the No. $\frac{1}{4}$ round bur. **E**, Facial view. **F**, Incisogingival section. Grooves depthwise are directed mostly incisally (gingivally) and slightly pulpally. **G**, Mesiodistal section.

around all the internal line angles of the tooth preparation may enhance the retention form.

If access is inadequate for use of the No. $\frac{1}{4}$ round bur, an angle-former chisel may be used to prepare the retention form. In addition, a No. $33\frac{1}{2}$ bur can be used. Both methods result in retention grooves that are angular, but positioned in the same location and approximately to the same depth as when the No. $\frac{1}{4}$ round bur is used. The rounded retention form placed with the No. $\frac{1}{4}$ round bur is generally preferred, however, because amalgam can be condensed into rounded areas better than into sharp areas, resulting in better

adaptation of amalgam into the retention grooves. If necessary, suitable hand instruments (e.g., chisels, margin trimmers) are used to plane the enamel margins, verifying soundness and 90-degree cavosurface angles. Finally, the preparation is cleaned and inspected for completeness. A desensitizer is then applied.

Large Preparations That Include Line Angles

Caries on the facial (or lingual) surface may extend beyond the line angles of the tooth. Maxillary molars, particularly the

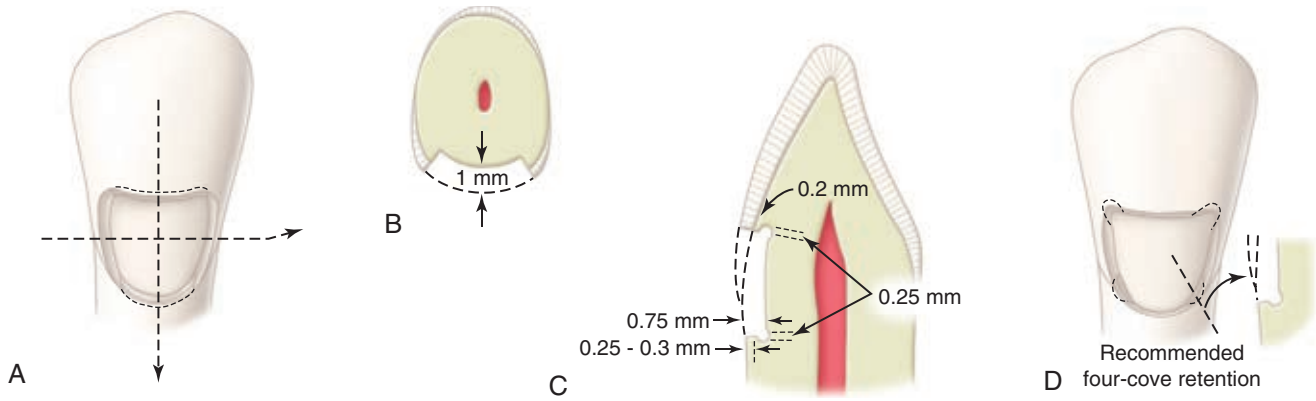


Fig. 15-32 A–C, Extended Class V tooth preparation (A) with the axial wall contoured parallel to the dentinoenamel junction (DEJ) mesiodistally (B) and incisogingivally (C). The axial wall pulpal depth is 1 mm in the crown and 0.75 mm in the root. In addition, note location and direction depth (0.25 mm) of the retention grooves and the dimension of the gingival wall (0.25 mm) from the root surface to the retention groove. D, Large Class V preparation with retention coves prepared in the four axial point angles.

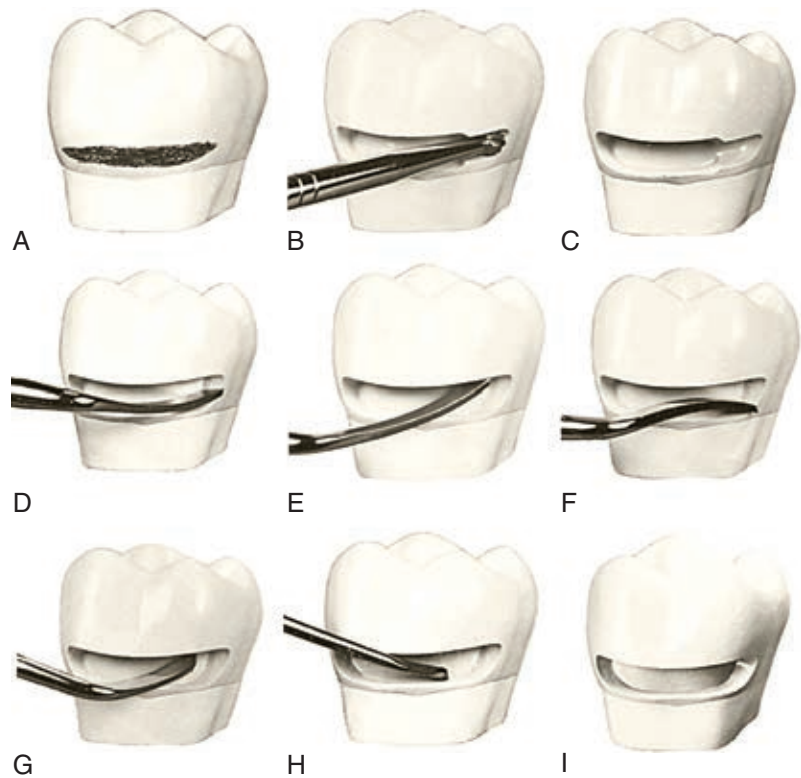


Fig. 15-33 Tooth preparation on maxillary molar. A, Caries extending around distofacial corner of the tooth. B and C, Distal extension is accomplished with round bur. D–F, A gingival margin trimmer may be useful in completing the distal half of the preparation when handpiece access is limited. G, A gingival margin trimmer may be used to provide the retention grooves. H, An angle-former chisel may be used to prepare the retention grooves in the distal portion of the preparation. I, Completed tooth preparation.

second molars, are most commonly affected by these extensive defects (Fig. 15-33, A). In this example, if the remainder of the distal surface is sound and the distal caries is accessible facially, the facial restoration should extend around the line angle. This prevents the need for a Class II proximal restoration to restore the distal surface. As much of the preparation as possible should be completed with a fissure bur. A round bur, approximately the same diameter as the fissure bur, is then used to initiate the distal portion of the preparation (see Fig. 15-33, B and C). Smaller round burs should be used to accentuate the internal line angles of the distal portion. Preparing the facial portion first provides better access and visibility to the distal

portion. Occasionally, hand instruments may be useful for completing the distal half of the preparation when space for the handpiece is limited (see Fig. 15-33, D through F).

Grooves placed along the entire length of the occlusoaxial and gingivoaxial line angles help ensure retention of the restoration. The No. $\frac{1}{4}$ round bur is used as previously described to prepare the retention grooves. A gingival margin trimmer or a 7-85-2½-6 angle-former chisel can be used in the distal half of the preparation to provide retention form when access for the handpiece is limited (see Fig. 15-33, G and H).

Because of the proximity of the coronoid process, access to the facial surfaces of maxillary molars, particularly the second



Fig. 15-34 The mandible shifted laterally for improved access and visibility.



Fig. 15-35 When a Class V outline form closely approaches an existing restoration, the preparation should be extended to remove the remaining thin enamel wall to achieve adjoining restorations.

molars, is often limited. Having the patient partially close and shift the mandible toward the tooth being restored improves access and visibility (Fig. 15-34).

If the Class V outline form approaches an existing proximal restoration, it is better to extend slightly into the bulk of the proximal restoration, rather than to leave a thin section of the tooth structure between the two restorations (Fig. 15-35). In this illustration, the previously placed amalgam served as the distal wall of the preparation. When proper treatment requires Class II and V amalgam restorations on the same tooth, the Class II preparation and restoration is completed before initiating the Class V restoration. If the Class V restoration were done first, it might be damaged by the matrix band and wedge needed for the Class II restoration.

Restorative Technique

Desensitizer Placement

The same considerations presented earlier apply for the Class V amalgam restoration.

Matrix Placement

Most Class V amalgam restorations are placed without the use of any type of matrix. The most difficult condensation occurs in a tooth preparation with an axial wall that is convex mesio-distally. Two alternative methods for insertion may be used.

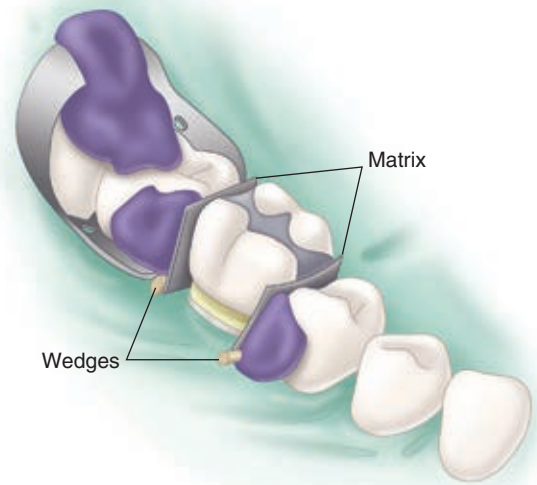


Fig. 15-36 Application of the matrix to confine amalgam in the mesial and distal extensions of the preparation.

The preferred method is the application of a matrix that confines amalgam in the mesial and distal portions of the preparation (Fig. 15-36). Short lengths of stainless steel matrix material, one each for the mesial and distal surfaces, are passed through the proximal contacts, carefully guided into the gingival sulcus, and wedged. The strips must be wide enough to extend occlusally through the respective proximal contacts and long enough to extend slightly past the facial line angles. The strip usually requires rigid material support for stability. The strips offer resistance against condensing the mesial and distal portions, which provides support for condensing the center of the restoration. The gingival edge of the steel strip often must be trimmed to conform to the circumferential contour (level) of the base of the gingival sulcus to prevent soft tissue damage. Rather than using two short pieces, the operator can use a longer length that may be passed through one proximal contact, extended around the lingual surface, and passed through the other contact, forming a U-shaped matrix. Trimming the gingival edge to conform to the interproximal soft tissue anatomy usually is more difficult with one matrix strip than when two strips are used.

A conventional Tofflemire band and retainer may be used with a window cut into the band allowing access to the preparation for condensation (Fig. 15-37). Alternatively, the tooth may be prepared and restored in sections without using a matrix. Each successive section of the preparation should be extended slightly into the previously condensed portion to ensure caries removal. This procedure is time-consuming but effective.

Insertion and Carving of the Amalgam

The amalgam carrier is used to insert the mixed amalgam into the preparation in small increments (Fig. 15-38, A). Amalgam is condensed into the retention areas first by using an appropriate condenser (see Fig. 15-38, B). Next, amalgam

Fig. 15-37 Customized matrix band used to restore an area of proximal root caries. **A**, Conventional Tofflemire matrix with window cut into the band to allow access for condensation. **B**, Matrix in place around the tooth, allowing lingual access to preparation.

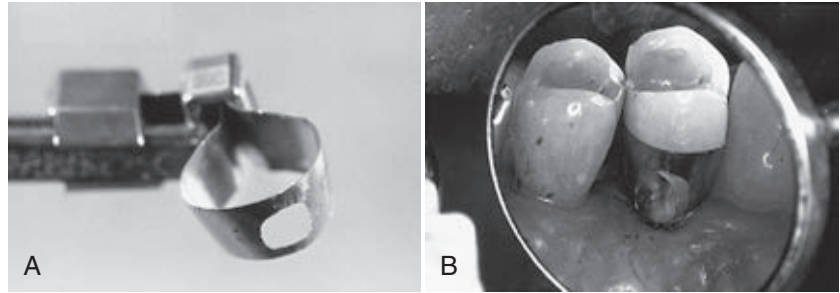
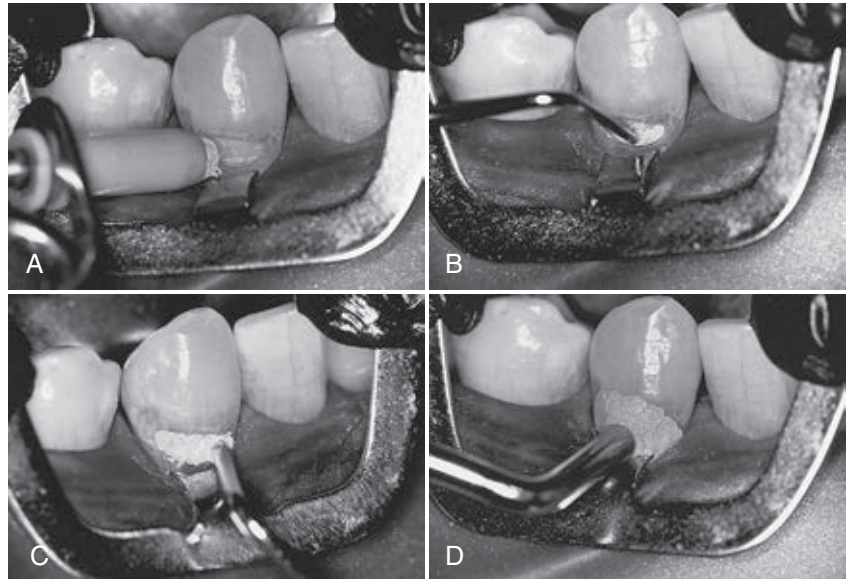


Fig. 15-38 Inserting amalgam. **A**, Place amalgam into the preparation in small increments. **B**, Condense first into the retention grooves with a small condenser. **C**, Condense against the mesial and distal walls. **D**, Overfill and provide sufficient bulk to allow for carving.



is condensed against the mesial and distal walls of the preparation (see Fig. 15-38, C). Finally, a sufficient bulk of amalgam is placed in the central portion to allow for carving the correct contour (see Fig. 15-38, D). As the surface of the restoration becomes more convex, condensation becomes increasingly difficult. It is important to guard against the “landsliding” of amalgam during over-packing. A large condenser or flat-bladed instrument held against amalgam may help resist pressure applied elsewhere on the restoration (Fig. 15-39).

Carving may begin immediately after the insertion of amalgam (Fig. 15-40). All carving should be done using the side of the explorer tine or a Hollenback No. 3 carver held parallel to the margins. The side of the carving instrument always should rest on the unprepared tooth surface adjacent to the prepared cavosurface margin; this prevents over-carving. The carving procedure is begun by removing excess amalgam to expose the incisal (or occlusal) margin. Removal of excess material continues until the mesial and distal margins are exposed. Finally, material excess at the gingival margin is carved away. Carving the marginal areas should result in developing the desired convex contours in the completed restoration. Improper use of the carving instruments results in a poorly contoured restoration. Note in Figure 15-41 how carving instruments are positioned to provide the desired contours. No amalgam excess should remain at the margins



Fig. 15-39 Use a large condenser or a flat-bladed instrument to offer resistance to condensation pressure applied elsewhere on the restoration.

because amalgam may break away, creating a defect at the margin, or cause gingival irritation.

In some instances, it is appropriate to change facial contours because of altered soft tissue levels (e.g., cervical lesions in periodontally treated patients). Facial contours may be increased (or relocated) only enough to prevent food impaction into the gingival sulcus and to provide access for the patient to clean the area. Over-contouring must be avoided because it results in reduced stimulation and cleansing of the gingiva during mastication.

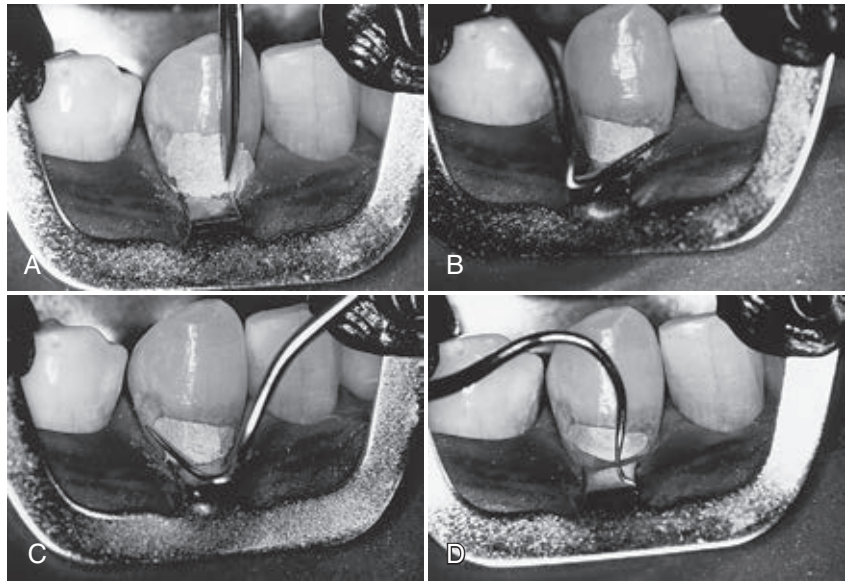


Fig. 15-40 Carving and contouring the restoration. **A**, Begin the carving procedure by removing any excess and locating the incisal margin. **B** and **C**, An explorer may be used to remove the excess and locate the mesial and distal margins. **D**, Remove the excess and locate the gingival margin.



Fig. 15-41 Positioning of the carving instrument to prevent over-carving amalgam and to develop the desired gingival contours.

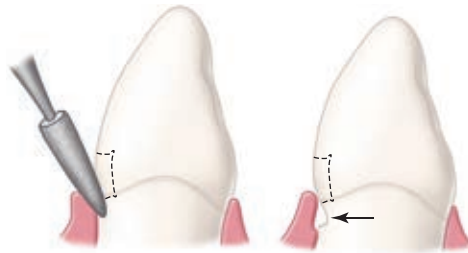


Fig. 15-42 Incorrect use of a pointed stone at the gingival margin results in the removal of cementum, notching of the tooth structure gingival to the margin, or both.

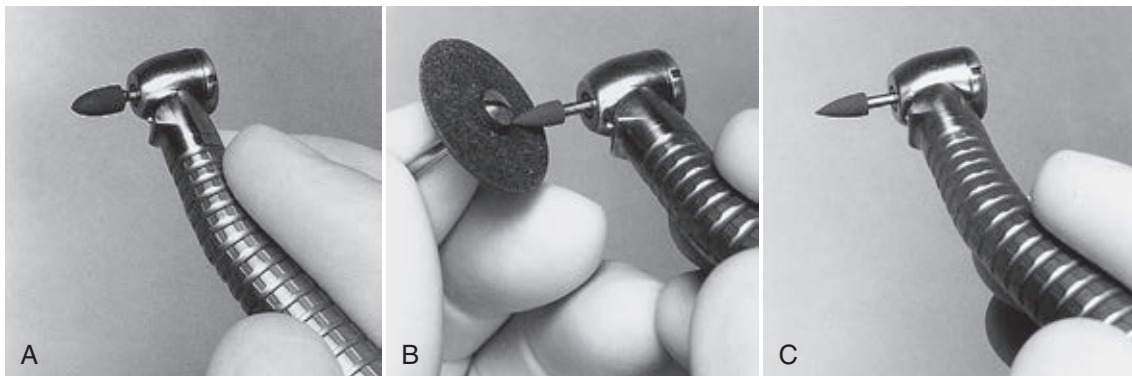


Fig. 15-43 Reshaping a rubber abrasive point against a mounted carborundum disk.

When a rubber dam and the No. 212 cervical retainer have been used for isolation, the retainer is removed using care to open the jaws of the retainer wide enough to prevent marring the surface of the restoration. The rubber dam is removed, and the area is examined carefully to ensure that no amalgam particles remain in the sulcus.

When a retraction cord is used for isolation, it may interfere with carving any excess amalgam at the gingival margin. If so, removal of the gross excess of amalgam is followed by careful removal of the cord, followed by completion of the carving along the margin.

Finishing and Polishing of the Amalgam

If carving procedures were performed correctly, no finishing of the restoration should be required. A slightly moistened

cotton pellet held in cotton pliers may be used to further smooth the carved restoration. Additional finishing and polishing of amalgam restorations may be necessary, however, to correct a marginal discrepancy or to improve contour. Care is required when using stones or any rotating cutting instruments on margins positioned below the cemento-enamel junction (CEJ) because of the possibility of removing cementum, notching the tooth structure gingival to the margin, or both (Fig. 15-42). Figure 15-43 illustrates re-shaping a rubber abrasive point to allow optimal access to the gingival portion of a Class V amalgam restoration.

Complex Amalgam Restorations

Lee W. Boushell, Aldridge D. Wilder, Jr.

Complex posterior restorations are used to replace any missing structure of teeth that have fractured, have severe caries involvement, or have existing restorative material. These restorations usually involve the replacement of one or more missing cusps and require additional means of retention. This chapter describes the use of dental amalgam for complex direct posterior restorations.

Review of Pertinent Material Qualities and Properties

The properties, advantages, and limitations of amalgam are discussed in [Chapter 13](#) and [Online Chapter 18](#). Amalgam is easy to use and has a high compressive strength, excellent wear resistance, and proven long-term clinical performance. It has a metallic color, does not strengthen the tooth, and does not bond to tooth structure and therefore requires a retentive tooth preparation.

Indications

Complex posterior amalgam restorations should be considered when large amounts of tooth structure are missing and when one or more cusps need capping ([Fig. 16-1](#)).¹ Complex amalgams can be used as (1) definitive final restorations, (2) foundations, (3) control restorations in teeth that have a questionable pulpal or periodontal prognosis, or (4) control restorations in teeth with acute or severe caries. When determining the appropriateness of a complex amalgam restoration, the factors discussed in the following sections must be considered.

Resistance and Retention Forms

In a tooth with severe caries or existing restorative material, any undermined enamel or weak tooth structure subject to fracture must be removed and restored. Usually, a

weakened tooth is best restored with a properly designed indirect (usually cast) restoration that prevents tooth fracture caused by mastication forces (see [Chapter 17](#)). In selected cases, amalgam preparations that improve the resistance form of a tooth can be designed ([Fig. 16-2](#)).

When conventional retention features are not adequate because of insufficient remaining tooth structure, the retention form can be enhanced by using pins, slots, and elective groove extensions. The retention features needed depend on the amount of tooth structure remaining and the tooth being restored. As more tooth structure is lost, more auxiliary retention is required. Pins, slots, and box-like forms also provide additional resistance form to the restoration.

Status and Prognosis of the Tooth

A tooth with severe caries that might require endodontic therapy or crown lengthening or that has an uncertain periodontal prognosis often is treated initially with a control restoration. A control restoration helps (1) protect the pulp from the oral cavity (i.e., fluids, thermal stresses, pH changes, bacteria), (2) provide an anatomic contour against which gingival tissue may be healthier, (3) facilitate control of caries and plaque, and (4) provide some resistance against tooth fracture (or propagation of an existing fracture). (See [Chapter 2](#) for caries-control rationale and techniques.)

The status and prognosis of the tooth determine the size, number, and placement of retention features. Larger restorations generally require more retention. The size, number, and location of retention features demand greater care in smaller teeth, in teeth with deep excavations, and in symptomatic teeth. Carelessness can risk pulpal irritation or exposure.

Role of the Tooth in Overall Treatment Plan

The restorative treatment choice for a tooth is influenced by its role in the overall treatment plan. Although complex amalgam restorations are used occasionally as an alternative

to indirect restorations, they often are used as foundations for full coverage restorations. Abutment teeth for fixed prostheses may use a complex restoration as a foundation (Fig. 16-3). Extensive caries or previous restorations on abutment teeth for removable prostheses generally indicate an indirect restoration for the resistance and retention forms and for development of external surface contours for retention of the prosthesis. A tooth may be treated with a complex direct restoration if adequate resistance and retention forms can be provided. For patients with periodontal and orthodontic problems, the complex restoration may be the restoration of choice until the final phase of treatment, when indirect restorations may be preferred.

Occlusion, Esthetics, and Economics

Complex amalgam restorations are sometimes indicated as interim restorations for teeth that require elaborate occlusal alterations, ranging from vertical dimension changes to correcting occlusal plane discrepancies. When esthetics is a primary consideration, a complex amalgam restoration may not be the treatment of choice because of the display of metal. When cost of indirect restorations is a major factor for the patient, the complex direct amalgam restoration may be an appropriate treatment option, provided that adequate resistance and retention forms are included (Fig. 16-4).

Age and Health of Patient

For some older patients and those who are debilitated, complex amalgam restoration may be the treatment preferred over the more expensive and time-consuming cast restoration.

Contraindications

The complex amalgam restoration might be contraindicated if the patient has significant occlusal problems, or if the tooth cannot be restored properly with direct restoration because of anatomic or functional considerations (or both). The complex amalgam restoration also might be contraindicated if the area to be restored has esthetic importance for the patient.



Fig. 16-1 Mesio-occluso-disto-lingual (MODL) complex amalgam tooth No. 3.



Fig. 16-3 Mesio-occluso-disto-facial (MODF) amalgam foundation tooth No. 15.



Fig. 16-4 Mesio-occluso-disto-facial-lingual (MODFL) complex amalgam tooth #19

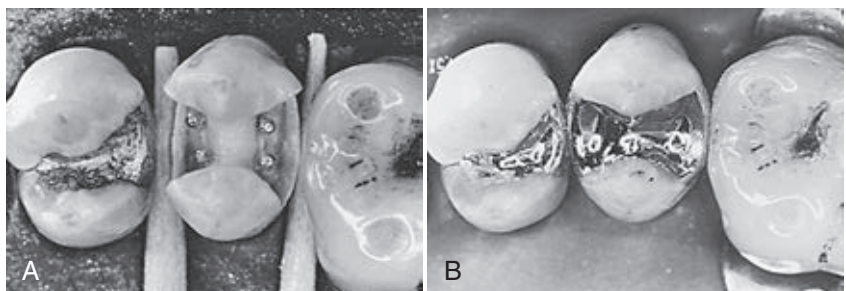


Fig. 16-2 Maxillary second premolar weakened by extensive caries and by the small fracture line extending mesiodistally on the center of the excavated dentinal wall. **A**, Minikin pins placed in the gingival floor improve resistance form after amalgam has been placed. **B**, Restorations polished.

Advantages

Conservation of Tooth Structure

The preparation for a complex amalgam restoration is usually more conservative than the preparation for an indirect restoration.

Appointment Time

The complex restoration can be completed in one appointment. An indirect restoration requires at least two appointments unless it is done using a chairside CAD/CAM (computer-aided design/computer-assisted manufacturing) system.

Resistance and Retention Forms

Amalgam restorations with cusp coverage significantly increase the fracture resistance of weakened teeth compared with amalgam restorations without cusp coverage.² Resistance and retention forms can be significantly increased by the use of pins and slots.

Economics

Compared with an indirect restoration, the amalgam restoration is a relatively inexpensive restorative procedure. When cost is a factor, the complex amalgam restoration may provide the patient with an alternative to extraction of the severely broken-down tooth.^{3,4}

Disadvantages

Tooth Anatomy

Proper contours and occlusal contacts and anatomy are sometimes difficult to achieve with large complex restorations.

Resistance Form

Resistance form is more difficult to develop than when preparing a tooth for a cusp-capping onlay (skirting axial line angles of the tooth) or a full crown. The complex amalgam restoration does not protect the tooth from fracture as effectively as an extracoronary restoration.

Clinical Technique

In this chapter, the word “vertical” is used to describe tooth preparation walls and other preparation aspects that are approximately parallel to the long axis of the tooth. The word “horizontal” is used to describe the walls and other aspects that are approximately perpendicular to the long axis of the tooth.

Initial Procedures: Summary

The treatment options should be discussed with the patient. Before the preparation for a complex amalgam restoration begins, an explanation of the procedure should be given to the

patient. The limitations of the restoration itself and the possible complications that might occur during the procedure also should be presented. The initial procedures for each of the complex amalgam restoration types are briefly discussed before the technique is presented.

Pin-Retained Amalgam Restorations

A pin-retained restoration is defined as any restoration requiring the placement of one or more pins in dentin to provide adequate resistance and retention forms. Pins are used whenever adequate resistance and retention forms cannot be established with slots, locks, or undercuts only.⁵ The pin-retained amalgam is an important adjunct in the restoration of teeth with extensive caries or fractures.⁶ Amalgam restorations including pins have significantly greater retention compared with restorations using boxes only or restorations relying solely on bonding systems.⁷ However, caution is indicated when using pins. Preparing pinholes and placing pins may create craze lines or fractures and internal stresses in dentin.⁸⁻¹⁰ Such craze lines and internal stress may have little or no clinical significance, but they can be important when minimal dentin is present. Pin retention increases the risk of penetrating into the pulp or perforating the external tooth surface. The use of pins decreases the tensile and horizontal strength of pin-retained amalgam restorations.^{11,12}

Slot-Retained Amalgam Restorations

For a complex restoration, a slot is a horizontal retention groove in dentin (Fig. 16-5). Slot retention can be used in conjunction with pin retention or as an alternative to it.¹³

Figure 16-6 illustrates the use of coves (placed with a No. ¼ bur) to provide additional retention form in a preparation that uses pins. Coves also may be used in preparations using slots (see Fig. 16-5). Proximal locks, as described in Chapter 14, also are placed in the proximal box and in other locations where sufficient vertical tooth preparation permits (Figs. 16-7 and 16-8).

Some operators use slot retention and pin retention interchangeably. Others more frequently use slot retention in preparations with vertical walls that allow retention locks to oppose one another. Pin retention is used more frequently in preparations with few or no vertical walls. Slots are particularly indicated in short clinical crowns and in cusps that have been reduced 2 to 3 mm for amalgam.¹³ Compared with pin placement, more tooth structure is removed in slot preparation. Slots are less likely to create microfractures in dentin, however, and to perforate the tooth or penetrate into the pulp. Medium-sized self-threading pins may elicit an inflammatory response if placed within 0.5 mm of the pulp, whereas slot placement does not.¹⁴ The retention potential of pins and slots is similar.¹⁵⁻¹⁸

Amalgam Foundations

A foundation is an initial restoration of a severely involved tooth. The tooth is restored so that the restorative material (amalgam, composite, or other) serves in place of tooth structure to provide the retention and resistance forms during the development of the final indirect restoration. A foundation is indicated for a tooth that lacks the resistance and retention

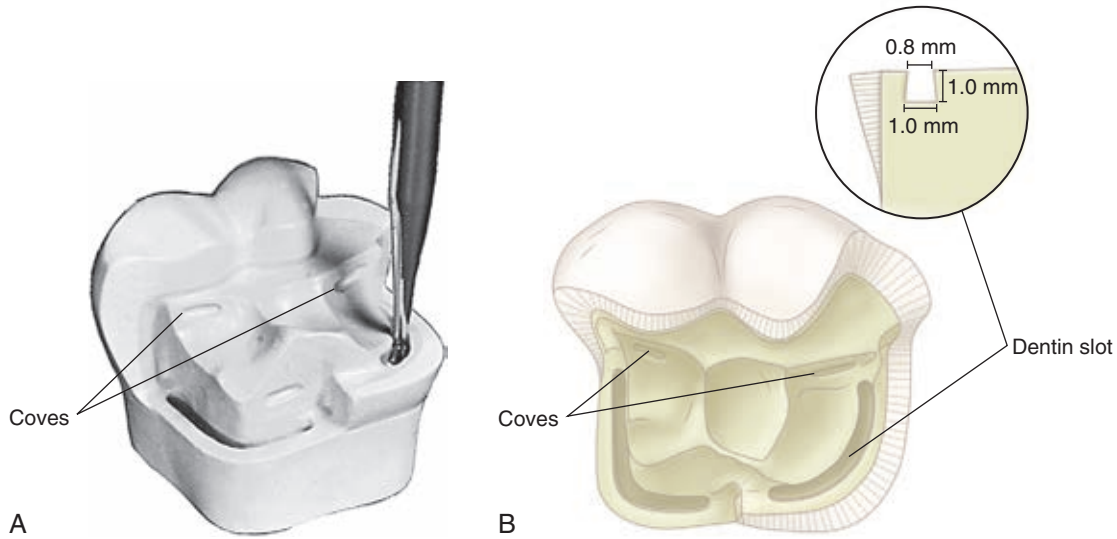


Fig. 16-5 Slots. **A** and **B**, With a No. 330 bur, dentinal slots are prepared approximately 1 mm deep and 0.5 to 1 mm inside the dentinoenamel junction (DEJ).



Fig. 16-6 Coves prepared in dentin with No. $\frac{1}{4}$ bur, where appropriate.



Fig. 16-8 Vertical locks prepared in dentin with a No. $\frac{1}{4}$ round or No. 169L bur, where appropriate.



Fig. 16-7 A retention lock is a prepared groove whose length is in a vertical plane and which is in dentin.

forms needed for an indirect restoration. The retention of the foundation material should not be compromised by tooth reduction during the final preparation for the indirect restoration. The foundation also should provide the resistance form against forces that otherwise might fracture the remaining tooth structure.

In contrast to a conventional amalgam restoration, an amalgam foundation might not depend primarily on the remaining coronal tooth structure for support. Instead, it may rely mainly on secondary preparation retention features (pins, slots, coves, and proximal retention locks). A temporary or caries-control restoration may serve as a foundation, but only if the retention and resistance forms of the restoration are appropriate.

A temporary or caries-control restoration is used to restore a tooth when definitive treatment is uncertain or when several teeth require immediate attention for control of caries. It also can be used when a tooth's prognosis is questionable. A temporary or control restoration might depend only on the remaining coronal tooth structure for support, however, using few auxiliary retention features. When preparing a tooth for either a foundation or a temporary restoration, remaining unsupported enamel may be left except at the gingival aspect to aid in forming a matrix for amalgam condensation. In each case, the remaining unsupported enamel is removed when the

indirect restoration is placed. Occasionally, when providing a temporary or control restoration, sufficient retention and resistance forms are included in the preparation to meet the requirements of a foundation.

As a rule, foundations are placed in anticipation of a full-coverage indirect restoration. Not all teeth with foundations, however, need to be immediately restored with full-coverage crowns. For example, amalgam can be used as a definitive partial-coverage restoration if only minimal coronal damage has occurred in endodontically treated teeth.¹⁹ The greatest influence on fracture resistance is the amount of remaining tooth structure.²⁰

The restorative materials used for foundations include amalgam, composite, and occasionally resin-modified glass ionomers (RMGIs). Of the direct filling materials, amalgam may be preferred by some clinicians because it is easy to use and is strong. Threaded pins and slots can be used for retention in vital teeth. Prefabricated posts and cast post and cores also may be used to provide additional retention for the foundation material in endodontically treated teeth receiving foundations. The use of prefabricated posts and cast post and cores is limited to endodontically treated teeth and is used generally on anterior teeth or single-canal premolars with little or no remaining coronal tooth structure. On endodontically treated molars, the pulp chamber or canals typically provide retention for the foundation, and it is not necessary to use any form of intra-radicular retention.

Tooth Preparation

Tooth Preparation for Pin-Retained Amalgam Restorations

INITIAL TOOTH PREPARATION

The general concept of the initial tooth preparation is presented in Chapter 14, and it applies to the pin-retained complex amalgam restorations described here. When caries is extensive, reduction of one or more of the cusps for capping may be indicated. For cusps prone to fracture, capping of cusps reduces the risk of cusp fracture and extends the life of the restoration.^{21,22} Complex amalgam restorations with one or more capped cusps have documented longevity of 72% after 15 years and show no differences in the survival rate of cusp-covered and non-cusp-covered amalgam restorations, whether or not pins were used.^{4,23}

When the facial or lingual extension exceeds two-thirds the distance from a primary groove toward the cusp tip (or when the faciolingual extension of the occlusal preparation exceeds two-thirds the distance between the facial and lingual cusp tips), reduction of the cusp for amalgam usually is required for the development of adequate resistance form (Fig. 16-9, A). Reduction should be accomplished during the initial tooth preparation because it improves access and visibility for subsequent steps. If the cusp to be capped is located at the correct occlusal height before preparation, depth cuts should be made on the remaining occlusal surface of each cusp to be capped, using the side of a carbide fissure bur or a suitable diamond instrument (see Fig. 16-9, B). The depth cuts should be a minimum of 2 mm for functional cusps and 1.5 mm for non-functional cusps.²⁴ To correct an occlusal relationship, if the unreduced cusp height is located at less than the correct occlusal height, the depth cuts may be less. Likewise, if the

unreduced cusp height is located at more than the correct occlusal height, the depth cuts may be deeper. The goal is to ensure that the final restoration has restored cusps with a minimal thickness of 2 mm of amalgam for functional cusps and 1.5 mm of amalgam for nonfunctional cusps (see Fig. 16-9, C), while developing an appropriate occlusal relationship.

Using the depth cuts as a guide, the reduction is completed to provide for a uniform reduction of tooth structure (see Fig. 16-9, D). The occlusal contour of the reduced cusp should be similar to the normal contour of the unreduced cusp. Any sharp internal corners of the tooth preparation formed at the junction of prepared surfaces should be rounded to reduce stress concentration in the amalgam and improve its resistance to fracture from occlusal forces (see Fig. 16-9, E). When reducing only one of two facial or lingual cusps, the cusp reduction should be extended just past the facial or lingual groove, creating a vertical wall against the adjacent unreduced cusp. Figure 16-9, F and G, illustrates a final restoration. The procedure for capping the distolingual cusp of a maxillary first molar is illustrated in Figure 14-68. Extending the facial or lingual wall of a proximal box to include the entire cusp is indicated only when necessary to include carious or unsupported tooth structure or existing restorative material. The typical extension of the proximal box for restoring an entire cusp is illustrated in Figures 14-69 and 14-70, B.

When possible, opposing vertical walls should be formed to converge occlusally, to enhance the primary retention form. Also, a facial or lingual groove can be extended arbitrarily to increase the retention form. The pulpal and gingival walls should be relatively flat and perpendicular to the long axis of the tooth.

FINAL TOOTH PREPARATION

After the initial tooth preparation of a severely involved tooth, removal of any remaining infected carious dentin or remaining old restorative material is usually necessary and is accomplished as described previously. An RMGI base can be applied, if needed; if used, a liner or base should not extend closer than 1 mm to a slot or a pin.

Pins placed into prepared pinholes (also referred to as *pin channels*) provide auxiliary resistance and retention forms. Coves and retention locks should be prepared when possible (Figs. 16-10, and 16-11). Coves are prepared in a horizontal plane, and locks are prepared in a vertical plane. These locks and coves should be prepared before preparing the pinholes and inserting the pins. Cusp reduction significantly diminishes the retention form by decreasing the height of the vertical walls. When additional retention is indicated, pins may be inserted in carefully positioned pinholes, thus increasing retention. Slots may be prepared along the gingival floor, axial to the dentinoenamel junction (DEJ) instead of, or in addition to, pinholes (see Fig. 16-10, B). Slot preparation is discussed later in this chapter.

TYPES OF PINS

The most frequently used pin type is the self-threading pin. Friction-locked and cemented pins, although still available, are rarely used (Fig. 16-12). The pin-retained amalgam restoration using self-threading pins originally was described by Going in 1966.²⁵ The diameter of the prepared pinhole is

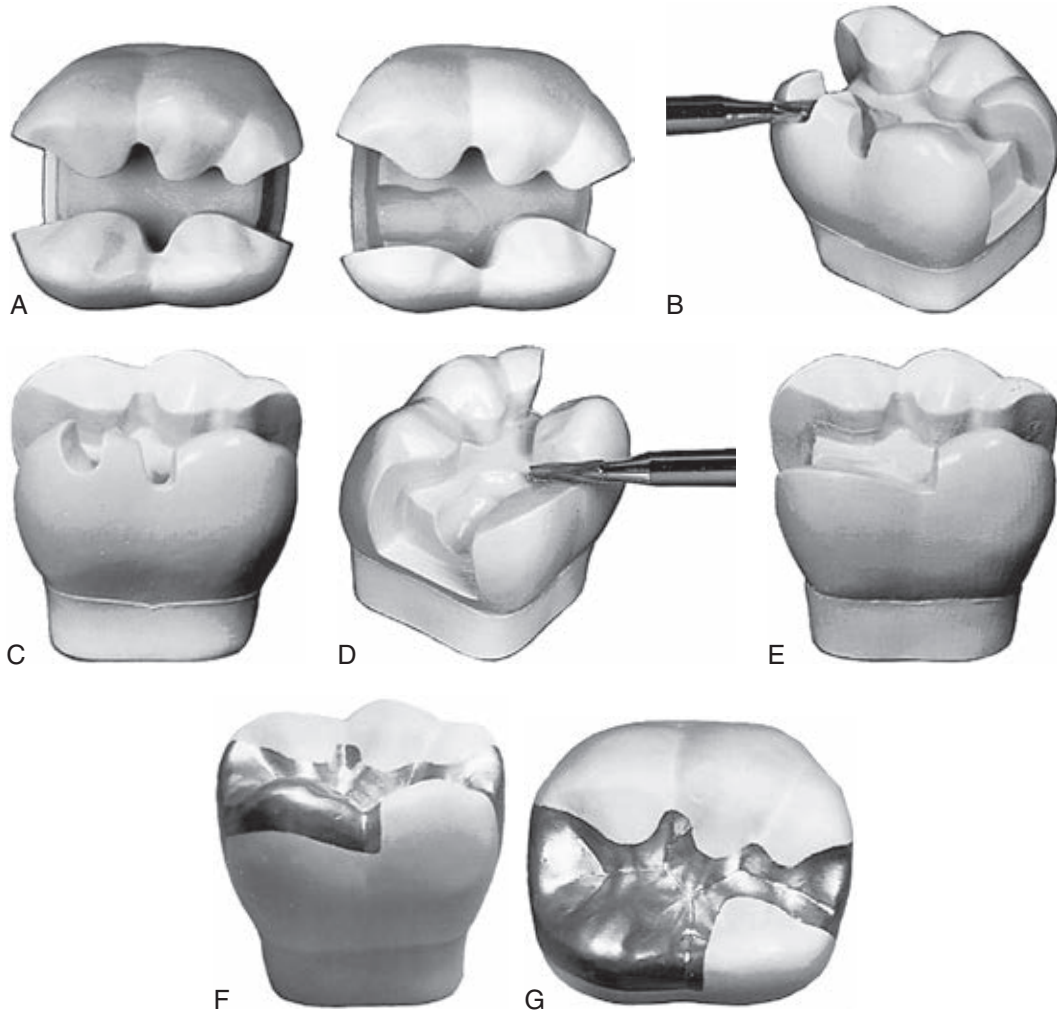


Fig. 16-9 Capping the cusp with amalgam. **A**, Comparison of the mesial aspects of normally extended (*left*) and extensive (*right*) mesio-occluso-distal tooth preparation. The resistance form of the mesiolingual cusp of extensive preparation is compromised and indicated for capping with amalgam. **B**, Preparing depth cuts. **C**, Depth cuts prepared. **D**, Reducing the cusp. **E**, Cusp reduced. **F** and **G**, Final restoration.

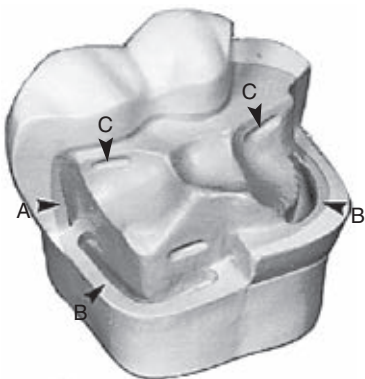


Fig. 16-10 Lock (A), slots (B), and coves (C).

0.0015 to 0.004 inch smaller than the diameter of the pin (Table 16-1). The threads engage dentin as the pin is inserted, thus retaining it. The elasticity (resiliency) of dentin permits insertion of a threaded pin into a hole of smaller diameter.²⁶ Although the threads of self-threading pins do not engage

dentin for their entire width, self-threading pins are the most retentive of the three types of pins (Fig. 16-13), being three to six times more retentive than cemented pins.²⁷⁻²⁹

Vertical and horizontal stresses can be generated in dentin when a self-threading pin is inserted. Craze lines in dentin may be related to the size of the pin. The insertion of 0.031-inch self-threading pins produces more dentinal craze lines than does the insertion of 0.021-inch self-threading pins.³⁰ Some evidence suggests, however, that self-threading pins may not cause dentinal crazing.²⁶ Pulpal stress is maximal when the self-threading pin is inserted perpendicular to the pulp.³¹ The depth of the pinhole varies from 1.3 to 2 mm, depending on the diameter of the pin used.³² A general guideline for pinhole depth is 2 mm.

Several styles of self-threading pins are available. The Thread Mate System (TMS) (Coltène/Whaledent Inc., Mahwah, NJ) is the most widely used self-threading pin because of its (1) versatility, (2) wide range of pin sizes, (3) color-coding system, and (4) greater retentiveness.^{33,34} TMS pins are available in gold-plated stainless steel or in titanium. Other titanium alloy pins (Max system, Coltène/Whaledent Inc.) are available.

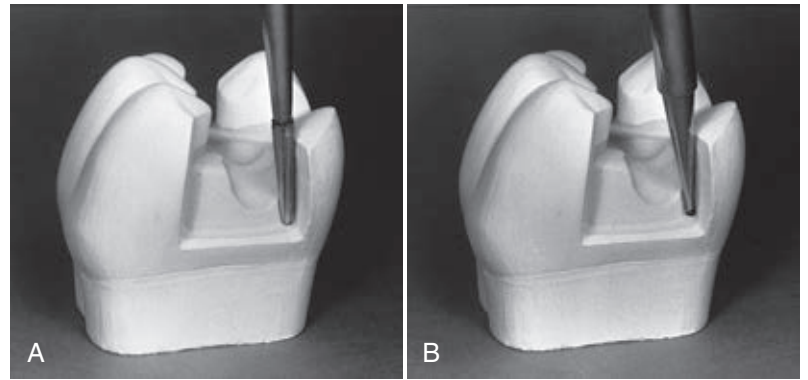


Fig. 16-11 Placement of retention locks. **A**, Position of No. 169L bur to prepare the retention lock. **B**, Lock prepared with No. $\frac{1}{4}$ bur.

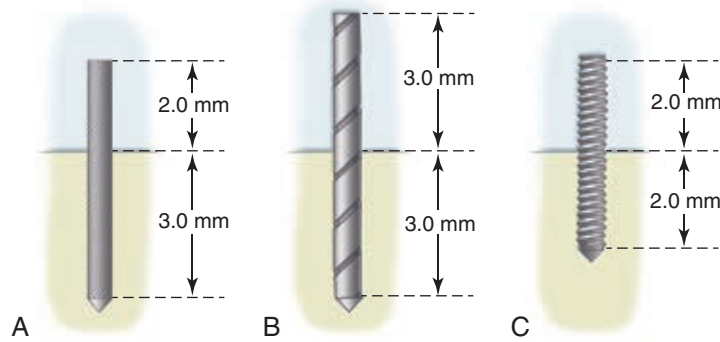


Fig. 16-12 Three types of pins. **A**, Cemented. **B**, Friction-locked. **C**, Self-threading.

Table 16-1 The Thread Mate System (TMS) Pins

Name	Illustration (not to scale)	Color Code	Pin Diameter (inches/mm)*	Drill Diameter (inches/mm)*	Total Pin Length (mm)	Pin Length Extending from Dentin (mm)
Regular (standard)		Gold	0.031/0.78	0.027/0.68	7.1	5.1
Regular (self-shearing)		Gold	0.031/0.78	0.027/0.68	8.2	3.2
Regular (two-in-one)		Gold	0.031/0.78	0.027/0.68	9.5	2.8
Minim (standard)		Silver	0.024/0.61	0.021/0.53	6.7	4.7
Minim (two-in-one)		Silver	0.024/0.61	0.021/0.53	9.5	2.8
Minikin (self-shearing)		Red	0.019/0.48	0.017/0.43	7.1	1.5
Minuta (self-shearing)		Pink	0.015/0.38	0.0135/0.34	6.2	1

*1 mm = 0.03937 inch.

FACTORS AFFECTING RETENTION OF THE PIN IN DENTIN AND AMALGAM

Type

With regard to the retentiveness of the pin in dentin, the self-threading pin is the most retentive, the friction-locked pin is intermediate, and the cemented pin is the least retentive.²⁷

Surface Characteristics

The number and depth of the elevations (serrations or threads) on the pin influence the retention of the pin in the amalgam restoration. The shape of the self-threading pin gives it the greatest retention value.

Orientation, Number, and Diameter

Placing pins in a non-parallel manner increases their retention. Bending pins to improve their retention in amalgam is not advisable because the bends may interfere with adequate condensation of amalgam around the pin and decrease amalgam retention. Bending also may weaken the pin and risk fracturing dentin. Pins should be bent only to provide for an adequate amount of amalgam (approximately 1 mm) between the pin and the external surface of the finished restoration (on the tip of the pin and on its lateral surface). Only the specific bending tool should be used to bend a pin, not other hand instruments.

In general, increasing the number of pins increases their retention in dentin and amalgam. The benefits of increasing the number of pins must be compared with the potential problems. As the number of pins increases, (1) the crazing of dentin and the potential for fracture increase, (2) the amount of available dentin between the pins decreases, and (3) the strength of the amalgam restoration decreases.^{35,36} Also, as the diameter of the pin increases, retention in dentin and amalgam generally increases. As the number, depth, and diameter of pins increase, the danger of perforating into the pulp or the external tooth surface increases. Numerous long pins also can

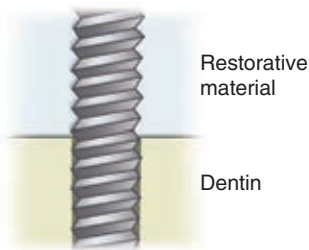


Fig. 16-13 The complete width of the threads of self-threading pins does not engage dentin.

severely compromise condensation of amalgam and amalgam's adaptation to the pins. A pin technique that permits optimal retention with minimal danger to the remaining tooth structure should be used.³⁷

Extension into Dentin and Amalgam

Self-threading pin extension into dentin and amalgam should be approximately 1.5 to 2 mm to preserve the strength of dentin and amalgam.²⁷ Extension greater than this is unnecessary for pin retention and is contraindicated.

PIN PLACEMENT FACTORS AND TECHNIQUES**Pin Size**

Four sizes of TMS pins are available (Fig. 16-14), each with a corresponding color-coded drill (see Table 16-1). Familiarity with drill sizes and their corresponding colors is necessary to ensure that a proper-sized pinhole is prepared for the desired pin. It is difficult to specify a particular size of pin that is always appropriate for a particular tooth. Two determining factors for selecting the appropriate-sized pin are the amount of dentin available to receive the pin safely and the amount of retention desired. In the TMS system, the pins of choice for severely involved posterior teeth are the Minikin (0.019 inch [0.48 mm]) and, occasionally, the Minim (0.024 inch [0.61 mm]). The Minikin pins usually are selected to reduce the risk of dentin crazing, pulpal penetration, and potential perforation. The Minim pins usually are used as a backup in case the pinhole for the Minikin is over-prepared or the pin threads strip dentin during placement and the Minikin pin lacks retention. Larger-diameter pins have the greatest retention.³⁸ The Minuta (0.015 inch [0.38 mm]) pin is approximately half as retentive as the Minim and one-third as retentive as the Minikin.^{33,34} It is usually too small to provide adequate retention in posterior teeth. The Regular (0.031 inch [0.78 mm]), or largest-diameter, pin is rarely used because a significant amount of stress and crazing, or cracking, in the

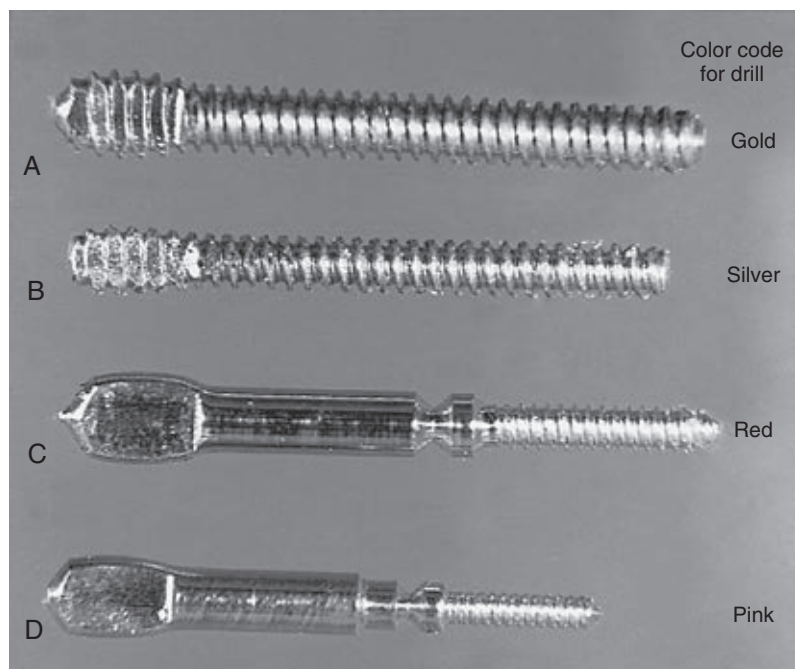


Fig. 16-14 Four sizes of the Thread Mate System (TMS) pins. **A**, Regular (0.031 inch [0.78 mm]). **B**, Minim (0.024 inch [0.61 mm]). **C**, Minikin (0.019 inch [0.48 mm]). **D**, Minuta (0.015 inch [0.38 mm]).

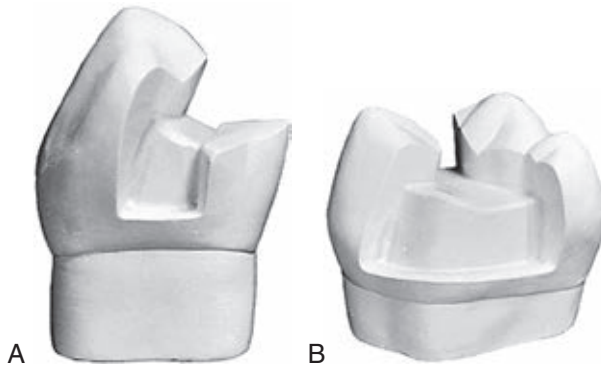


Fig. 16-15 Examples illustrating reduction of cusps without need for pins. **A**, Mandibular first premolar with lingual cusp reduced for capping. **B**, Maxillary second molar prepared for restoration of mesial and distal surfaces and distofacial cusp.

tooth (dentin and enamel) may be created during its insertion.^{30,39} Of the four types of pins, the Regular pin is associated with the highest incidence of dentinal cracking communicating with the pulp chamber.¹⁰

Number of Pins

Several factors must be considered when deciding how many pins are required: (1) the amount of missing tooth structure, (2) the amount of dentin available to receive the pins safely, (3) the amount of retention required, and (4) the size of the pins. As a rule, one pin per missing axial line angle should be used. Certain factors may cause the operator to alter this rule. The fewest pins possible should be used to achieve the desired retention for a given restoration. If only 2 to 3 mm of the occlusogingival height of a cusp has been removed, no pin is required because enough tooth structure remains to use conventional retention features (Fig. 16-15; see also Fig. 16-9). Although the retention of the restoration increases as the number of pins increases, an excessive number of pins can fracture the tooth and significantly weaken the amalgam restoration.

Location

Several factors aid in determining the pinhole locations: (1) knowledge of normal pulp anatomy and external tooth contours, (2) a current radiograph of the tooth, (3) a periodontal probe, and (4) the patient's age. Although the radiograph is only a two-dimensional image of the tooth, it can give an indication of the position of the pulp chamber and the contour of the mesial and distal surfaces of the tooth. Consideration also must be given to the placement of pins in areas where the greatest bulk of amalgam would occur to minimize the weakening effect of the pins on the tooth structure.⁴⁰ Areas of occlusal contacts on the restoration must be anticipated because a pin oriented vertically and positioned directly below an occlusal load weakens amalgam significantly.⁴¹ Occlusal clearance should be sufficient to provide 2 mm of amalgam over the pin.^{42,43}

Several attempts have been made to identify the ideal location of the pinhole.^{9,14,30,44} The following principles of pin placement are recommended. In the cervical third of molars and premolars (where most pins are located), pinholes should be located near the line angles of the tooth except as described

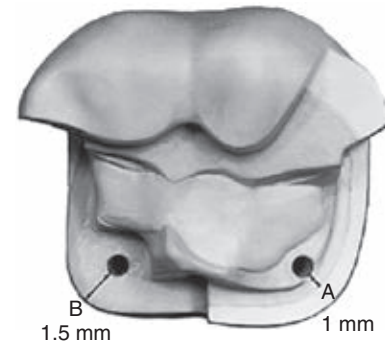


Fig. 16-16 Pinhole position. **A**, Position relative to the dentinoenamel junction (DEJ). **B**, Position relative to external tooth surface.

later.^{37,45} The pinhole should be positioned no closer than 0.5 to 1 mm to the DEJ or no closer than 1 to 1.5 mm to the external surface of the tooth, whichever distance is greater (Fig. 16-16). Before the final decision is made about the location of the pinhole, the operator should probe the gingival crevice carefully to determine if any abnormal contours exist that would predispose the tooth to an external perforation. The pinhole should be parallel to the adjacent external surface of the tooth.

The position of a pinhole must not result in the pin being so close to a vertical wall of tooth structure that condensation of amalgam against the pin or wall is jeopardized (Fig. 16-17, **A**). It may be necessary to first prepare a recess in the vertical wall with the No. 245 bur to permit proper pinhole preparation and to provide a minimum of 0.5 mm clearance around the circumference of the pin for adequate condensation of amalgam (see Fig. 16-17, **B** and **C**).⁴⁶ If necessary, after a pin is inappropriately placed, the operator should provide clearance around the pin to provide sufficient space for the smallest condenser nib to ensure that amalgam can be condensed adequately around the pin. A No. 169L bur can be used, taking care not to damage or weaken the pin. Pinholes should be prepared on a flat surface that is perpendicular to the proposed direction of the pinhole. Otherwise, the drill tip may slip or “crawl,” and a depth-limiting drill (discussed later) cannot prepare the hole as deeply as intended (Fig. 16-18).

Whenever three or more pinholes are placed, they should be located at different vertical levels on the tooth, if possible; this reduces stresses resulting from pin placement in the same horizontal plane of the tooth. Spacing between pins, or the inter-pin distance, must be considered when two or more pinholes are prepared. The optimal inter-pin distance depends on the size of pin to be used. The minimal inter-pin distance is 3 mm for the Minikin pin and 5 mm for the Minim pin.³⁵ Maximal inter-pin distance results in lower levels of stress in dentin.⁴⁷

Several posterior teeth have anatomic features that may preclude safe pinhole placement. Fluted and furcal areas should be avoided.⁴⁶ Specifically, external perforation may result from pinhole placement (1) over the prominent mesial concavity of the maxillary first premolar; (2) at the mid-lingual and mid-facial bifurcations of the mandibular first and second molars; and (3) at the mid-facial, mid-mesial, and mid-distal furcations of the maxillary first and second molars. Pulpal penetration may result from pin placement at the mesiofacial corner of the maxillary first molar and the mandibular first molar.

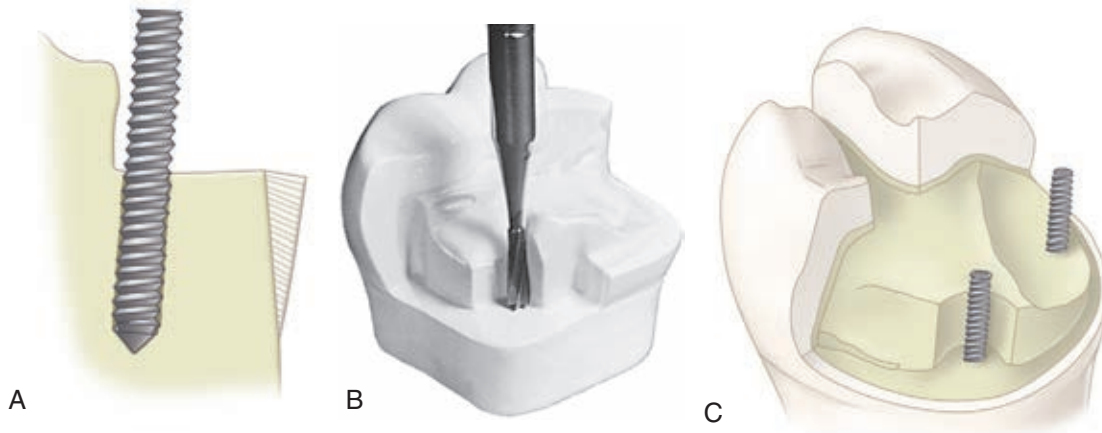


Fig. 16-17 A, Pin placed too close to the vertical wall such that adequate condensation of amalgam is jeopardized. B and C, Recessed area prepared in the vertical wall of the mandibular molar with a No. 245 bur to provide adequate space for amalgam condensation around the pin.

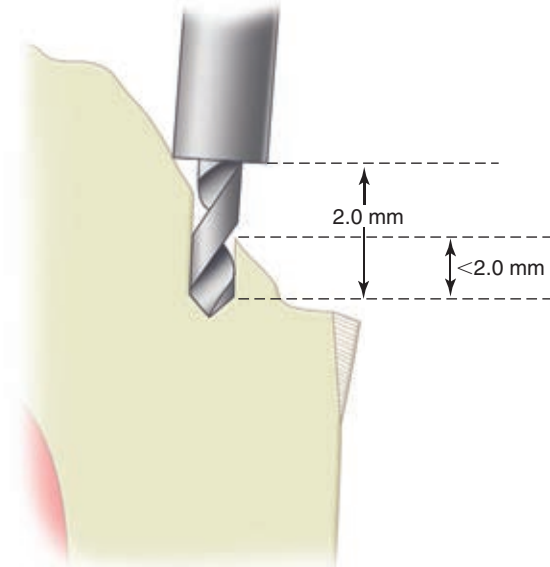


Fig. 16-18 Use of a depth-limiting drill to prepare a pinhole in the surface that is not perpendicular to the direction of the pinhole results in a pinhole of inadequate depth.

When possible, the location of pinholes on the distal surface of mandibular molars and lingual surface of maxillary molars should be avoided. Obtaining the proper direction for preparing a pinhole in these locations is difficult because of the abrupt flaring of the roots just apical to the cemento-enamel junction (CEJ) (Fig. 16-19). If the pinhole is placed parallel to the external surface of the tooth crown in these areas, penetration into the pulp is likely.⁴⁵

When the pinhole locations have been determined, a No. ¼ round bur is first used to prepare a pilot hole (dimple) approximately one half the diameter of the bur at each location (Fig. 16-20). The purpose of this hole is to permit more accurate placement of the twist drill and to prevent the drill from “crawling” when it has begun to rotate.

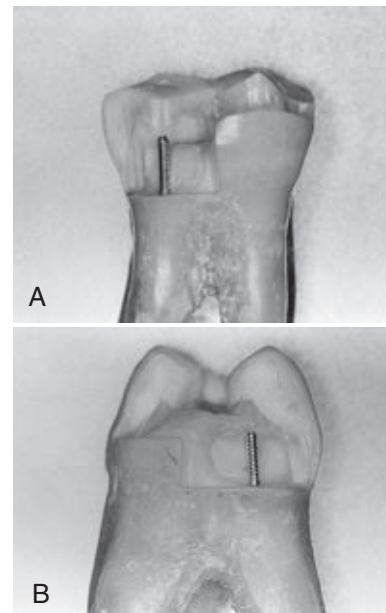


Fig. 16-19 Distal flaring of the mandibular molar (A) and palatal root flaring of the maxillary molar (B). Root angulation should be considered before pinhole placement.

Pinhole Preparation

The Kodex drill (a twist drill) should be used for preparing pinholes (Fig. 16-21). The aluminum shank of this drill, which acts as a heat absorber, is color coded so that it can be matched easily with the appropriate pin size (see Tables 16-1 and 16-2). The drill shanks for the Minuta and Minikin pins are tapered to provide a built-in “wobble” when placed in a latch-type contra-angle handpiece. This wobble allows the drill to be “free-floating” and to align itself as the pinhole is prepared to minimize dentinal crazing or the breakage of small drills.

Because the optimal depth of the pinhole into the dentin is 2 mm (only 1.5 mm for the Minikin pin), a depth-limiting



Fig. 16-20 Pilot hole (dimple) prepared with a No. $\frac{1}{4}$ bur.

drill should be used to prepare the hole (see Fig. 16-21). This type of drill can prepare the pinhole to the correct depth only when used on a flat surface that is perpendicular to the drill (see Fig. 16-18). When the location for starting a pinhole is not perpendicular to the desired pinhole direction, the location area should be flattened, or the standard twist drill should be used (see Fig. 16-21). The standard twist drill has blades that are 4 to 5 mm in length, which would allow preparation of a pinhole with an effective depth. Creation of a flat area and use of the depth-limiting drill is recommended.

With the drill in the latch-type contra-angle handpiece, the drill is placed in the gingival crevice beside the location for the pinhole and positioned such that it lies flat against the external surface of the tooth; without changing the angulation obtained from the crevice position, the handpiece is moved occlusally and the drill placed in the previously prepared pilot hole (Fig. 16-22, A). The drill is then viewed from a 90-degree angle to the previous viewing position to ascertain that the drill also is angled correctly in this plane (see Fig. 16-22, B). Incorrect angulation of the drill may result in pulpal exposure or external perforation. If the proximity of an adjacent tooth interferes

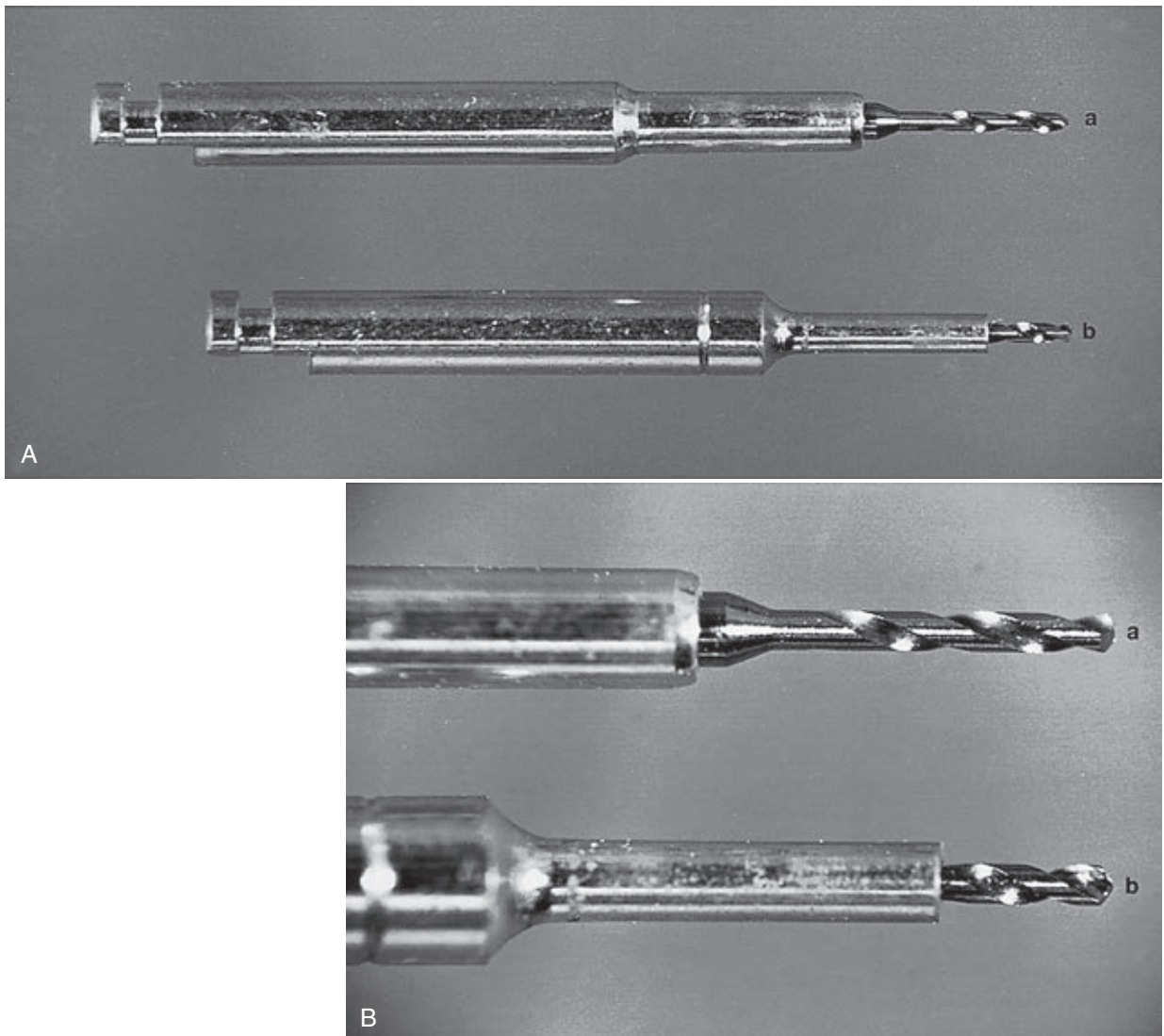


Fig. 16-21 A, Two types of Kodex twist drills: standard (a) and depth-limiting (b). B, Drills enlarged: standard (a) and depth-limiting (b).

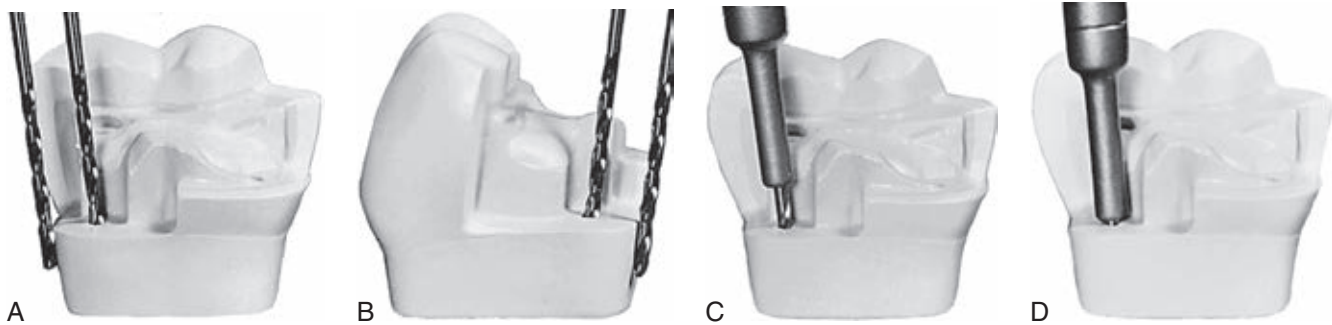


Fig. 16-22 Determining the angulation for the twist drill. **A**, Drill placed in the gingival crevice, positioned flat against the tooth, and moved occlusally into position without changing the angulation obtained. **B**, A repeated while viewing the drill from position 90 degrees left or right of that viewed in A. **C** and **D**, With twist drill at correct angulation, the pinhole is prepared in one or two thrusts until the depth-limiting portion of drill is reached.

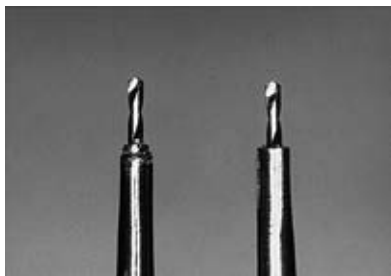


Fig. 16-23 Minikin self-limiting drill with worn shank shoulder (left) compared with a new drill with an unworn shoulder (right).

with placement of the drill into the gingival crevice, a flat, thin-bladed hand instrument is placed into the crevice and against the external surface of the tooth to indicate the proper angulation for the drill.⁴⁸ With the drill tip in its proper position and with the handpiece rotating at very low speed (300–500 revolutions per minute [rpm]), pressure is applied to the drill. The pinhole is prepared, in one or two movements, until the depth-limiting portion of the drill is reached. The drill is immediately removed from the pinhole (see Fig. 16-22, C and D). Using more than one or two movements, tilting the handpiece during the drilling procedure, or allowing the drill to rotate more than briefly at the bottom of the pinhole will result in a pinhole that is too large. The drill should never stop rotating (from insertion to removal from the pinhole) to prevent the drill from binding and breaking while in the pinhole.

Dull drills used to prepare pinholes can cause increased frictional heat and cracks in the dentin. Standlee et al. showed that a twist drill becomes too dull for use after cutting 20 pinholes or less, and the signal for discarding the drill is the need for increased pressure on the handpiece.⁴⁹ Using a drill when its self-limiting shank shoulder has become rounded is contraindicated (Fig. 16-23). A worn and rounded shoulder may not properly limit pinhole depth and may permit pins to be placed too deeply.

Certain clinical locations require extra care in determining pinhole angulation. The distal aspect of mandibular molars and the lingual aspect of maxillary molars have been mentioned previously as areas of potential problems because of the abrupt flaring of the roots just apical to the CEJ (see Fig. 16-19). Mandibular posterior teeth (with their lingual crown tilt), teeth that are rotated in the arch, and teeth that are

abnormally tilted in the arch warrant careful attention before and during pinhole placement. For mandibular second molars that are severely tilted mesially, care must be exercised to orient the drill properly to prevent external perforation on the mesial surface and pulpal penetration on the distal surface (Fig. 16-24). Because of limited interarch space, it is sometimes difficult to orient the twist drill correctly when placing pinholes at the distofacial or distolingual line angles of the mandibular second and third molars (Fig. 16-25).

Pin Design

For each of the four sizes of TMS pins, several designs are available: standard, self-shearing, two-in-one, Link Series, and Link Plus (Fig. 16-26).

The pin is free floating in the plastic sleeve, and this allows it to align itself as it is threaded into the pinhole (Fig. 16-27). When the pin reaches the bottom of the hole, the top portion of the pin shears off, leaving a length of pin extending from dentin. The plastic sleeve is then discarded. The Minuta, Minikin, Minim, and Regular pins are available in the Link Series. The Link Series pins are recommended because of their versatility, self-aligning ability, and retentiveness.³³

The Link Plus pins are self-shearing and are available as single and two-in-one pins contained in color-coded plastic sleeves (Fig. 16-28). This design has a sharper thread, a shoulder stop at 2 mm, and a tapered tip to fit the bottom of the pinhole more readily as prepared by the twist drill. It also provides a 2.7-mm length of pin to extend out of dentin, which usually needs to be shortened. Theoretically, and as suggested by Standlee et al, these innovations should reduce the stress created in the surrounding dentin as the pin is inserted and reduce the apical stress at the bottom of the pinhole.⁵⁰ Kelsey et al showed for the two-in-one Link Plus pin that the first and second pins seat completely into the pinhole before shearing.⁵¹ The Link Series pin is contained in a color-coded plastic sleeve that fits a latch-type contra-angle handpiece or the specially designed plastic hand wrench (Fig. 16-29, D).

The self-shearing pin has a total length that varies according to the diameter of the pin (see Table 16-1). It also consists of a flattened head to engage the hand wrench or the appropriate handpiece chuck for threading into the pinhole. When the pin approaches the bottom of the pinhole, the head of the pin shears off, leaving a length of pin extending from dentin.

The two-in-one pin is actually two pins in one, with each one being shorter than the standard pin. The two-in-one pin

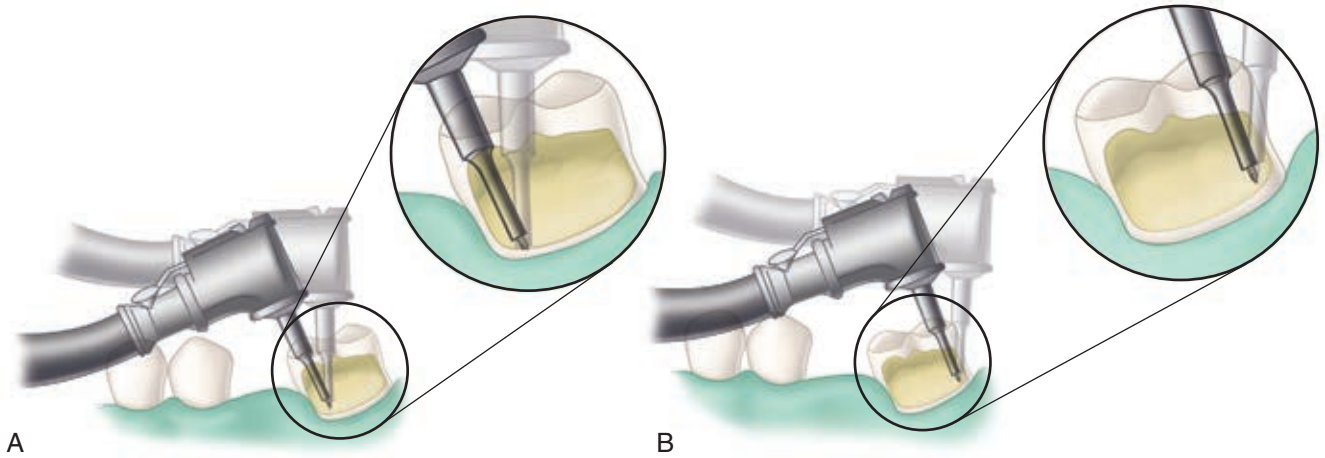


Fig. 16-24 Care must be exercised when preparing pinholes in mesially tilted molars to prevent external perforation on mesial surface (A) and pulpal penetration on the distal surface (B). Broken line indicates incorrect angulation of the twist drill.

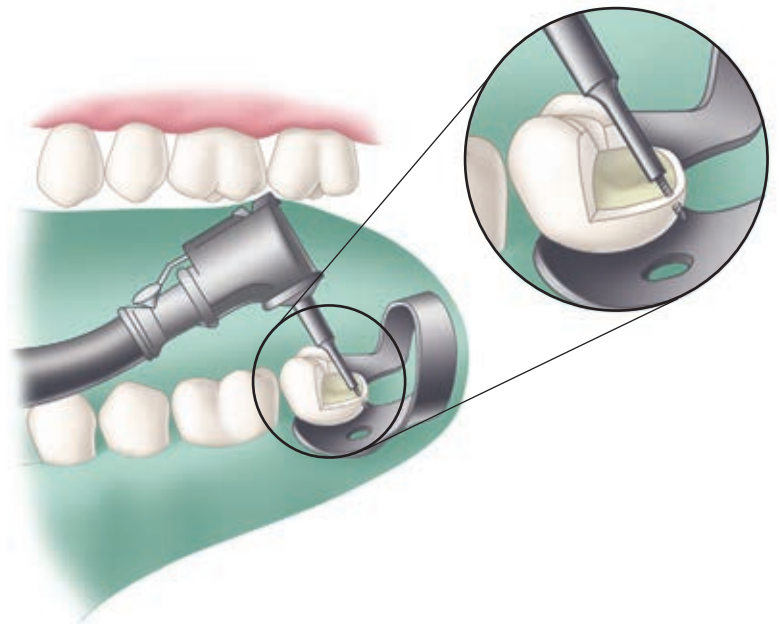


Fig. 16-25 When placing pinholes in molars and interarch space is limited care must be exercised to prevent external perforation on distal surface.

is approximately 9.5 mm in length and has a flattened head to aid in its insertion. When the pin reaches the bottom of the pinhole, it shears approximately in half, leaving a length of pin extending from dentin with the other half remaining in the hand wrench or the handpiece chuck. This second pin may be positioned in another pinhole and threaded to place in the same manner as the standard pin. The designs available with each size of pin are shown in [Table 16-1](#) and [Table 16-2](#).

Selection of a particular pin design is influenced by the size of the pin being used, the amount of interarch space available, and operator preference. The Minuta and Minikin pins are available only in the self-shearing and Link (also self-shearing) designs. With minimal interarch space, the two-in-one design is undesirable because of its length. The two-in-one pin and the self-shearing pin sometimes may fail to reach the bottom of the pinhole, whereas 93% of Link Series and Link Plus two-in-one pins extended to the optimal depth of 2 mm.⁵²⁻⁵⁵

Pin Insertion

Two instruments for the insertion of threaded pins are available: (1) conventional latch-type contra-angle handpieces ([Figs. 16-30 and 16-31](#)) and (2) TMS hand wrenches (see [Fig. 16-29](#)). The results of studies are conflicting as to which method of pin insertion produces the best results. The latch-type handpiece is recommended for the insertion of the Link Series and the Link Plus pins. The hand wrench is recommended for the insertion of standard pins.

When using the latch-type handpiece, a Link Series or a Link Plus pin is inserted into the handpiece and positioned over the pinhole. The handpiece is activated at low speed until the plastic sleeve shears from the pin. The pin sleeve is discarded. For low-speed handpieces with a low gear, the low gear should be used. Using the low gear increases the torque and increases the tactile sense of the operator. It also reduces the risk of stripping the threads in dentin when the pin is in place.

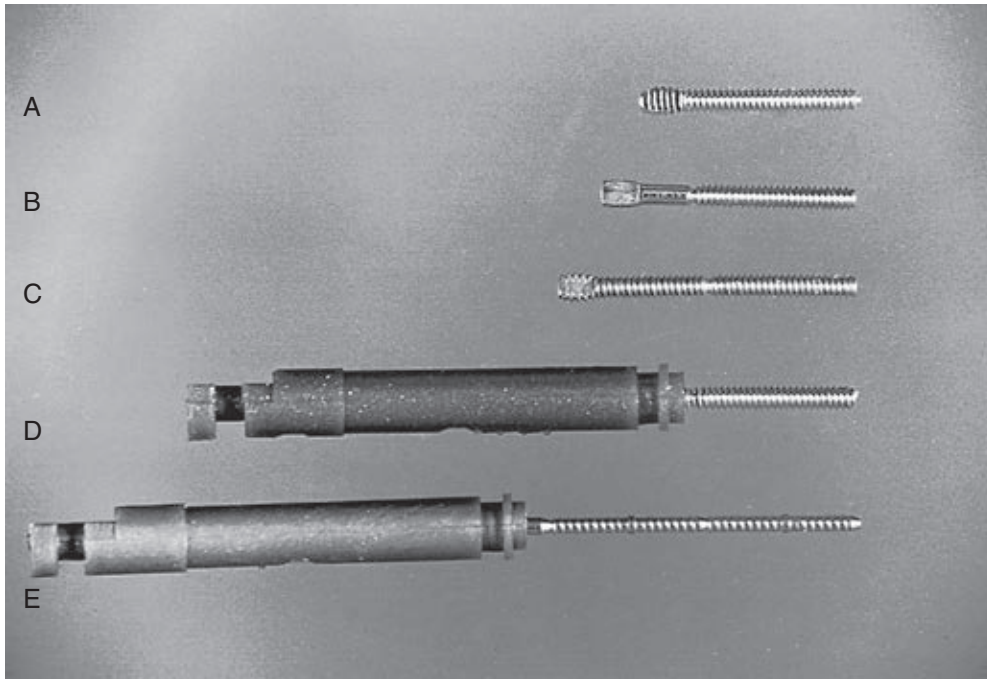


Fig. 16-26 Five designs of the Thread Mate System (TMS) pins. **A**, Standard. **B**, Self-shearing. **C**, Two-in-one. **D**, Link Series. **E**, Link Plus.



Fig. 16-27 Cross-sectional view of Link Series pin.

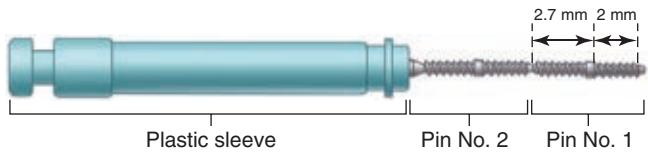


Fig. 16-28 Link Plus pin.

A standard design pin is placed in the appropriate wrench (Fig. 16-32, *A*) and slowly threaded clockwise into the pinhole until a definite resistance is felt when the pin reaches the bottom of the hole (see Fig. 16-32, *B*). The pin should be rotated one-quarter to one half-turn counterclockwise to reduce the dentinal stress created by the end of the pin that is pressing on dentin.⁵⁶ The hand wrench should be removed from the pin carefully. If the hand wrench is used without rubber dam isolation, a gauze throat shield must be in place, and a strand of dental tape approximately 12 to 15 inches (30–38 cm) in length should be tied securely to the end of the wrench (Fig. 16-33) to prevent accidental swallowing or aspiration by the patient.

After the pins are placed, their lengths are evaluated (see Fig. 16-32, *C*). Any length of pin greater than 2 mm should be removed. A sharp No. $\frac{1}{4}$, No. $\frac{1}{2}$, or No. 169L bur, at high speed and oriented perpendicular to the pin, is used to remove the excess length (Fig. 16-34, *A*). If oriented otherwise, the rotation of the bur may loosen the pin by rotating it

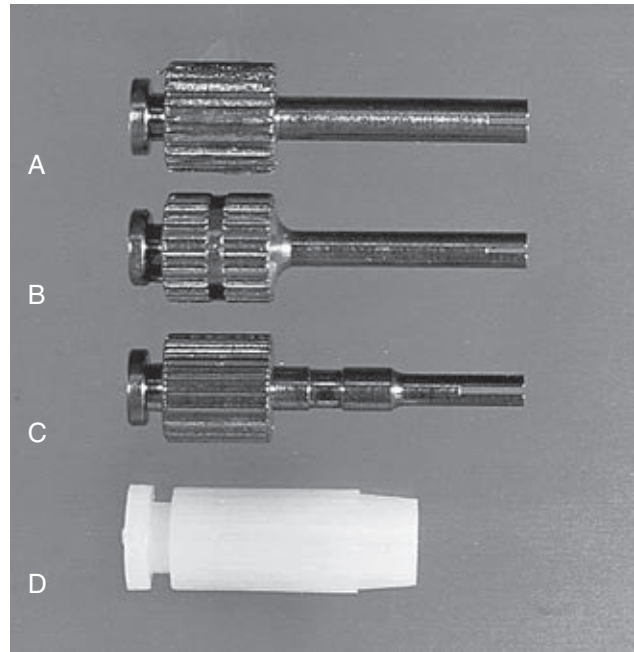


Fig. 16-29 Hand wrenches for the Thread Mate System (TMS) pins. **A**, Regular and Minikin. **B**, Minim. **C**, Minuta. **D**, Link Series and Link Plus.

counterclockwise. During removal of excess pin length, the assistant may apply a steady stream of air to the pin and have the evacuator tip positioned to remove the pin segment. Also, during removal, the pin may be stabilized with a small hemostat or cotton pliers. After placement, the pin should be tight, immobile, and not easily withdrawn.

Using a mirror, the preparation is viewed from all directions (particularly from the occlusal direction) to determine if any

Table 16-2 The Thread Mate System (TMS) Link Series and Link Plus Pins

Name	Illustration (not to scale)	Color Code	Pin Diameter (inches/mm)*	Drill Diameter (inches/mm)*	Pin Length Extending from Sleeve (mm)	Pin Length Extending from Dentin (mm)
LINK SERIES						
Regular		Gold	0.031/0.78	0.027/0.68	5.5	3.2 (single shear)
Regular		Gold	0.031/0.78	0.027/0.68	7.8	2.6 (double shear)
Minim		Silver	0.024/0.61	0.021/0.53	5.4	3.2 (single shear)
Minim		Silver	0.024/0.61	0.021/0.53	7.6	2.6 (double shear)
Minikin		Red	0.019/0.48	0.017/0.43	6.9	1.5 (single shear)
Minuta		Pink	0.015/0.38	0.0135/0.34	6.3	1 (single shear)
LINK PLUS						
Minim		Silver	0.024/0.61	0.021/0.53	10.8	2.7 (double shear)

*1 mm = 0.03937 inch.

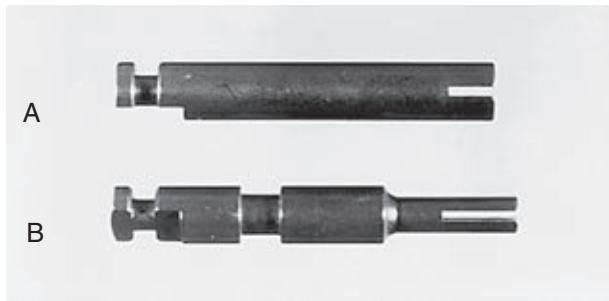


Fig. 16-30 Handpiece chucks for the Thread Mate System (TMS) regular self-shearing and Minikin pins (A) and TMS Minuta pins (B).

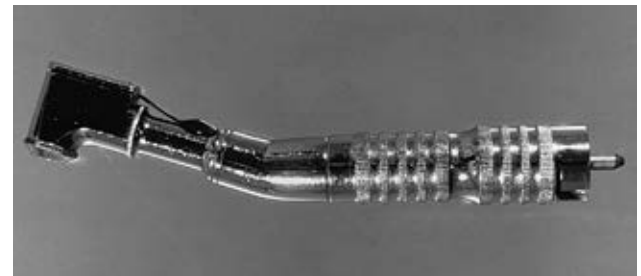


Fig. 16-31 Conventional latch-type contra-angle handpiece.



Fig. 16-32 A, Use of a hand wrench to place a pin. B, Threading the pin to the bottom of the pinhole and reversing the wrench one-quarter to one-half turn. C, Evaluating the length of the pin extending from dentin.

pins need to be bent to be positioned within the anticipated contour of the final restoration and to provide adequate bulk of amalgam between the pin and the external surface of the final restoration (see Fig. 16-34, B and C). Pins should not be bent to make them parallel or to increase their retentiveness. Occasionally, bending a pin may be necessary to allow for

condensation of amalgam occlusogingivally. When pins require bending, the TMS bending tool (Fig. 16-35, A) must be used. The bending tool should be placed on the pin where the pin is to be bent, and with firm controlled pressure, the bending tool should be rotated until the desired amount of bend is achieved (see Fig. 16-35, B through D). Use of the

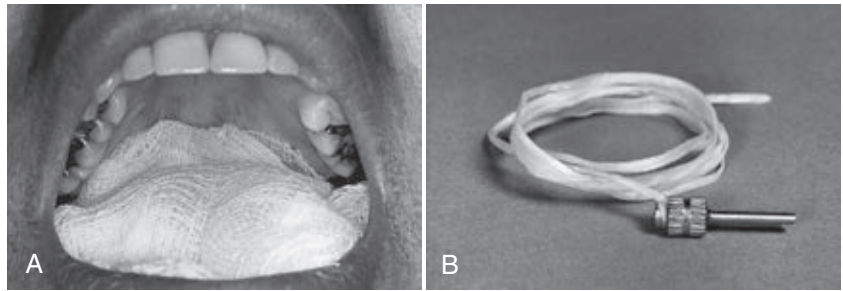


Fig. 16-33 Precautions to be taken if a rubber dam is not used. **A**, Gauze throat shield. **B**, Hand wrench with 12 to 15 inches (30–38 cm) of dental tape attached.



Fig. 16-34 **A**, Use of sharp No. $\frac{1}{4}$ bur held perpendicular to the pin to shorten the pin. **B** and **C**, Evaluating the preparation to determine the need for bending the pins.

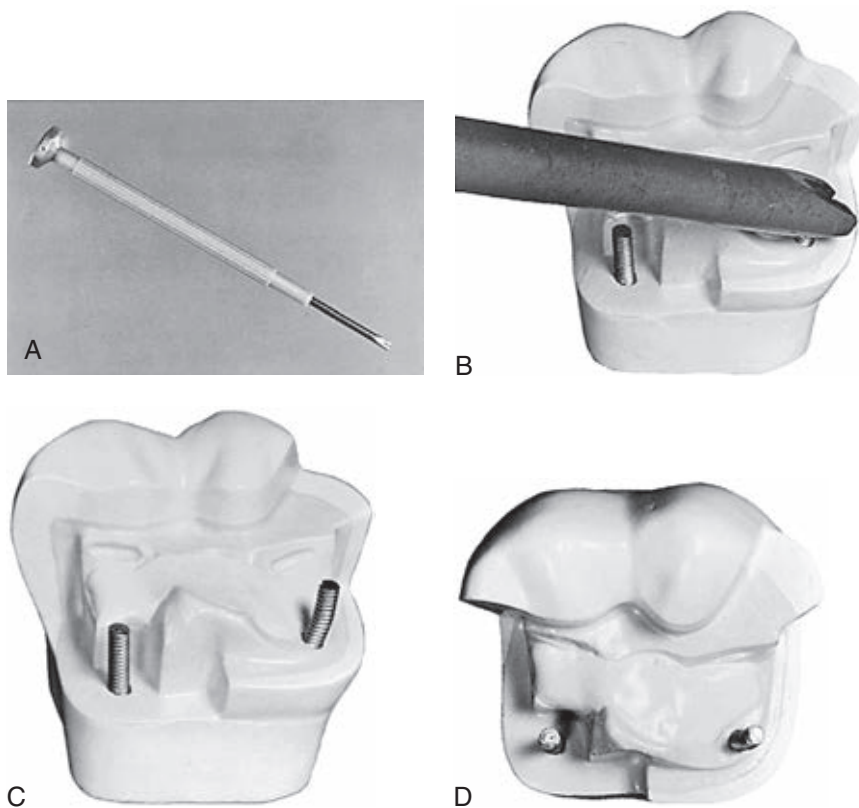


Fig. 16-35 **A**, The Thread Mate System (TMS) bending tool. **B**, Use of the bending tool to bend the pin. **C** and **D**, The pin is bent to a position that provides adequate bulk of amalgam between the pin and the external surface of the final restoration.

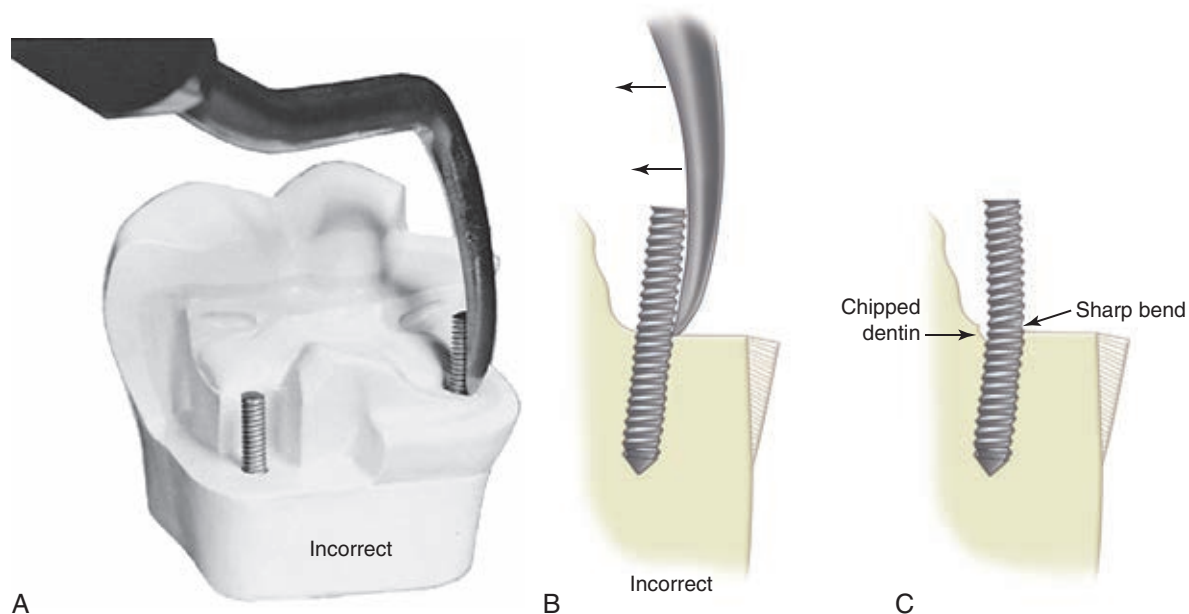


Fig. 16-36 **A**, A Black spoon excavator or other hand instrument should not be used to bend the pin. **B** and **C**, Use of hand instruments may create a sharp bend in the pin and fracture dentin.

bending tool allows placement of the fulcrum at some point along the length of the exposed pin. Other instruments should not be used to bend a pin because the location of the fulcrum would be at the orifice of the pinhole. These hand instruments may cause crazing or fracture of dentin, and the abrupt or sharp bend that usually results increases the chances of breaking the pin (Fig. 16-36). Also, the operator has less control when pressure is applied with a hand instrument, and the risk of slipping is increased.

POSSIBLE PROBLEMS WITH PINS

Failure of Pin-Retained Restorations

The failure of pin-retained restorations might occur at any of five different locations (Fig. 16-37). Failure can occur (1) within the restoration (restoration fracture), (2) at the interface between the pin and the restorative material (pin-restoration separation), (3) within the pin (pin fracture), (4) at the interface between the pin and dentin, and (5) within dentin (dentin fracture). Failure is more likely to occur at the pin–dentin interface than at the pin–restoration interface. The operator must keep these areas of potential failure in mind at all times and apply the necessary principles to minimize the possibility of an inadequate restoration.

Broken Drills and Broken Pins

Occasionally, a twist drill breaks if it is stressed laterally or allowed to stop rotating before it is removed from the pinhole. Use of sharp twist drills helps eliminate the possibility of drill breakage. Pins also can break during bending if care is not exercised. The treatment for broken drills and broken pins is to choose an alternative location, at least 1.5 mm remote from the broken item, and prepare another pinhole. Removal of a broken pin or drill is difficult, if not impossible, and usually should not be attempted. The best solution for these two problems is prevention.

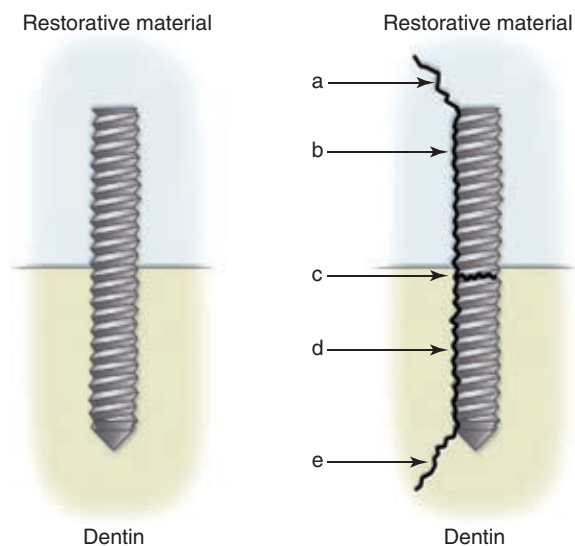


Fig. 16-37 Five possible locations of failure of pin-retained restorations: fracture of restorative material (a), separation of pin from restorative material (b), fracture of pin (c), separation of pin from dentin (d), fracture of dentin (e).

Loose Pins

Self-threading pins sometimes do not engage dentin properly because the pinhole was inadvertently prepared too large or a self-shearing pin failed to shear, resulting in stripped-out dentin. The pin should be removed from the tooth and the pinhole re-prepared with the next largest size drill, and the appropriate pin should be inserted. Preparing another pinhole of the same size 1.5 mm from the original pinhole also is acceptable.

As described earlier, a properly placed pin can be loosened while being shortened with a bur, if the bur is not held perpendicularly to the pin and the pin is stabilized. A loose pin should be removed from the pinhole by holding a rotating bur parallel to the pin and lightly contacting the surface of the pin; this causes the pin to rotate counterclockwise out of the pinhole. A second attempt should be made with the same-size pin. If the second pin fails to engage dentin tightly, a larger hole is prepared, and the appropriate pin is inserted. Preparing another pinhole of the same size 1.5 mm from the original pinhole also is acceptable.

Penetration into the Pulp and Perforation of the External Tooth Surface

Penetration into the pulp or perforation of the external surface of the tooth is obvious if hemorrhage occurs in the pinhole after removal of the drill. Usually, the operator can tell when a penetration or perforation has occurred by an abrupt loss of resistance of the drill to hand pressure. Also, if a standard or Link Series pin continues to thread into the tooth beyond the 2 mm depth of the pinhole, this is an indication of a penetration or perforation. A pulpal penetration might be suspected if the patient is anesthetized and has had no sensitivity to tooth preparation until the pinhole is being completed or the pin is being placed. With profound anesthesia, however, some patients may not feel pulpal penetration.

Radiographs can confirm that a pulpal penetration has not occurred if the view shows dentin between the pulp and the pin. A radiograph projecting the pin in the same region as the pulp does not confirm a pulpal penetration because the pin and the pulp may be superimposed as a result of angulation. In contrast, a radiograph showing a pin projecting outside the tooth confirms external perforation. A radiograph showing the pin inside the projected outline of the tooth does not exclude the possibility of an external perforation.

In an asymptomatic tooth, a pulpal penetration is treated as any other small mechanical exposure. If the exposure is discovered after preparation of the pinhole, any hemorrhage is controlled. A calcium hydroxide liner is placed over the opening of the pinhole, and another hole is prepared 1.5 to 2 mm away. If the exposure is discovered as the pin is being placed, the pin is removed and the area of pulp penetration treated as described. Although certain studies have shown that the pulp tolerates pin penetration when the pin is placed in a relatively sterile environment, it is not recommended that pins be left in place when a pulpal penetration has occurred.^{43,57} If the pin were left in the pulp, (1) the depth of the pin into pulpal tissue would be difficult to determine, (2) considerable postoperative sensitivity might ensue, and (3) the pin location might complicate subsequent endodontic therapy. Regardless of the method of treatment rendered, the patient must be informed of the perforation or pulpal penetration at the completion of the appointment. The affected tooth should be evaluated periodically using appropriate radiographs. The patient should be instructed to inform the dentist if any discomfort develops.

Because most teeth receiving pins have had extensive caries, restorations, or both, the health of the pulp probably has already been compromised to some extent. The ideal treatment of a pulpal penetration for such a compromised tooth generally is endodontic therapy. Endodontic treatment should be strongly considered when such a tooth is to receive an indirect restoration.

An external perforation might be suspected if an unanesthetized patient senses pain when a pinhole is being prepared or a pin is being placed in a tooth that has had endodontic therapy. Observation of the angulation of the twist drill or the pin should indicate whether a pulpal penetration or external perforation has occurred. Perforation of the external surface of the tooth can occur occlusal or apical to the gingival attachment. Careful probing and radiographic examination must diagnose the location of a perforation accurately. The method of treatment for a perforation often depends on the experience of the operator and the particular circumstances of the tooth being treated.

Three options are available for perforations that occur occlusal to the gingival attachment: (1) The pin can be cut off flush with the tooth surface and no further treatment rendered; (2) the pin can be cut off flush with the tooth surface and the preparation for an indirect restoration extended gingivally beyond the perforation; or (3) the pin can be removed, if still present, and the external aspect of the pinhole enlarged slightly and restored with amalgam. Surgical reflection of gingival tissue may be necessary to render adequate treatment. The location of perforations occlusal to the attachment often determines the option to be pursued.

Two options are available for perforations that occur apical to the attachment: (1) Reflect the tissue surgically, remove the necessary bone, enlarge the pinhole slightly, and restore with amalgam, or (2) perform a crown-extension procedure, and place the margin of a cast restoration gingival to the perforation (Fig. 16-38). As with perforations located occlusal to the gingival attachment, the location of the perforation and the design of the present or planned restoration help determine which option to pursue. As with pulpal penetration, the patient must be informed of the perforation and the proposed treatment. The prognosis of external perforations is favorable when they are recognized early and treated properly.

Tooth Preparation for Slot-Retained Amalgam Restorations

Slot length depends on the extent of the tooth preparation. A slot may be continuous or segmented, depending on the amount of missing tooth structure and whether pins were used. Shorter slots provide as much resistance to horizontal force as do longer slots.⁵⁸ Preparations with shorter slots fail less frequently than do preparations with longer slots.⁵⁸

A No. 330 bur is used to place a slot in the gingival floor 0.5 mm axial of the DEJ (see Fig. 16-5). The slot is 1 mm in depth and 1 mm or more in length, depending on the distance between the vertical walls.

Tooth Preparation for Amalgam Foundations

The technique of tooth preparation for a foundation depends on the type of retention that is selected—pin retention; slot retention; or, in the case of endodontically treated teeth, pulp chamber retention. The techniques have in common the axial location of the retention. As stated previously, the retention for a foundation must be sufficiently deep axially so that the final preparation for the subsequent indirect restoration does not compromise the resistance and retention forms of the foundation. The technique for each type of retention is discussed below.

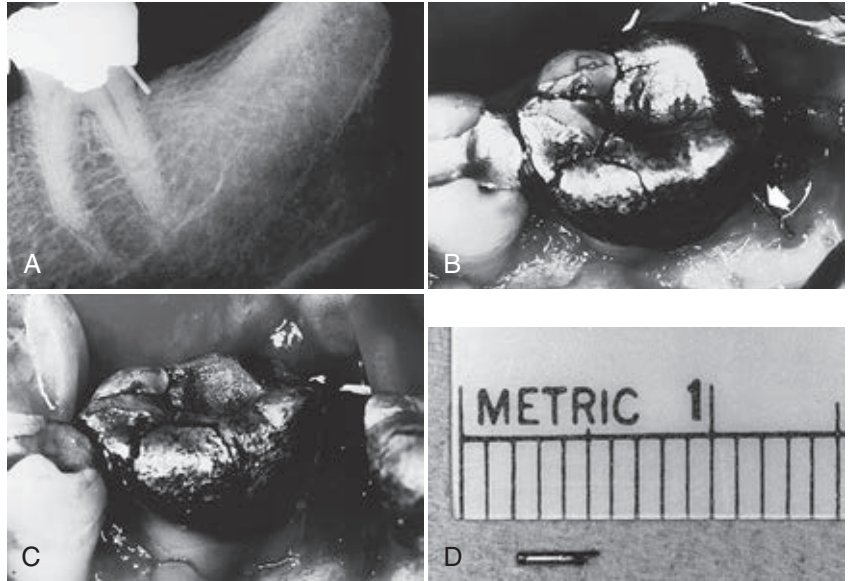


Fig. 16-38 External perforation of a pin. **A**, Radiograph showing the external perforation of a pin. **B**, Surgical access to extruding pin (arrow). **C**, Pin cut flush with the tooth structure and crown-lengthening procedure performed. **D**, Length of pin removed.

PIN RETENTION

Severely broken teeth with few or no vertical walls, in which an indirect restoration is indicated, may require a pin-retained foundation. The main difference between the use of pins for foundations and the use of pins in definitive restorations is the distance of the pinholes from the external surface of the tooth.⁵⁹ For foundations, the pinholes must be located farther from the external surface of the tooth (farther internally from the DEJ), and more bending of the pins may be necessary to allow for adequate axial reduction of the foundation without exposing the pins during the cast metal tooth preparation. Any removal of the restorative material from the circumference of the pin would compromise its retentive effect. If the material is removed from more than half the diameter of the pin, any retentive effect of the pin probably has been eliminated.

The location of the pinhole from the external surface of the tooth for foundations depends on (1) the occlusogingival location of the pin (external morphology of the tooth), (2) the type of restoration to be placed (a porcelain-fused-to-metal [PFM] or all-ceramic preparation requires more reduction than a full gold crown), and (3) the type of margin to be prepared. Preparations with heavily chamfered margins at a normal occlusogingival location require pin (and slot) placement at a greater axial depth. Proximal retention locks still should be used, wherever possible. The length of the pins also must be considered to permit adequate occlusal reduction without exposing the pins.

SLOT RETENTION

Slots are placed in the gingival floor of a preparation with a No. 330 bur (see Fig. 16-5). Foundation slots, as with pins, are placed slightly more axial (farther inside the DEJ) than indicated for conventional amalgam preparations. This more pulpal positioning depends on the type of preparation for a casting that is planned. The preparation for an indirect restoration should not eliminate or cut into the foundation's retentive features. The number of remaining vertical walls determines the indication for slots. Slots are used to oppose

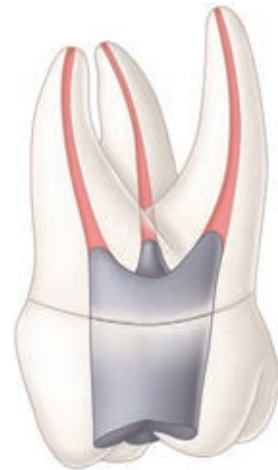


Fig. 16-39 Pulp chamber retention with 2- to 4-mm extension of the foundation into the canal spaces.

retention locks in vertical walls or to provide retention where no vertical walls remain. Slots are generally 1 mm in depth and the width of the No. 330 bur. Their length is usually 2 to 4 mm, depending on the distance between the remaining vertical walls. Increasing the width and depth of the slot does not increase the retentive strength of the amalgam restoration.²⁴ Retention locks are placed in the remaining vertical walls with a No. 169L or No. $\frac{1}{4}$ bur as illustrated in Fig. 16-7.

PULP CHAMBER RETENTION

For developing foundations in multi-rooted, endodontically treated teeth, an alternative technique has been recommended only when (1) dimension of the pulp chamber is adequate to provide retention and bulk of amalgam, and (2) dentin thickness in the region of the pulp chamber is adequate to provide rigidity and strength to the tooth.⁶⁰ Extension into the root canal space 2 to 4 mm is recommended when the pulp chamber height is 2 mm or less (Fig. 16-39).⁶¹ When the

pulp chamber height is 4 to 6 mm in depth, no advantage is gained from extension into the root canal space. After matrix application, amalgam is thoroughly condensed into the pulp canals, the pulp chamber, and the coronal portion of the tooth. Natural undercuts in the pulp chamber and the divergent canals provide the necessary retention form. The resistance form against forces that otherwise may cause tooth fracture is improved by gingival extension of the crown preparation approximately 2 mm beyond the foundation onto sound tooth structure. This extension should have a total taper of opposing walls of less than 10 degrees.⁶² If the pulp chamber height is less than 2 mm, the use of a prefabricated post, cast post and core, pins, or slots should be considered.

Restorative Technique
Desensitizer Placement

The completed preparation is treated with a desensitizer to reduce dentin permeability.

Matrix Placement

One of the most difficult steps in restoring a severely carious posterior tooth is development of a satisfactory matrix. Fulfilling the objectives of a matrix is complicated by possible gingival extensions, missing line angles, and capped cusps typical of complex tooth preparations.

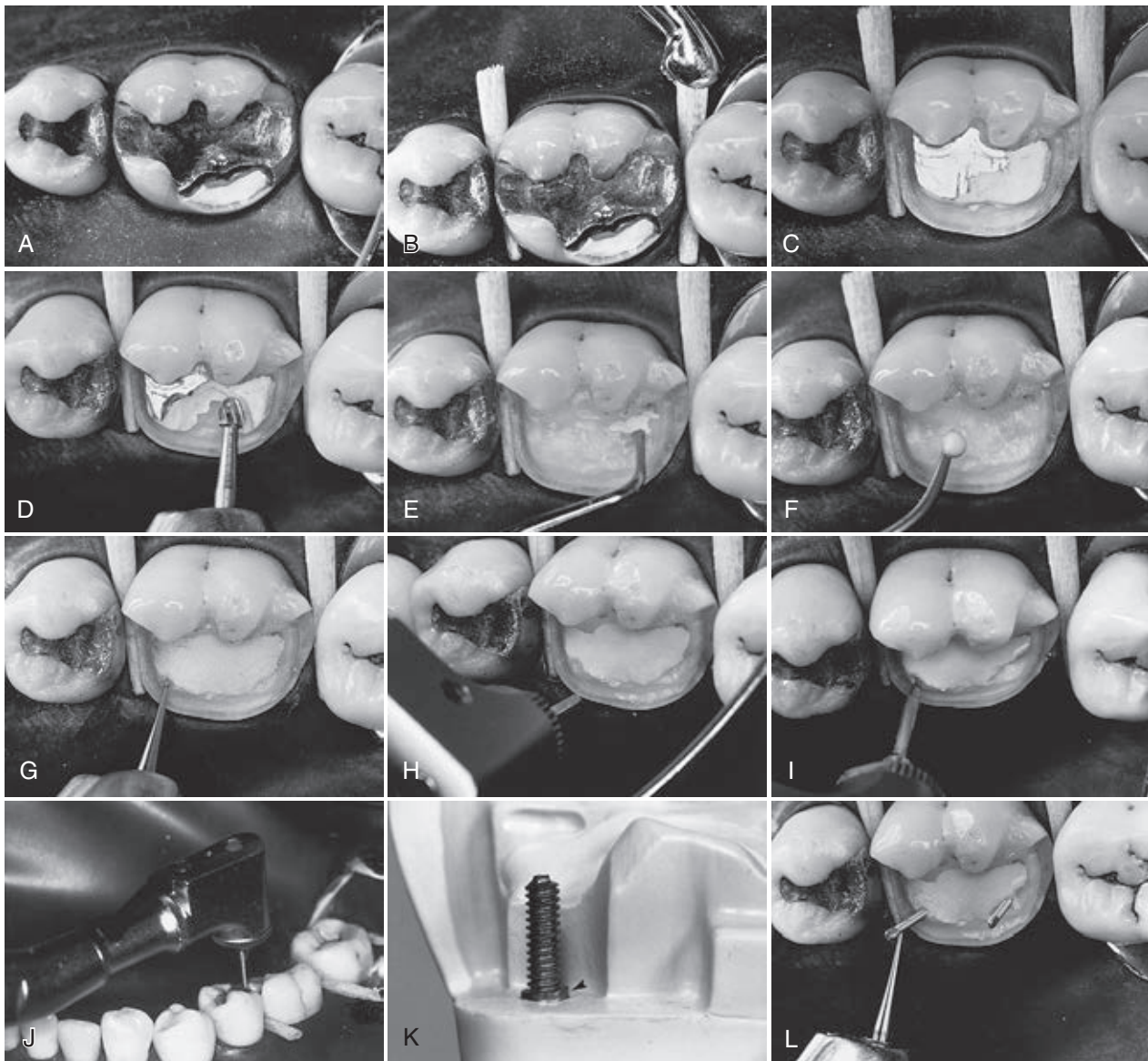


Fig. 16-40 **A**, Mandibular first molar with fractured distolingual cusp. **B**, Insertion of wedges. **C**, Initial tooth preparation. **D** and **E**, Excavation of any infected dentin; if indicated, any remaining old restorative material is removed. **F**, Application of a liner and a base (if necessary). **G**, Preparation of pilot holes. **H**, Alignment of the twist drill with the external surface of the tooth. **I**, Preparation of pinholes. **J**, Insertion of Link pins with a slow-speed handpiece. **K**, Depth-limiting shoulder (arrowhead) of inserted Link Plus pin. **L**, Use of a No. $\frac{1}{4}$ bur to shorten pins.

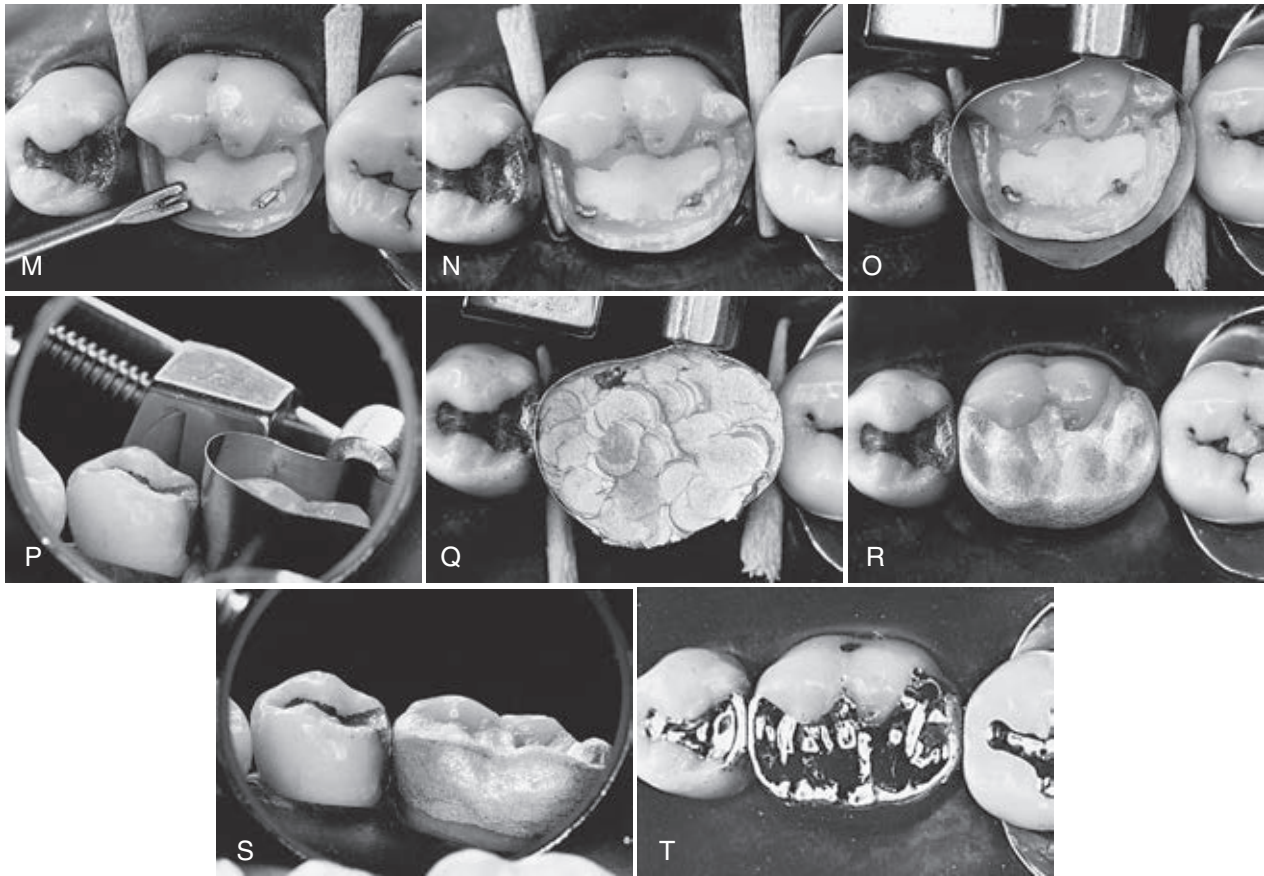


Fig. 16-40, cont'd **M**, Bending pins (if necessary) with a bending tool. **N**, Final tooth preparation. **O**, Tofflemire retainer and matrix band applied to the prepared tooth. **P**, Reflecting light to evaluate the proximal area of the matrix band. **Q**, Preparation overfilled. **R**, Restoration carved. **S**, Reflecting light to evaluate the adequacy of the proximal contact and contour. **T**, Restoration polished.

UNIVERSAL MATRIX

The Tofflemire retainer and band can be used successfully for most amalgam restorations (Fig. 16-40). Use of the Tofflemire retainer requires sufficient tooth structure to retain the band after it is applied. When the Tofflemire retainer is placed appropriately, but an opening remains next to prepared tooth structure, a closed system can be developed as illustrated in Figure 16-41. A strip of matrix material that is long enough to extend from the mesial to the distal corners of the tooth is cut. The strip must extend into these corners sufficiently that the band, when tight, holds the strip in position. Also, it must not extend into the proximal areas, or a ledge would result in the restoration contour when the matrix is removed. The Tofflemire retainer is loosened one-half turn, and the strip of matrix material is inserted next to the opening between the matrix band and the tooth. The retainer is then tightened and the matrix is completed. Sometimes, it is helpful to place a small amount of rigid material (hard-setting polyvinyl siloxane [PVS] or compound) between the strip and the open aspect of the band retainer to stabilize and support the strip (see Fig. 16-41, *G* and *H*).

When little tooth structure remains and deep gingival margins are present, the Tofflemire matrix may not function successfully, and the Automatrix system (DETNSPLY Caulk, Milford, DE) may be an alternative method (Fig. 16-42).

AUTOMATRIX

The Automatrix is a retainerless matrix system designed for any tooth regardless of its circumference and height. The Automatrix bands are supplied in three widths: (1) $\frac{3}{16}$ inch, (2) $\frac{1}{4}$ inch, and (3) $\frac{5}{16}$ inch (4.8 mm, 6.35 mm, and 7.79 mm). The medium band is available in two thicknesses (0.0015 inch and 0.002 inch [0.038 mm and 0.05 mm]). The $\frac{3}{16}$ -inch and the $\frac{5}{16}$ -inch band widths are available in the 0.002-inch thickness only. Advantages of this system include (1) convenience, (2) improved visibility because of absence of a retainer, and (3) ability to place the auto-lock loop on the facial or lingual surface of the tooth. Disadvantages of this system are that (1) the band is flat and difficult to burnish and is sometimes unstable even when wedges are in place, and (2) development of proper proximal contours and contacts can be difficult with the Automatrix bands. Use of the Automatrix system is illustrated in Figure 16-43.

Regardless of the type of matrix system used, the matrix must be stable. If the matrix for a complex amalgam restoration is not stable during condensation, a homogeneous restoration will not be developed. The restoration might be improperly condensed, disintegrate when the matrix is removed, or eventually fail because of lack of sufficient strength. In addition to providing stability, the matrix should extend beyond the gingival margins of the preparation enough

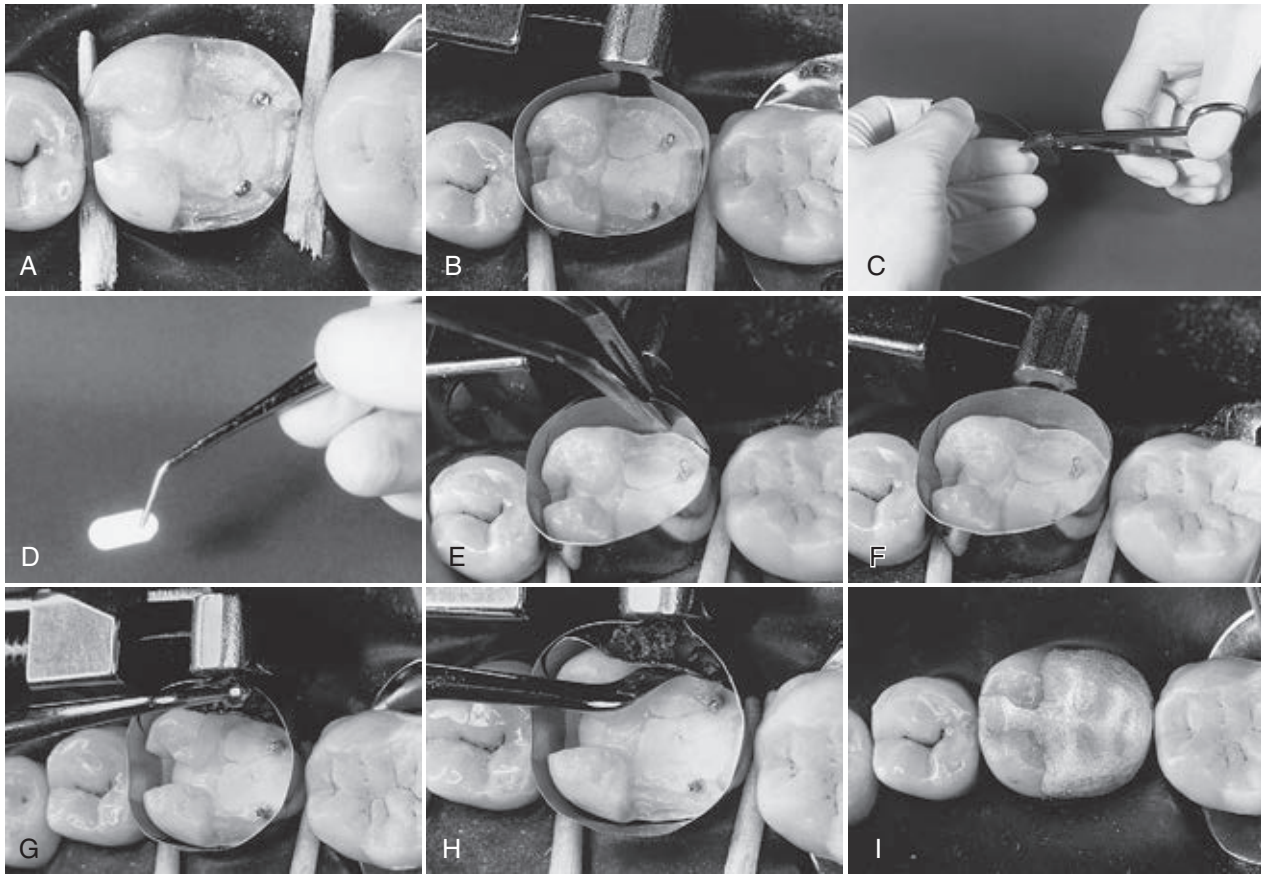


Fig. 16-41 Technique for closing the open space of the Tofflemire matrix system. **A**, Tooth preparation with wedges in place. **B**, Open aspect of the matrix band next to the prepared tooth structure. **C** and **D**, Cutting an appropriate length of the matrix material. **E**, Insertion of a strip of the matrix material. **F**, Closed matrix system. **G** and **H**, Placement of the rigid supporting material between the strip and the matrix band, and contouring, if necessary. **I**, Restoration carved.

to provide support for the matrix and to permit appropriate wedge stabilization. The matrix should extend occlusally beyond the marginal ridge of the adjacent tooth by 1 to 2 mm. Matrix stability during condensation is especially important for slot-retained amalgam restorations. If the matrix is not secure during condensation, it may slip out of position causing loss of the restoration. Clinical experience determines whether the pin-retained amalgam or slot-retained amalgam is more appropriate.

Insertion, Contouring, and Finishing of Amalgam

A high-copper alloy is strongly recommended for the complex amalgam restoration because of excellent clinical performance and high early compressive strengths.⁶³⁻⁶⁵ Spherical alloys have a higher early strength than admixed alloys, and spherical alloys can be condensed more quickly with less pressure to ensure good adaptation around the pins. Proximal contacts can be easier to achieve with admixed alloys because of their condensability, however, and their extended working time might allow more adequate time for condensation, removal of the matrix band, and final carving. Because complex amalgam restorations usually are quite large, a slow-set or medium-set amalgam may be selected to provide more time for the carving and adjustment of the restoration.

Regardless of the insertion technique, care must be taken to condense amalgam thoroughly in and around the retentive features of the preparation, such as slots, grooves, and pins. If a mix of amalgam becomes dry or crumbly, a new mix is triturated immediately. Condensation is continued until the preparation is overfilled.

With a complex (or any large) amalgam, carving time must be properly allocated. The time spent on occlusal carving must be shortened to allow adequate time for carving the more inaccessible gingival margins and the proximal and axial contours. The bulk of excess amalgam on the occlusal surface is removed and the anatomy grossly developed, especially the marginal ridge heights, with a discoid carver. The occlusal embrasures are defined by running the tine of an explorer against the internal aspect of the matrix band. Appropriate marginal ridge heights and embrasures reduce the potential of fracturing the marginal ridge when the matrix is removed.

Matrix removal is crucial when placing complex amalgam restorations, especially slot-retained restorations.¹³ If the matrix is removed prematurely, the newly placed restoration may fracture immediately adjacent to the areas where amalgam has been condensed into the slot(s). Any rigid material supporting the matrix is removed with an explorer or a Black spoon. Tofflemire matrices are removed first by loosening and removing the retainer while the wedges are still in place. Leaving the wedges in place may help prevent fracturing the



Fig. 16-42 **A**, Automatrix retainerless matrix system. **B**, Automatrix band. **C**, Automate II tightening device. **D**, Shielded nippers. (**A**, courtesy of Dentsply Caulk, Milford, DE.)

marginal ridge amalgam. It may be beneficial to place a fingertip on the occlusal surface of the restored tooth to stabilize the matrix while loosening and removing the retainer from the band. Otherwise, the torqued force of loosening the retainer may fracture the inserted amalgam. The matrix is removed by sliding each end of the band in an oblique direction (i.e., moving the band facially or lingually while simultaneously moving it in an occlusal direction). Moving the band obliquely toward the occlusal surface minimizes the possibility of fracturing the marginal ridge. Preferably, the matrix band should be removed in the same direction as the wedge placement to prevent dislodging the wedges. Automatrix bands are removed by using the system's instruments and, after the band is open, by the same technique described for the Tofflemire-retained matrices. The carving of the restoration is then continued (see Figs. 16-40, *R*, and 16-43, *N*).

The wedges are then removed, and the interproximal gingival excess of amalgam is removed with an amalgam knife or an explorer. Facial and lingual contours are developed with a Hollenback carver, an amalgam knife, or an explorer to complete the carving (see Fig. 16-40, *R*). Appropriately shaped

rotary instruments are used to complete the occlusal carving if amalgam has become so hard that the force needed to carve with hand instruments might fracture portions of the restoration.

Each proximal contact is evaluated by using a mirror occlusally and lingually to ensure that no light can be reflected between the restoration and the adjacent tooth at the level of the proximal contact (see Fig. 16-40, *S*). When the proper proximal contour or contact cannot be achieved in a large, complex restoration, it may be possible to prepare a conservative two-surface tooth preparation within the initial amalgam to restore the proper proximal surface. Amalgam forming the walls of this "ideal" preparation must have sufficient bulk to prevent future fracture.

The rubber dam is removed, and the occlusal surface of the amalgam is adjusted to obtain appropriate occlusal contacts. Thin, unwaxed dental floss may be passed through the proximal contacts once to remove amalgam shavings and smooth the proximal surface of amalgam. The floss is wrapped around the proximal aspect of the adjacent tooth when being inserted to reduce the force applied to the newly condensed amalgam.



Fig. 16-43 Application of Automatrix for developing a pin-retained amalgam crown on the mandibular first molar. **A**, Tooth preparation with wedges in place. **B**, Enlargement of the circumference of the band, if necessary. **C**, Burnishing the band with an egg-shaped burnisher. **D–F**, Placement of the band around the tooth, tightening with an Automate II tightening device, and setting wedges firmly in place. **G**, Application of the green compound. **H**, Contouring of the band with the back of a warm Black spoon excavator. **I**, Overfilling the preparation and carving the occlusal aspect. **J** and **K**, Use of shielded nippers to cut an auto-lock loop. **L**, Separating the band with an explorer. **M**, Removing the band in an oblique direction (facially with some occlusal vector). **N**, Restoration carved. **O**, Restoration polished.

Amalgam excess and loose particles are removed from the gingival sulcus by moving the floss occlusogingivally and faciolingually. The patient should be cautioned not to apply biting forces to the restoration for several hours. Fast-setting high-copper amalgam can be prepared within 30 to 45 minutes after insertion of the foundation. Further finishing and polishing of the complex amalgam may be accomplished, if desired, as early as 24 hours after placement.

Summary

The complex amalgam remains a predictable, cost-effective, and safe means for the restoration of posterior teeth that are missing large amounts of structure. The design of the tooth preparation must be based on the material properties of dental amalgam for success. Restoration of normal anatomic contours can be readily accomplished with dental amalgam through the use of slots, pins, and customized matrix designs.

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Class II Cast Metal Restorations

John R. Sturdevant

The cast metal restoration is versatile and is especially applicable to Class II onlay preparations. The process has many steps, involves numerous dental materials, and requires meticulous attention to detail. Typically, a dental laboratory is involved, and the dentist and the laboratory technician must be devoted to perfection. The high degree of satisfaction and service derived from a properly made cast metal restoration is a reward for the painstaking application required.¹ The Class II *inlay* involves the occlusal surface and one or more proximal surfaces of a posterior tooth. When cusp tips are restored, the term *onlay* is used. The procedure requires two appointments: the first for preparing the tooth and making an impression, and the second for delivering the restoration to the patient. The fabrication process is referred to as an *indirect procedure* because the casting is made on a replica of the prepared tooth in a dental laboratory.

Material Qualities

Cast metal restorations can be made from a variety of casting alloys. Although the physical properties of these alloys vary, their major advantages are their high compressive and tensile strengths. These high strengths are especially valuable in restorations that rebuild most or all of the occlusal surface.

The American Dental Association (ADA) Specification No. 5 for Dental Casting Gold Alloys requires a minimum total gold-plus-platinum-metals content of 75 weight percent (wt%). Such traditional high-gold alloys are unreactive in the oral environment and are some of the most biocompatible materials available to the restorative dentist.² At present, four distinct groups of alloys are in use for cast restorations: (1) traditional high-gold alloys, (2) low-gold alloys, (3) palladium-silver alloys, and (4) base metal alloys. Each of the alternatives to high-gold alloys has required some modification of technique or acceptance of reduced performance, most commonly related to decreased tarnish resistance and decreased burnishability.³ Also, they have been associated with higher incidences of post-restorative allergy, most often exhibited by irritated soft tissue adjacent to the restoration.²

Indications

Large Restorations

The cast metal inlay is an alternative to amalgam or composite when the higher strength of a casting alloy is needed or when

the superior control of contours and contacts that the indirect procedure provides is desired. The cast metal onlay is often an excellent alternative to a crown for teeth that have been greatly weakened by caries or by large, failing restorations but where the facial and lingual tooth surfaces are relatively unaffected by disease or injury. For such weakened teeth, the superior physical properties of a casting alloy are desirable to withstand the occlusal loads placed on the restoration; also, the onlay can be designed to distribute occlusal loads over the tooth in a manner that decreases the chance of tooth fracture in the future. Preserving intact facial and lingual enamel (or cementum) is conducive to maintaining the health of contiguous soft tissue. When proximal surface caries is extensive, favorable consideration should be given to the cast inlay or onlay. The indirect procedure used to develop the cast restoration allows more control of contours and contacts (proximal and occlusal).

Endodontically Treated Teeth

A molar or premolar with endodontic treatment can be restored with a cast metal onlay, provided that the onlay has been thoughtfully designed to distribute occlusal loads in such a manner as to reduce the chance of tooth fracture.

Teeth at Risk for Fracture

Fracture lines in enamel and dentin, especially in teeth having extensive restorations, should be recognized as cleavage planes for possible future fracture of the tooth. Restoring these teeth with a restoration that braces the tooth against fracture injury may be warranted sometimes. Such restorations are cast onlays (with skirting) and crowns.

Dental Rehabilitation with Cast Metal Alloys

When cast metal restorations have been used to restore adjacent or opposing teeth, the continued use of the same material may be considered to eliminate electrical and corrosive activity that sometimes occurs between dissimilar metals in the mouth, particularly when they come in contact with each other.

Diastema Closure and Occlusal Plane Correction

Often, the cast inlay or onlay is indicated when extension of the mesiodistal dimension of the tooth is necessary to form a contact with an adjacent tooth. Cast onlays also can be used to correct the occlusal plane of a slightly tilted tooth.

Removable Prosthodontic Abutment

Teeth that are to serve as abutments for a removable partial denture can be restored with a cast metal restoration. The major advantages of a cast restoration are as follows: (1) The superior physical properties of the cast metal alloy allow it to better withstand the forces imparted by the partial denture, and (2) the rest seats, guiding planes, and other aspects of contour relating to the partial denture are better controlled when the indirect technique is used.

Contraindications

High Caries Rate

Facial and lingual (especially lingual) smooth-surface caries indicates a high caries activity that should be brought under control before expensive cast metal restorations are used. Full crown restorations are usually indicated if caries is under control, but defects exist on the facial and lingual surfaces, as well as on the occlusal and proximal surfaces.

Young Patients

With younger patients, direct restorative materials (e.g., composite or amalgam) are indicated, unless the tooth is severely broken or endodontically treated. An indirect procedure requires longer and more numerous appointments, access is more difficult, the clinical crowns are shorter, and younger patients may neglect oral hygiene, resulting in additional caries.

Esthetics

The dentist must consider the esthetic impact (display of metal) of the cast metal restoration. This factor usually limits the use of cast metal restorations to tooth surfaces that are invisible at a conversational distance. Composite and porcelain restorations are alternatives in esthetically sensitive areas.

Small Restorations

Because of the success of amalgam and composite, few cast metal inlays are done in small Class I and II restorations.

Advantages

Strength

The inherent strength of dental casting alloys allows them to restore large damaged or missing areas and be used in ways that protect the tooth from future fracture injury. Such restorations include onlays and crowns.

Biocompatibility

As previously mentioned, high-gold dental casting alloys are unreactive in the oral environment. This biocompatibility can be helpful for many patients who have allergies or sensitivities to other restorative materials.

Low Wear

Although individual casting alloys vary in their wear resistance, castings are able to withstand occlusal loads with minimal changes. This is especially important in large restorations that restore a large percentage of occlusal contacts.

Control of Contours and Contacts

Through the use of the indirect technique, the dentist has great control over contours and contacts. This control becomes especially important when the restoration is larger and more complex.

Disadvantages

Number of Appointments and Higher Chair Time

The cast inlay or onlay requires at least two appointments and much more time than a direct restoration, such as amalgam or composite.

Temporary Restorations

Patients must have temporary restorations between the preparation and delivery appointments. Temporaries occasionally loosen or break, requiring additional visits.

Cost

In some instances, cost to the patient becomes a major consideration in the decision to restore teeth with cast metal restorations. The cost of materials, laboratory bills, and the time involved make indirect cast restorations more expensive than direct restorations.

Technique Sensitivity

Every step of the indirect procedure requires diligence and attention to detail. Errors at any part of the long, multi-step process tend to be compounded, resulting in less than ideal fits.

Splitting Forces

Small inlays may produce a wedging effect on facial or lingual tooth structure and increase the potential for splitting the tooth. Onlays do not have this disadvantage.

Initial Procedures

Occlusion

Before the anesthetic is administered and before preparation of any tooth, the occlusal contacts of teeth should be



Fig. 17-1 A–C, Evaluate occlusal relationships in maximum intercuspation (A) and during mandibular movements (B and C). Be alert for problems with tooth alignment and contact position. Note the amount of posterior separation provided by the guidance of anterior teeth (working side) and articular eminence (nonworking side).

evaluated. As part of this evaluation, the dentist must decide if the existing occlusal relationships can be improved with the cast metal restoration. An evaluation should include (1) the occlusal contacts in maximum intercuspation where teeth are brought into full interdigitation and (2) the occlusal contacts that occur during mandibular movements (Fig. 17-1). The pattern of occlusal contacts influences the preparation design, selection of interocclusal records, and type of articulator or cast development needed.

Anesthesia

Local anesthesia of the tooth to be operated on and of adjacent soft tissue usually is recommended. Anesthesia in these areas eliminates pain and reduces salivation, resulting in a more pleasant procedure for the patient and the operator.

Considerations for Temporary Restorations

Before preparation of the tooth, consideration must be given to the method that will be used to fabricate the temporary restoration. Most temporary restoration techniques require the use of a preoperative impression to reproduce the occlusal, facial, and lingual surfaces of the temporary restoration to the preoperative contours.

The technique involves making a preoperative impression with an elastic impression material. Alginate impression materials may be used and are relatively inexpensive. The preoperative impression may be made with a polyvinyl siloxane (PVS) impression material if additional accuracy, stability, and durability are required. If the tooth to be restored has any large defects such as a missing cusp, either of two methods may be used to reproduce the missing cusp in the temporary. First, an instrument can be used to remove the impression material in the area of the missing cusp or tooth structure, to simulate the desired form for the temporary restoration. Second, wax can be added to the tooth before the impression, as follows: The tooth is dried and large defects filled with utility wax. The wax is smoothed, and an impression is made by using a quadrant tray if no more than two teeth are to be prepared (Fig. 17-2, A). A full-arch tray may be used for greater stability. The tray filled with impression material is then seated (see Fig. 17-2, B). After the impression has set, the impression is removed

and examined for completeness (see Fig. 17-2, C). Alginate impressions can distort quickly if they are allowed to gain or lose moisture, so the impression is wrapped in wet paper towels to serve as a humidifier (see Fig. 17-2, D). Pre-operative polyvinyl impressions do not need to be wrapped. The pre-operative impression is set aside for later use in forming the temporary restoration.

Tooth Preparations for Class II Cast Metal Restorations

A small, distal, cavitated caries lesion in the maxillary right first premolar is used to illustrate the classic two-surface preparation for an inlay (Fig. 17-3, A). Treatment principles for other defects are presented later. As indicated previously, few small one-surface or two-surface inlays are done. Because the description of a small tooth preparation presents the basic concepts, it is used to illustrate the technique. More extensive tooth preparations are presented later.

Tooth Preparation for Class II Cast Metal Inlays

Initial Preparation

Carbide burs used to develop the vertical internal walls of the preparation for cast metal inlays and onlays are plane cut, tapered fissure burs. These burs are plane cut so that the vertical walls are smooth. The side and end surfaces of the bur should be straight to aid in the development of uniformly tapered walls and smooth pulpal and gingival walls. Recommended dimensions and configurations of the burs to be used are shown in Figure 17-3, B. Suggested burs are the No. 271 and the No. 169L burs (Brasseler USA, Inc., Savannah, GA). Before using unfamiliar burs, the operator is cautioned to verify measurements to judge the depth into the tooth during preparation. The sides and end surface of the No. 271 bur meet in a slightly rounded manner so that sharp, stress-inducing internal angles are not formed in the preparation.⁴ The marginal bevels are placed with a slender, fine-grit, flame-shaped diamond instrument such as the No. 8862 bur (Brasseler USA, Inc.).

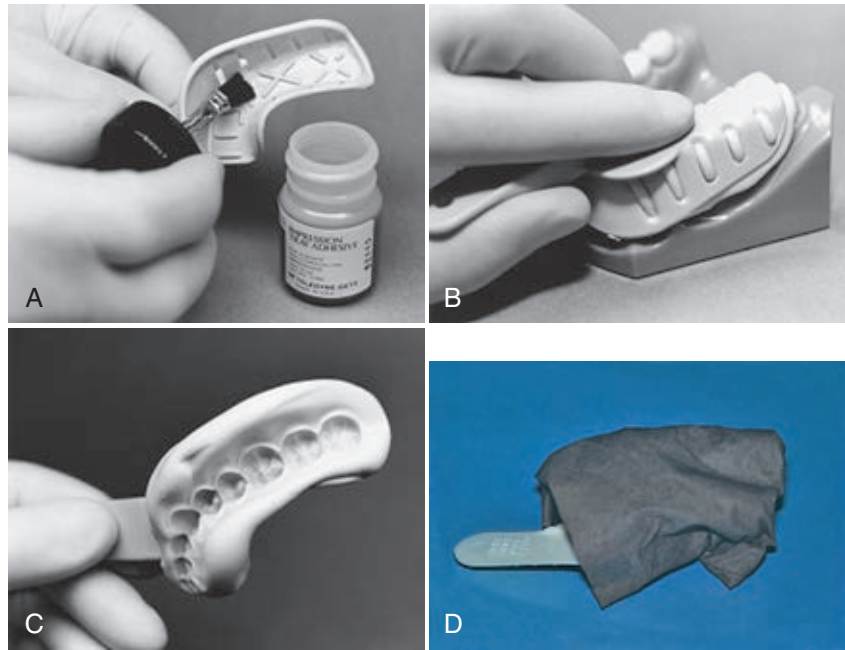


Fig. 17-2 **A**, Applying tray adhesive to stock quadrant tray. **B**, Making pre-operative impression. **C**, Inspecting pre-operative impression for completeness. **D**, When using alginate, wrap the impression with wet paper towels to serve as a humidor.



Fig. 17-3 **A**, Proposed outline form for disto-occlusal preparation. **B**, Dimensions and configuration of No. 271, No. 169L, and No. 8862 instruments. **C**, Conventional 4-degree divergence from line of draw (line *xy*).

Throughout the preparation for a cast inlay, the cutting instruments used to develop the vertical walls are oriented to a single “draw” path, usually the long axis of the tooth crown, so that the completed preparation has draft (no undercuts) (see Fig. 17-3, C). The gingival-to-occlusal divergence of these preparation walls may range from 2 to 5 degrees per wall from the line of draw. If the vertical walls are unusually short, a maximum of 2 degrees occlusal divergence is desirable to increase retention potential. As the occlusogingival height increases, the occlusal divergence should increase because lengthy preparations with minimal divergence (more parallel) may present difficulties during the seating and withdrawal of the restoration.

OCCLUSAL STEP

With the No. 271 carbide bur held parallel to the long axis of the tooth crown, the dentist enters the fossa or pit closest to the involved marginal ridge, using a punch cut to a depth of 1.5 mm to establish the depth of the pulpal wall (Fig. 17-4, A and B). In the initial preparation, this specified depth should not be exceeded, regardless of whether the bur end is in dentin, caries, old restorative material, or air. The bur should be rotating at high speed (with air-water spray) before application to the tooth and should not stop rotating until it is removed; this minimizes perceptible vibration and prevents breakage or chipping of the bur blades. A general rule is to maintain the long axis of the bur parallel to the long axis of the tooth crown

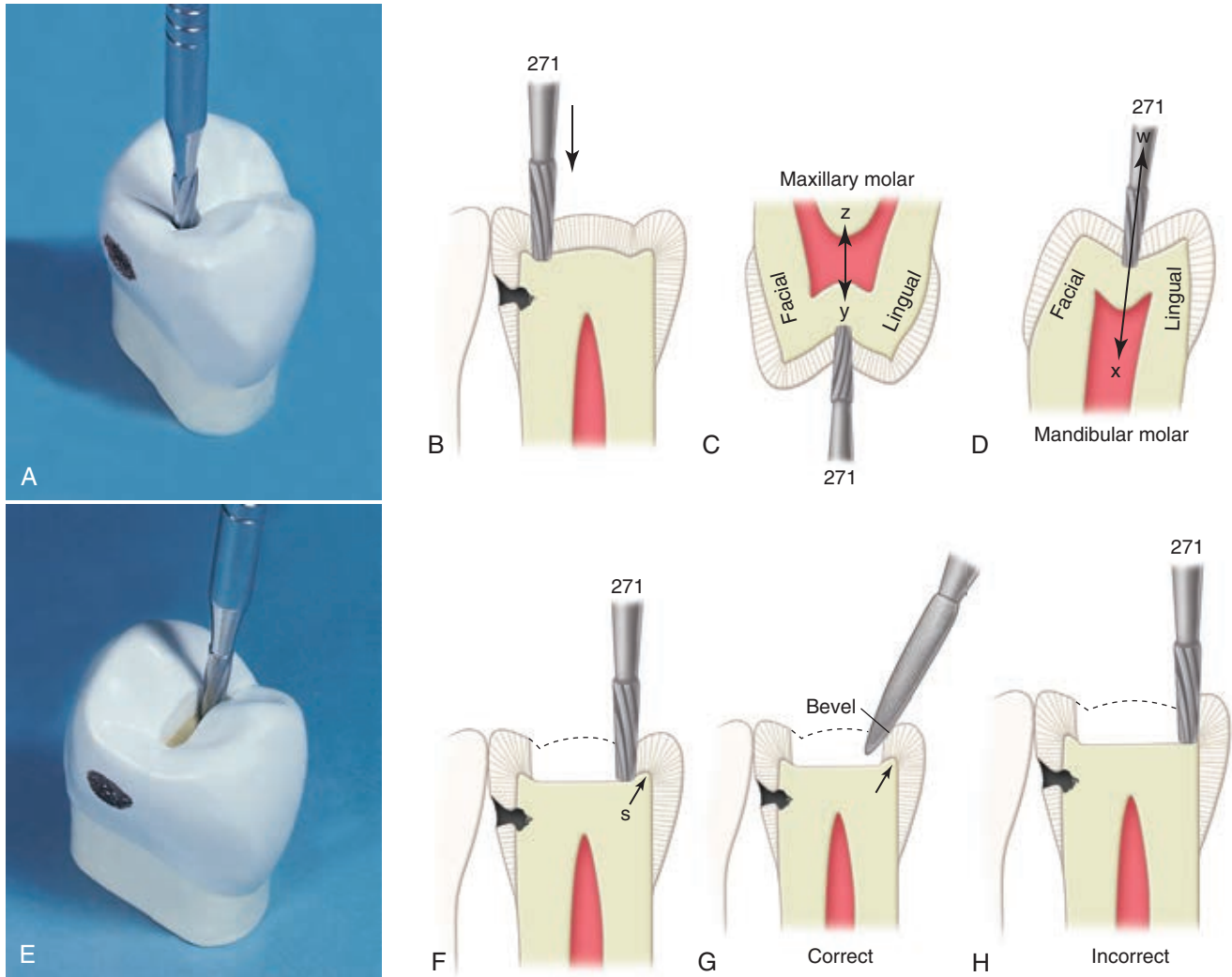


Fig. 17-4 **A** and **B**, Bur after punch cut to a depth of 1.5 mm. **C**, For maxillary posterior teeth, the long axis of the bur should parallel the long axis of the tooth crown (line *yz*). **D**, For molar and second premolar teeth of mandibular dentition, the long axis of the bur should tilt slightly lingually to parallel the long axis of the tooth crown (line *wx*). **E** and **F**, Extending the mesial wall, taking care to conserve dentin that supports marginal ridge (*s*). **G**, The marginal bevel can provide additional extension. **H**, Improper extension that has weakened the marginal ridge.

at all times (see Fig. 17-4, *B* and *C*). For mandibular molars and second premolars whose crowns tilt slightly lingually, this rule dictates that the bur should also be tilted slightly (5–10 degrees) lingually to conserve the strength of the lingual cusps (see Fig. 17-4, *D*). When the operator is cutting at high speeds, a properly directed air-water spray is used to provide the necessary cooling and cleansing effects.⁵

Maintaining the 1.5-mm initial depth and the same bur orientation, the dentist extends the preparation outline mesially along the central groove or fissure to include the mesial fossa or pit (see Fig. 17-4, *E* and *F*). Ideally, the faciolingual dimension of this cut should be minimal. The dentist takes care to keep the mesial marginal ridge strong by not removing the dentin support of the ridge (see Fig. 17-4, *F* and *H*). The use of light intermittent pressure minimizes heat production on the tooth surface and reduces the incidence of enamel crazing ahead of the bur. Occasionally, a fissure extends onto the mesial marginal ridge. This defect, if shallow, may be treated with enameloplasty, or it may be included in the

outline form with the cavosurface bevel, which is applied in a later step in the tooth preparation (see Fig. 17-4, *G*).

Enameloplasty, as presented in earlier chapters, occasionally reduces extension along the fissures, conserving the tooth structure vital for pulp protection and the strength of the remaining tooth crown. The extent to which enameloplasty can be used usually cannot be determined until the operator is in the process of extending the preparation wall, when the depth of the fissure in the enamel wall can be observed (Fig. 17-5). When enameloplasty shows a fissure in a marginal ridge to be deeper than one third the thickness of enamel, the procedures described in the later section should be used.

Extend to include faulty facial and lingual fissures radiating from the mesial pit. During this extension cutting, the operator is cautioned again not to remove the dentin support of the proximal marginal ridge. To conserve the tooth structure and the strength of the remaining tooth, the final extension up these fissures can be accomplished with the slender No. 169L carbide bur (Fig. 17-6, *A*). The tooth structure and strength

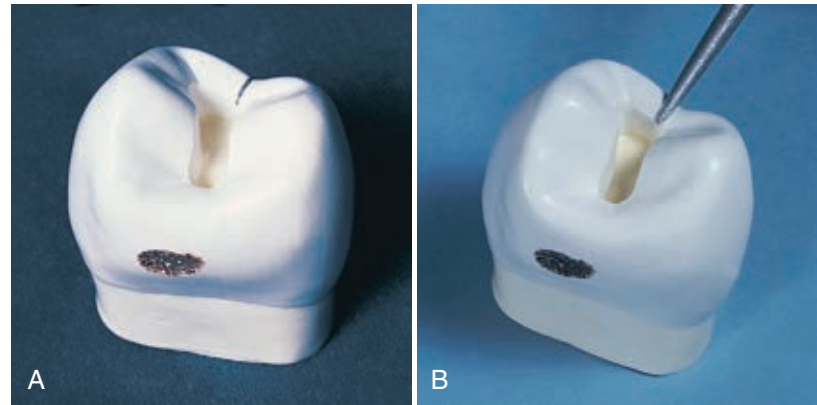


Fig. 17-5 **A**, Shallow enamel fault that is no deeper than one third the thickness of enamel. **B**, Using fine-grit diamond instrument to remove enamel that contains shallow fault.

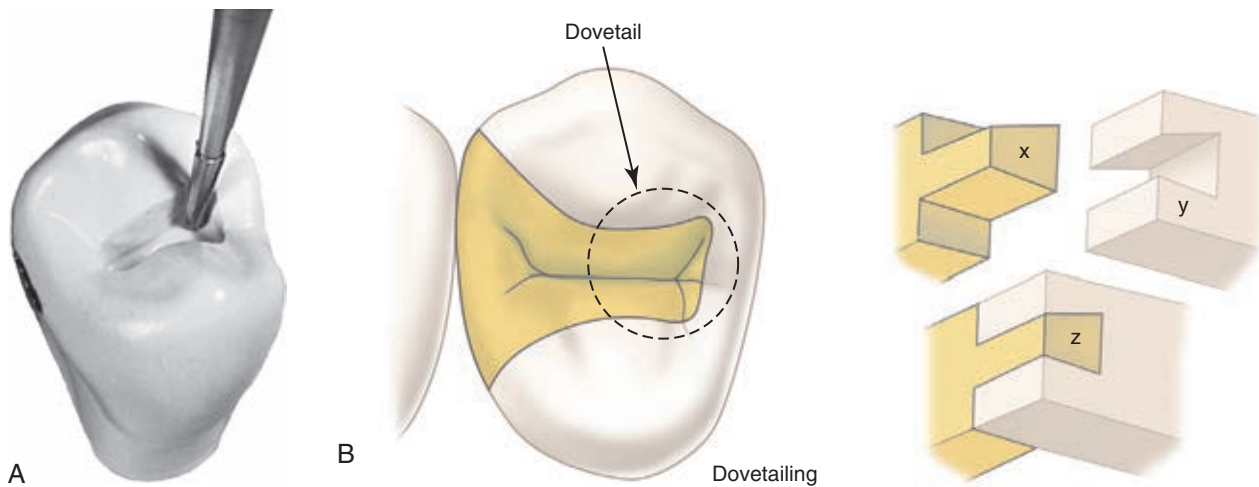


Fig. 17-6 **A**, Extending up the mesiofacial triangular groove using the slender No. 169L bur. **B**, Dovetail retention form is created by extension shown in A. As *x* fits into *y* only in one direction resulting in *z*, similarly dovetail portion of inlay fits into the dovetail portion of the preparation only in an occlusal-to-gingival direction.

can be conserved further by using (1) enameloplasty of the fissure ends, when possible, and (2) the marginal bevel of the final preparation to include (eliminate) the terminal ends of these fissures in the outline form. The facial and lingual extensions in the mesial pit region should provide the desired dovetail retention form, which resists distal displacement of the inlay (see Fig. 17-6, B). When these facial and lingual grooves are not faulty, sufficient facial extension in the mesial pit region should be made to provide this dovetail retention form against distal displacement. Minor extension in the transverse ridge area to include any remaining facial or lingual caries may necessitate additional facial or lingual extension in the mesial pit to provide this dovetail feature. (During such facial or lingual extensions to sound tooth structure, the bur depth is maintained at 1.5 mm.) If major facial or lingual extension is required to remove undermined occlusal enamel, capping the weak remaining cuspal structure and additional features in the preparation to provide adequate retention and resistance forms may be indicated. These considerations are discussed in subsequent sections.

Continuing at the initial depth, the occlusal step is extended distally into the distal marginal ridge sufficiently to expose the junction of the proximal enamel and dentin (Fig. 17-7, A and

B). While extending distally, the dentist progressively widens the preparation to the desired faciolingual width in anticipation of the proximal box preparation. The increased faciolingual width enables the facial and lingual walls of the box to project (visually) perpendicularly to the proximal surface at positions that clear the adjacent tooth by 0.2 to 0.5 mm (see Fig. 17-7, F). The facial and lingual walls of the occlusal step should go around the cusps in graceful curves, and the prepared isthmus in the transverse ridge ideally should be only slightly wider than the bur, thus conserving the dentinal protection for the pulp and maintaining the strength of the cusps. If the occlusal step has been prepared correctly, any caries on the pulpal floor should be uncovered by facial and lingual extensions to sound enamel (supported by dentin).

PROXIMAL BOX

Continuing with the No. 271 carbide bur, the distal enamel is isolated by cutting a proximal ditch (see Fig. 17-7, C through F). The harder enamel should guide the bur. Slight pressure toward enamel is necessary to prevent the bur from cutting only dentin. If the bur is allowed to cut only dentin, the resulting axial wall would be too deep. The mesiodistal width of the ditch should be 0.8 mm (the tip diameter of the bur) and

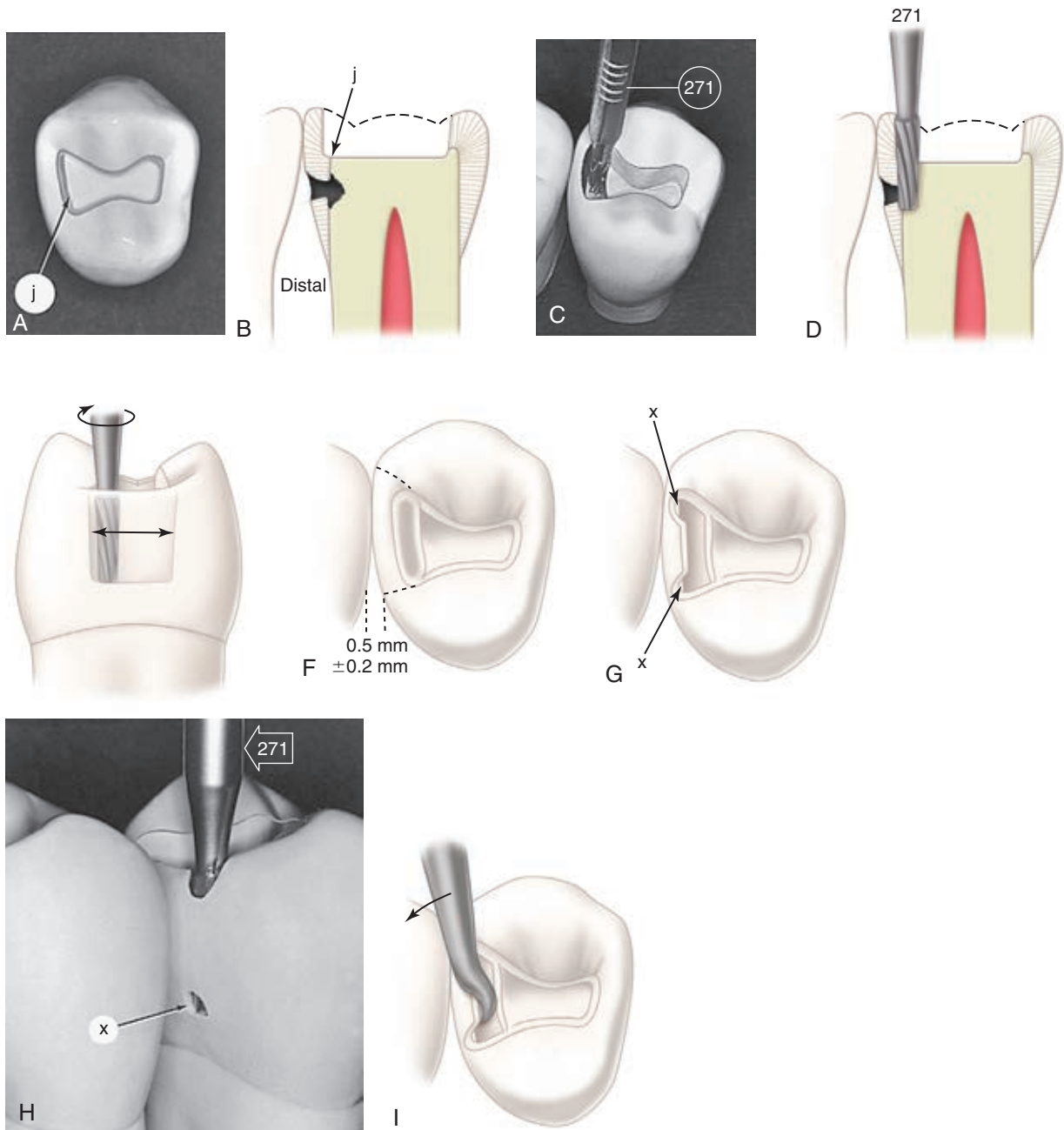


Fig. 17-7 **A**, After exposing the junction (*j*) of proximal enamel and dentin. **B**, Sectional drawing of **A**. **C**, Cutting the proximal ditch. **D**, Sectional drawing of **C**. **E**, Proximal view of **D**. **F**, Occlusal view of the proximal ditch with proposed ideal clearance with the adjacent tooth. **G** and **H**, Proximal ditch extended distally. *x*, penetration of enamel by side of bur at its gingival end. **I**, Breaking away isolated enamel.

prepared approximately two thirds (0.5 mm) at the expense of dentin and one third (0.3 mm) at the expense of enamel. The gingival extension of this cut may be checked with the length of the bur by first measuring the depth from the height of the marginal ridge and then removing the bur and holding it beside the tooth. A periodontal probe also may be used for this measurement. While penetrating gingivally, the dentist extends the proximal ditch facially and lingually beyond the caries to the desired position of the facioaxial and linguoaxial line angles. If the caries lesion is minimal, the ideal extension facially and lingually is performed as previously described (see Fig. 17-7, *F*). Ideal gingival extension of a minimal, cavitated

lesion eliminates caries on the gingival floor and provides a 0.5-mm clearance of the unbeveled gingival margin with the adjacent tooth. Moderate to extensive caries on the proximal surface dictates continued extension of the proximal ditch to the extent of the caries at the dentinoenamel junction (DEJ), but not pulpally (see Fig. 17-11, *D*). When preparing the proximal portion of the preparation, the dentist maintains the side of the bur at the specified axial wall depth regardless of whether it is in dentin, caries, old restorative material, or air. The operator should guard against overcutting the facial, lingual, and gingival walls, which would not conserve the tooth structure and could result in (1) overextension of the

margins in the completed preparation, (2) a weakened tooth, and (3) possible injury of soft tissue. Because the proximal enamel diminishes in thickness from the occlusal to gingival level, the end of the bur is closer to the external tooth surface as the cutting progresses gingivally. The axial wall should follow the contour of the tooth faciolingually. Any carious dentin on the axial wall should not be removed at this stage of the preparation.

With the No. 271 carbide bur, the dentist makes two cuts, one at the facial limit of the proximal ditch and the other at the lingual limit, extending from the ditch perpendicularly toward the enamel surface (in the direction of the enamel rods) (see Fig. 17-7, G). These cuts are extended until the bur is nearly through the marginal ridge enamel (the side of the bur may emerge slightly through the surface at the level of the gingival floor) as shown in Figure 17-7, H. This weakens the enamel by which the remaining isolated portion is held. Also, the level of the gingival floor is verified by observing where the end of the bur emerged through the proximal surface. If indicated, additional gingival extension can be accomplished while the remaining enamel still serves to guide the bur and to prevent it from marring the proximal surface of the adjacent tooth. At this time, however, the remaining wall of enamel often breaks away during cutting, especially when high speeds are employed. If the isolated wall of enamel is still present, it can be fractured out with a spoon excavator (see Fig. 17-7, I). At this stage, the ragged enamel edges left from breaking away the proximal surface may be touching the adjacent tooth.

Planing the distofacial, distolingual, and gingival walls by hand instruments to remove all undermined enamel may be indicated if minimal extension is needed to fulfill an esthetic objective. Depending on access, the operator can use a No. 15 (width) straight chisel, bin-angle chisel (Fig. 17-8), or enamel hatchet. For a right-handed operator, the distal beveled bin-angle chisel is used on the distofacial wall of a disto-occlusal preparation for the maxillary right premolar. The dentist planes the wall by holding the instrument in the modified palm-and-thumb grasp and uses a chisel-like motion in an occlusal-to-gingival direction (see Fig. 17-8, A and B). The dentist planes the gingival wall by using the same instrument as a hoe, scraping in a lingual-to-facial direction (see Fig. 17-8, C). In this latter action, the axial wall may be planed with the side edge (secondary edge) of the blade. The distolingual wall is planed smooth by using the bin-angle chisel with the mesial bevel (see Fig. 17-8, D). When proximal caries is minimal, ideal facial and lingual extensions at this step in the preparation result in margins that clear the adjacent tooth by 0.2 to 0.5 mm.

The experienced operator usually does not use chisel hand instruments during the preparation for inlays, considering that the narrow, flame-shaped, fine-grit diamond instrument, when artfully used, removes ragged, weak enamel during application of the cavosurface bevel and flares and causes the patient to be less apprehensive (see Figs. 17-12 and 17-13). If the diamond instrument is to be used exclusively in finishing the enamel walls and margins, this procedure is postponed until after the removal of any remaining infected dentin, old restorative material, or both and the application of any necessary base. Waiting prevents any hemorrhage (which occasionally follows the beveling of the gingival margin) from hindering (1) the suitable removal of remaining infected dentin and old restorative material and (2) the proper application of a

necessary base. Hand instruments are more useful on the mesiofacial surfaces of maxillary premolars and first molars, where minimal extension is desired to prevent an unsightly display of metal.

Shallow (0.3-mm deep) retention grooves may be cut in the facioaxial and linguoaxial line angles with the No. 169L carbide bur (see Fig. 17-8, E through I). These grooves are indicated especially when the prepared tooth is short. When properly positioned, the grooves are in sound dentin, close to but not contacting, the DEJ. The long axis of the bur must be held parallel to the line of draw. Preparing these grooves may be postponed until after any required bases are applied during the final preparation.

Final Preparation

REMOVAL OF INFECTED CARIOUS DENTIN AND PULP PROTECTION

After the initial preparation has been completed, the dentist evaluates the internal walls of the preparation visually and tactilely (with an explorer) for indications of any remaining carious dentin. If carious dentin remains, and if it is judged to be infected, but shallow or moderate (≥ 1 mm of remaining dentin between the caries and the pulp), satisfactory isolation for the removal of such caries and the application of any necessary base may be attained by reducing salivation through anesthesia and the use of cotton rolls, a saliva ejector, and gingival retraction cord. The retraction cord also serves to widen the gingival sulcus and slightly retract the gingiva in preparation for beveling and flaring the proximal margins (Fig. 17-9; see also Fig. 17-12, A and B). For insertion of the cord, see the sections on preparation of bevels and flares and tissue retraction. The removal of the remaining caries and placement of a necessary base can be accomplished during the time required for the full effect of the inserted cord. A slowly revolving round bur (No. 2 or No. 4) or spoon excavator is used to remove carious infected dentin (see Fig. 17-9, F and G). If a bur is used, visibility can be improved by using air alone. This excavation is done just above stall-out speed with light, intermittent cutting. The operator should avoid unnecessarily desiccating the exposed dentin during this procedure.

Light-cured glass ionomer cement may be mixed and applied with a suitable applicator to these shallow (or moderately deep) excavated regions to the depth and form of the ideally prepared surface. Placing a base takes little time and should be considered because it results in working dies (subsequently in the laboratory phase) that have preparation walls with no undercuts and “ideal” position and contour. Also, applying a base at this time minimizes additional irritation of the pulp during subsequent procedures necessary for the completion of the restoration. The light-cured glass ionomer adheres to the tooth structure and does not require retentive undercuts when the base is small to moderate. The material is applied by conveying small portions on the end of a periodontal probe and is light-cured when the correct form has been achieved (see Fig. 17-9, H and I). Any excess cement can be trimmed back to the ideal form with the No. 271 carbide bur after the cement has hardened.

If the caries lesion is judged to approach the pulp closely, a rubber dam should be applied before the removal of infected dentin. Rubber dam provides the optimal environment for

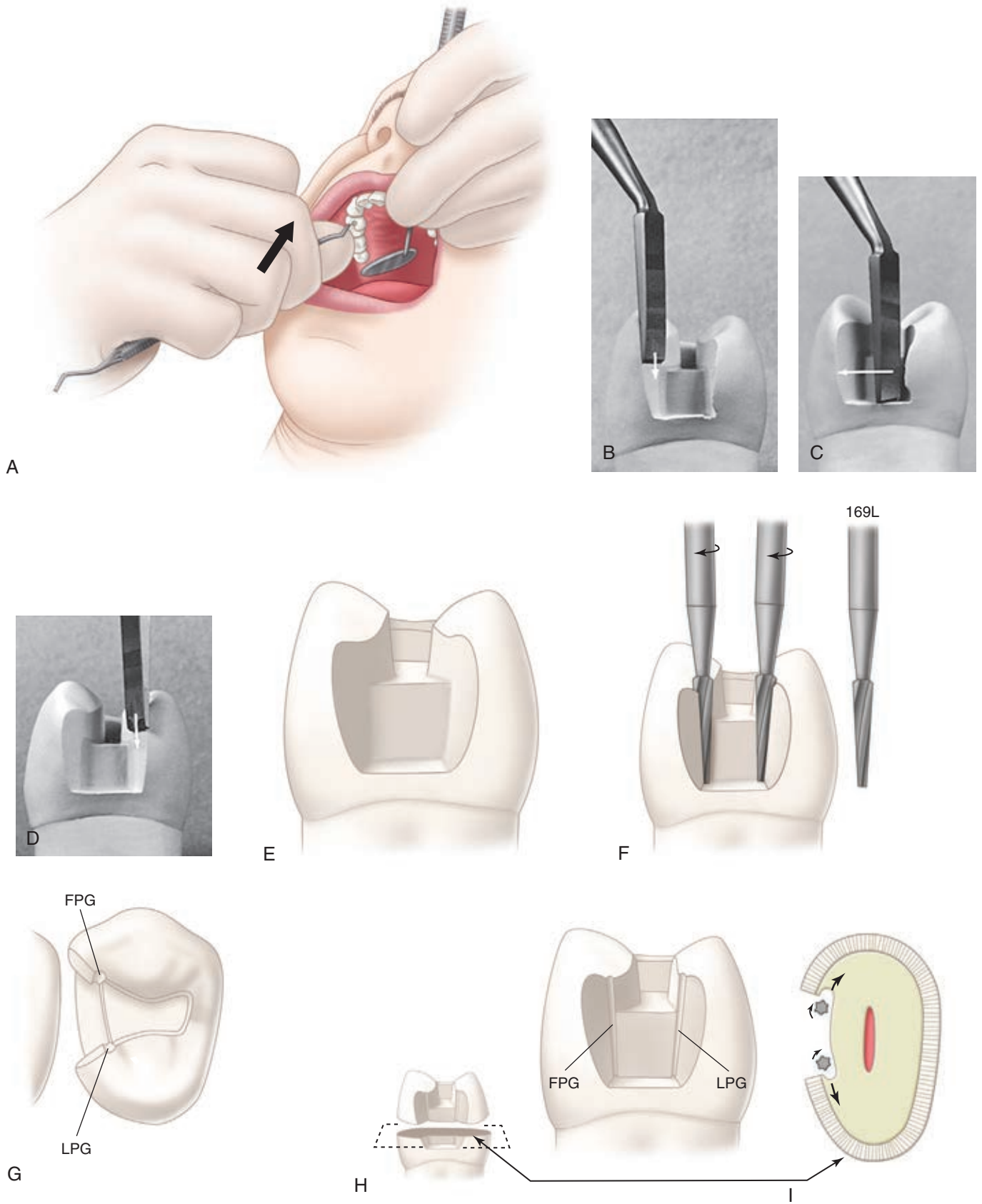


Fig. 17-8 **A–D**, Using modified palm-and-thumb grasp (**A**) to plane distofacial and distolingual walls (**B** and **D**) and to scrape gingival wall (**C**). **E**, Before cutting retention grooves. **F**, Cutting retention grooves. **G** and **H**, Facial proximal groove (*FPG*) and lingual proximal groove (*LPG*). **I**, Section in plane *x*. Large arrows depict the direction of translation of the rotating bur.

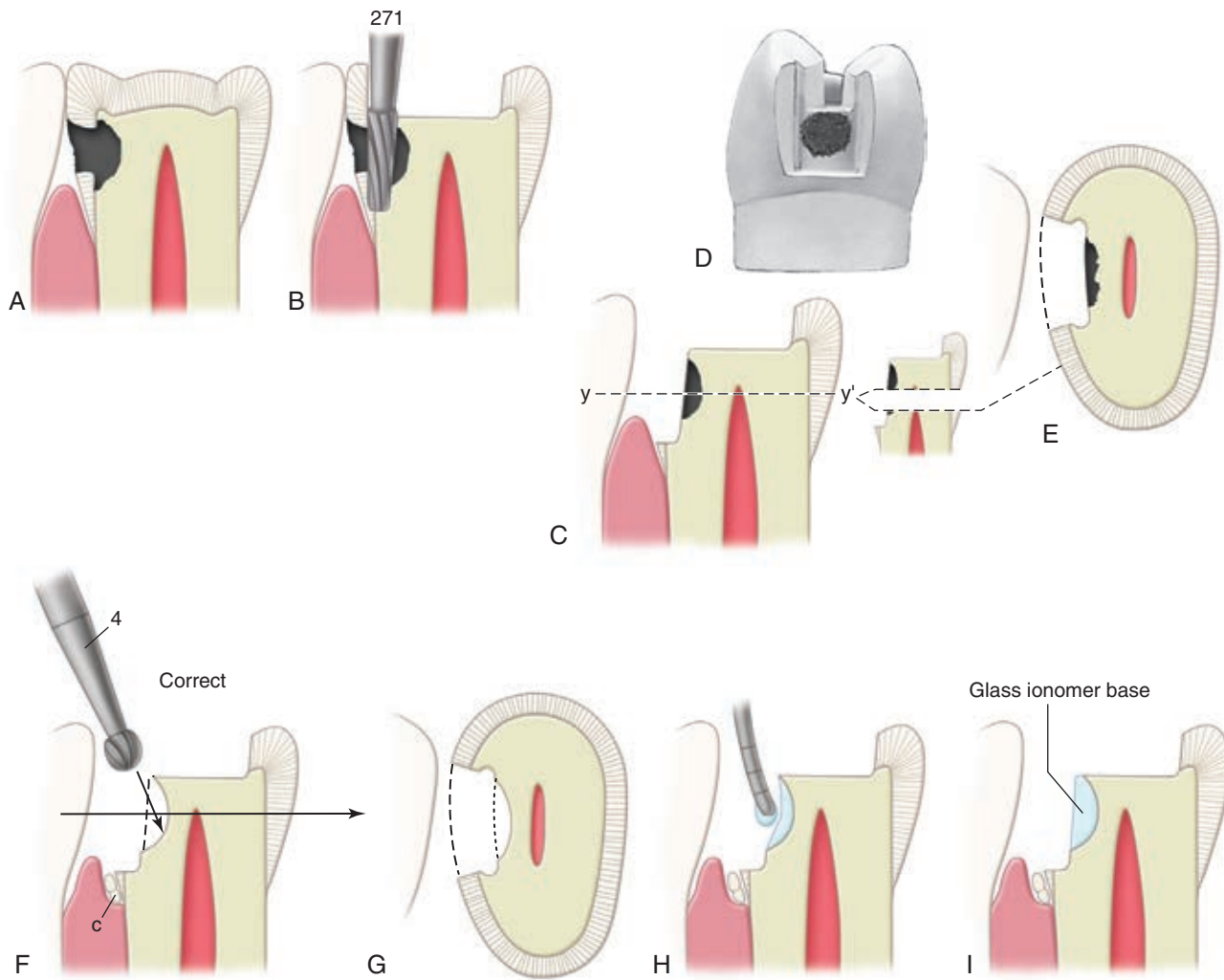


Fig. 17-9 Moderately deep caries. **A–C**, Extending the proximal ditch gingivally (**B**) to a sound floor free from caries (**C**). **D**, Remaining caries on the axial wall. **E**, Section of **C** in plane *yy*. **F**, Removing the remaining infected dentin. *c*, inserted retraction cord. **G**, Section of **F**. **H**, Inserting glass ionomer base with periodontal probe. **I**, Completed base.

successfully treating a pulp exposure should it occur. When excavating extensive caries, the dentist attempts to remove only infected dentin and not affected dentin because removal of the latter might expose a healthy pulp. Ideally, caries removal should continue until the remaining dentin is as hard as normal dentin; however, heavy pressure should not be applied with an explorer tip (or any other instrument) on dentin next to the pulp to avoid unnecessary pulpal exposure. If removal of soft, infected dentin leads directly to a pulpal exposure (carious pulpal exposure), root canal treatment should be accomplished before completing the cast metal restoration.

If the pulp is inadvertently exposed as a result of operator error or misjudgment (mechanical pulpal exposure), the operator must decide whether to proceed with the root canal treatment or to attempt a direct pulp capping procedure. A clinical evaluation should be made to determine the health of the pulp. A favorable prognosis for the pulp after direct pulp capping may be expected if the following criteria are met:

- The exposure is small (<0.5 mm in diameter).
- The tooth has been asymptomatic, showing no signs of pulpitis.
- Any hemorrhage from the exposure site is easily controlled.
- The invasion of the pulp chamber was relatively atraumatic with little physical irritation to the pulp tissue.
- A clean, uncontaminated operating field is maintained (i.e., by using a rubber dam).

If the excavation closely approaches the pulp or if a direct pulp cap is indicated, the dentist should first apply a lining of calcium hydroxide using a flow technique (without pressure). This calcium hydroxide liner should cover and protect any possible near or actual exposure and extend over a major portion of the excavated dentinal surface (Fig. 17-10, **A**). Although undetected, an exposed recessional tract of a pulp horn may exist in any deep excavation. Calcium hydroxide treatment of an exposed, healthy pulp promotes the formation of a dentin bridge, which would close the exposure.³ The

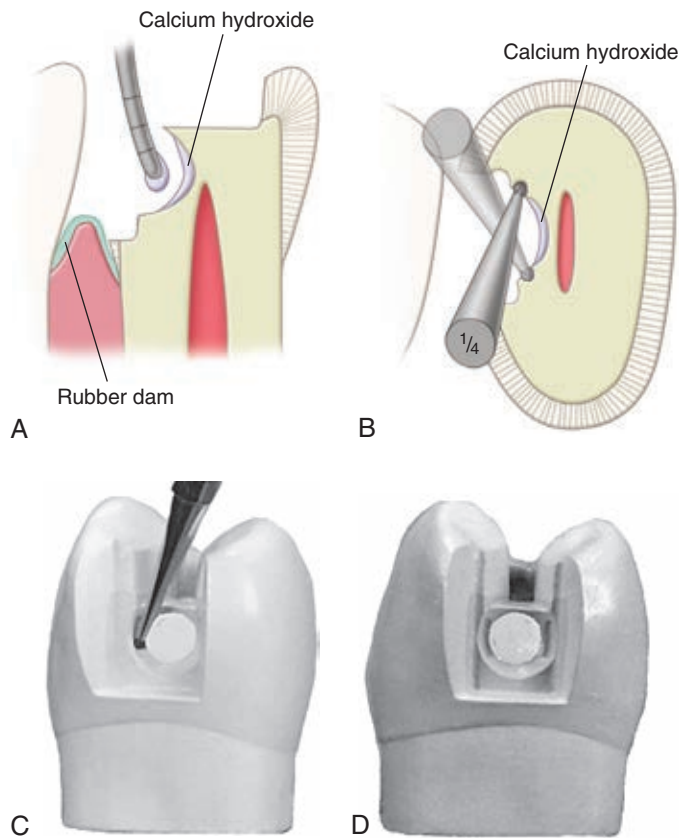


Fig. 17-10 **A**, Deep caries excavations near the pulp are first lined with calcium hydroxide. Note the rubber dam. **B–D**, Cutting retention covers for retaining glass ionomer cement.

peripheral 0.5 to 1 mm of the dentin excavation should be left available for bonding the subsequently applied light-cured glass ionomer cement base.

Although the light-cured glass ionomer cement is adhesive to dentin, large cement bases can be subjected to considerable stresses during fabrication of the temporary and try-in and cementation of the cast metal restoration. Also, if a calcium hydroxide liner has been applied, less dentin is available for adhesive bonding. In these circumstances, small mechanical undercuts can increase the retention of the glass ionomer base. If suitable undercuts are not present after the removal of infected dentin, retention covers are placed with the No. $\frac{1}{4}$ carbide bur (see Fig. 17-10, *B through D*). These covers are placed in the peripheral dentin of the excavation and are as remote from the pulp as possible. Light-cured glass ionomer cement should be applied without pressure. It should completely cover the calcium hydroxide lining and some peripheral dentin for good adhesion (Fig. 17-11). The cement base should be sufficiently thick in dimension to protect the thin underlying dentin and the calcium hydroxide liner from subsequent stresses. Usually, good resistance form dictates that the pulpal wall should not be formed entirely by a cement base; rather, in at least two regions, one diametrically across the excavation from the other, the pulpal wall should be in normal position, flat, and formed by sound dentin (see region S in Fig. 17-11, *E*, which depicts basing in a mandibular molar). The dentist should consider the addition of other

retention features such as proximal grooves if a major portion of a proximal axial wall is composed mostly of cement base because this base should not be relied on for contributing to retention of the cast restoration (see Fig. 17-8, *F*).

Any remaining old restorative material on the internal walls should be removed if any of the following conditions are present: (1) The old material is judged to be thin, nonretentive, or both, (2) radiographic evidence of caries under the old material is present, (3) the pulp was symptomatic preoperatively, or (4) the periphery of the remaining restorative material is not intact (i.e., some breach exists in the junction of the material with the adjacent tooth structure that may indicate caries under the material). If none of these conditions is present, the operator may elect to leave the remaining restorative material to serve as a base, rather than risk unnecessary removal of sound dentin or irritation or exposure of the pulp. The same isolation conditions described previously for the removal of infected dentin also apply for the removal of old restorative material.

Future root canal therapy is a possibility for any tooth treated for deep caries that approximates or exposes the pulp. When treating a tooth that has had such extensive caries, the following should be considered: (1) reducing all cusps to cover the occlusal surface with metal, for better distribution of occlusal loads, and (2) adding skirts to the preparation to augment the resistance form because teeth are more prone to fracture after root canal therapy.

PREPARATION OF BEVELS AND FLARES

After the cement base (where indicated) is completed, the slender, flame-shaped, fine-grit diamond instrument is used to bevel the occlusal and gingival margins and to apply the secondary flare on the distolingual and distofacial walls. This should result in 30- to 40-degree marginal metal on the inlay (see Figs. 17-12, *H*, 17-13, *J*, and 17-14, *B*). This cavosurface design helps seal and protect the margins and results in a strong enamel margin with an angle of 140 to 150 degrees. A cavosurface enamel angle of more than 150 degrees is incorrect because it results in a less defined enamel margin (finish line), and the marginal cast metal alloy is too thin and weak if its angle is less than 30 degrees. Conversely, if the enamel margin is 140 degrees or less, the metal is too bulky and difficult to burnish when its angle is greater than 40 degrees (see Fig. 17-14, *F*).

Usually, it is helpful to insert a gingival retraction cord of suitable diameter into the gingival sulcus adjacent to the gingival margin and leave it in place for several minutes just before the use of the flame-shaped diamond instrument on the proximal margins (Fig. 17-12, *A through C*). The cord should be small enough in diameter to permit relatively easy insertion and to preclude excessive pressure against the gingival tissue, and yet it should be large enough to widen the sulcus to about 0.5 mm. Immediately before the flame-shaped diamond instrument is used, the cord may be removed to create an open sulcus that improves visibility for beveling the gingival margin and helps prevent injury and subsequent hemorrhage of gingival tissue. Some operators prefer to leave the cord in the sulcus while placing the gingival bevel.

Using the flame-shaped diamond instrument that is rotating at high speed, the dentist prepares the lingual secondary flare (see Fig. 17-12, *D through F*; Fig. 17-13, *A*). The dentist approaches from the lingual embrasure (see Fig. 17-12, *F*),

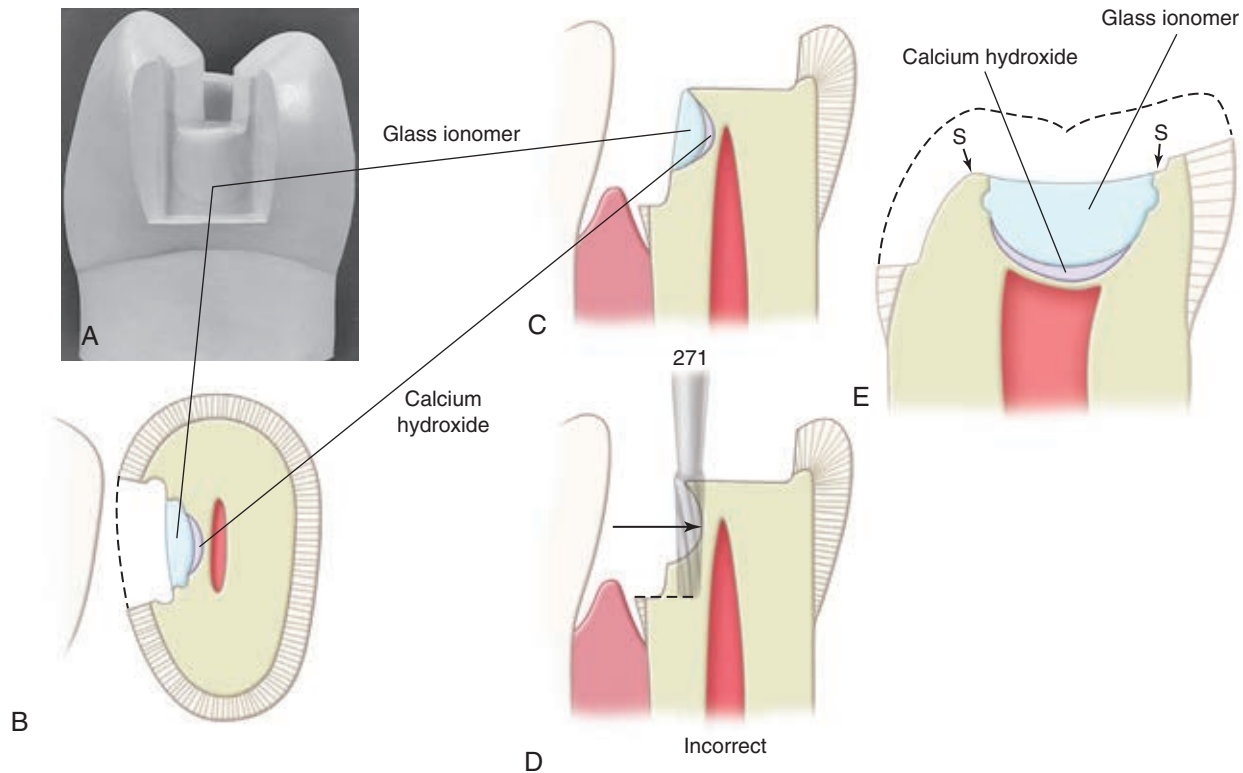


Fig. 17-11 A–C, Completed base for the treatment of deep caries. **D**, Never deepen entire axial wall with the side of a fissure bur to remove caries because the pulp would be greatly irritated from the resulting closeness of the gingivoaxial region of the preparation. **E**, Cement base placed deep in the excavation on the mandibular molar. Note the flat seats in sound dentin (S) that are required for adequate resistance form.

moving the instrument mesiofacially. The direction of the distolingual wall and the position of the distolingual margin are compared before and after this extension (see Figs. 17-8, G, and 17-13, A). The distolingual wall extends from the linguoaxial line angle into the lingual embrasure in two planes (see Fig. 17-13, A). The first is termed *lingual primary flare*; the second is termed *lingual secondary flare*. During this (secondary) flaring operation, the long axis of the instrument is held nearly parallel to the line of draw, with only a slight tilting mesially and lingually for assurance of draft (see Fig. 17-12, D and E), and the direction of translation of the instrument is that which results in a marginal metal angle of 40 degrees (see Figs. 17-12, F, and 17-13, J).

The dentist bevels the gingival margin by moving the instrument facially along the gingival margin (see Figs. 17-12, G, and 17-13, A). While cutting the gingival bevel, the rotational speed should be reduced to increase the sense of touch; otherwise, over-beveling may result. The instrument should be tilted slightly mesially to produce a gingival bevel with the correct steepness to result in 30-degree marginal metal (see Fig. 17-12, C, H, and J). If the instrument is not tilted in this manner, the bevel is too steep, resulting in gingival bevel metal that is too thin (<30-degree metal) and too weak. Although the instrument is tilted mesially, its long axis must not tilt facially or lingually (see Fig. 17-12, G). The gingival bevel should be 0.5 to 1 mm wide and should blend with the lingual secondary flare.

The operator completes the gingival bevel and prepares the facial secondary flare (see Fig. 17-13, A through F). The long

axis of the instrument during this secondary flare is again returned nearly to the line of draw, with only a small tilting mesially and facially, and the direction of translation of the instrument is that which results in 40-degree marginal metal (see Fig. 17-13, E and J). When the adjacent proximal surface (mesial of the second premolar) is not being prepared, care must be exercised to avoid abrading the adjacent tooth and overextending the distofacial margin. To prevent such abrasion or overextension, the instrument may be raised occlusally (using the narrower portion at its tip end) to complete the most facial portion of the wall and margin (see Fig. 17-13, D). Also, the more slender No. 169L carbide bur may be used, rather than the flame-shaped diamond instrument (see Fig. 17-13, H). The No. 169L bur produces an extremely smooth surface to the secondary flare and a smooth, straight distofacial margin. When access permits, a fine-grit sandpaper disk may be used on the facial and lingual walls and on the margins of the proximal preparation, especially when minimal extension of the facial margin is desired (see Fig. 17-13, I). This produces smooth walls and helps create respective margins that are straight (not ragged) and sound.

In the flaring and beveling of the proximal margins, as described in the previous paragraphs, the procedure began at the lingual surface and proceeded to the facial surface. The direction may be reversed, however, starting at the facial surface and moving toward the lingual surface. On the mesiofacial surface of maxillary premolars and first molars where extension of the facial margin should be minimal, it is usually desirable to use the lingual-to-facial direction.

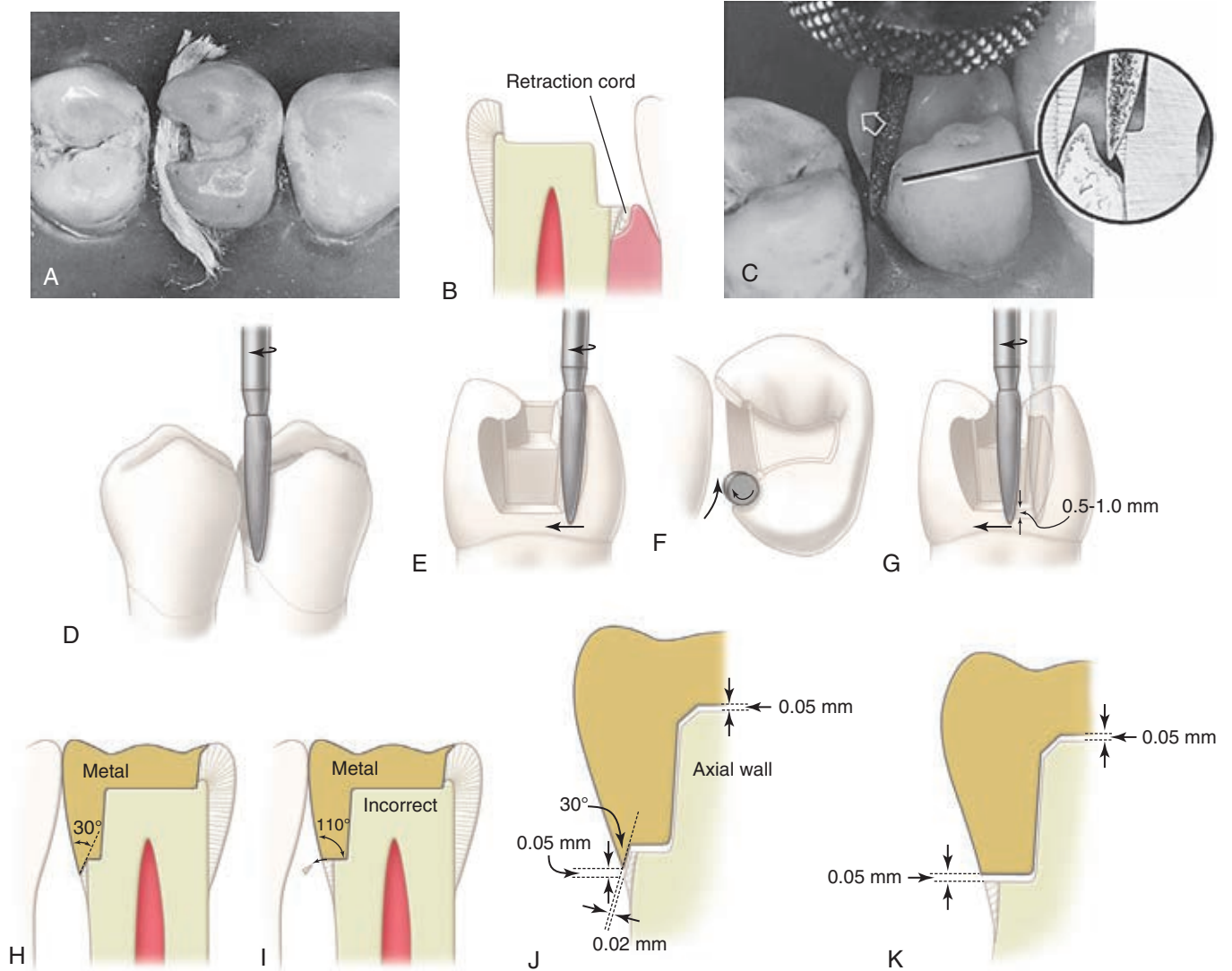


Fig. 17-12 **A** and **B**, The retraction cord is inserted in the gingival sulcus and left for several minutes. **C**, An open gingival sulcus after the cord shown in **A** is removed facilitates beveling the gingival margin with a diamond instrument. **D–F**, Diamond instrument preparing lingual secondary flare. Large arrow in **F** indicates the direction of the translation. **G**, Beveling the gingival margin. Note in **C** the mesial tilting of diamond instrument to produce a bevel that is properly directed to result in 30-degree marginal metal as shown in **H**. **H**, Properly directed gingival bevel resulting in 30-degree marginal metal. **I**, Failure to bevel the gingival margin results in a weak margin formed by undermined rods (note the easily displaced wedge of enamel) and 110-degree marginal metal, an angular design unsuitable for burnishing. **J**, Lap, sliding fit of prescribed bevel metal decreases the 50- μ m error of seating to 20 μ m. **K**, A 50- μ m error of seating produces an equal cement line of 50 μ m along the unbeveled gingival margin.

The gingival bevel serves the following purposes:

- Weak enamel is removed. If the gingival margin is in the enamel, it would be weak if not beveled because of the gingival declination of the enamel rods (see Fig. 17-12, *I*).
- The bevel results in 30-degree metal that is burnishable (on the die) because of its angular design (see Fig. 17-12, *H*). Bulky 110-degree metal along an unbeveled margin is not burnishable (see Fig. 17-12, *I*).
- A lap, sliding fit is produced at the gingival margin (see Fig. 17-12, *J*). This helps improve the fit of the casting in this region. With the prescribed gingival bevel, if the inlay fails to seat by 50 μ m, the void between the bevel metal and the gingival bevel on the tooth may be 20 μ m; however, failure to apply such a bevel would result in a void

(and a cement line) as great as in the failure to seat (see Fig. 17-12, *K*).

Uninterrupted blending of the gingival bevel into the secondary flares of the distolingual and distofacial walls results in the distolingual and distofacial margins joining the gingival margin in a desirable arc of a small circle; also, the gingivofacial and gingivolingual line angles no longer extend to the marginal outline. If such line angles are allowed to extend to the preparation outline, early failure may follow because of an “open” margin, dissolution of exposed cement, and eventual leakage, all potentially resulting in caries.

The secondary flare is necessary for several reasons: (1) The secondary flaring of the proximal walls extends the margins into the embrasures, making these margins more self-cleaning

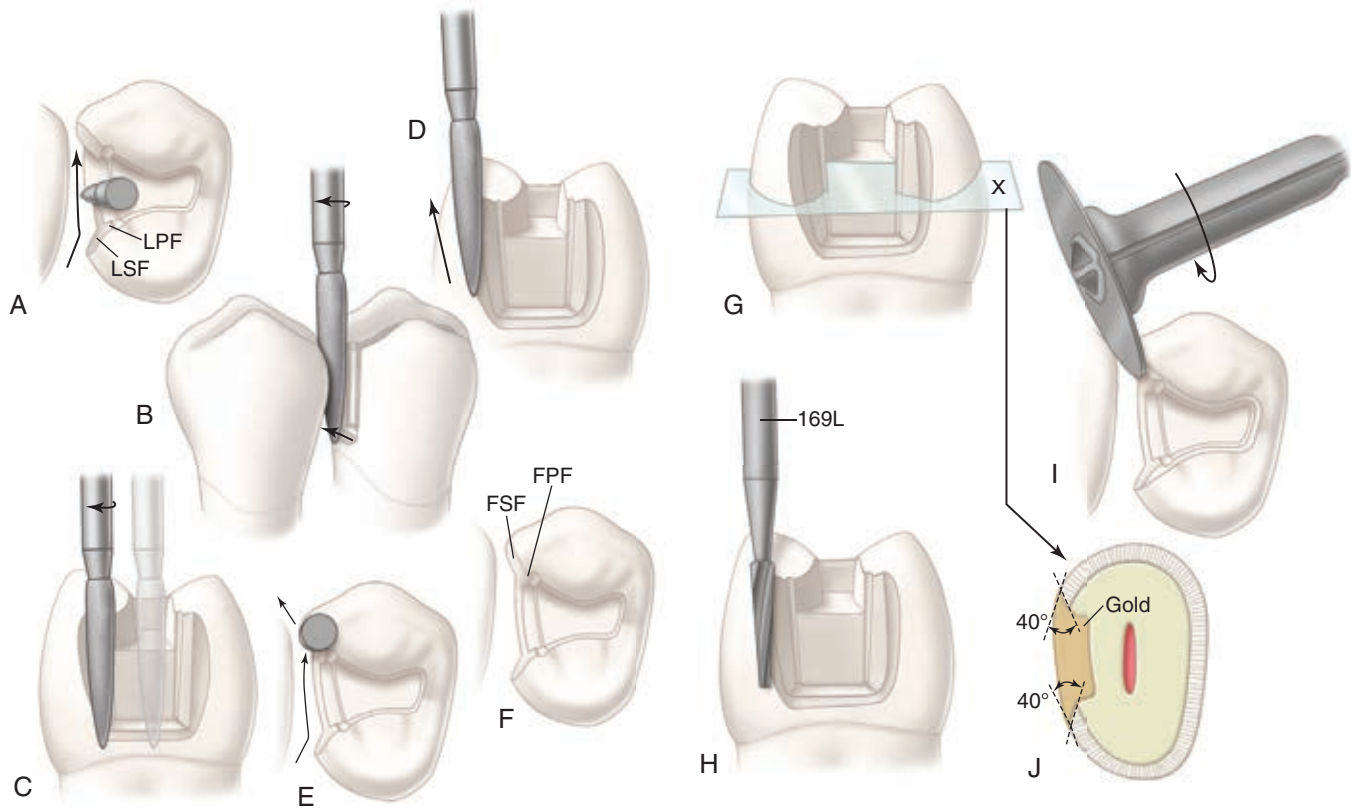


Fig. 17-13 **A**, Occlusal view of Figure 17-12, **G**. *LSF*, lingual secondary flare; *LPF*, lingual primary flare. **B–E**, Preparing the facial secondary flare. Large arrows in **B**, **D**, and **E** indicate the direction of the translation. **F**, Completed facial secondary flare. *FSF*, facial secondary flare; *FPF*, facial primary flare. **G**, Distal view of **F**. *x*, Plane of cross-section shown in **J**. **H** and **I**, Preparing the secondary flare with the No. 169L carbide bur (**H**) or with paper disk (**I**). **J**, The secondary flares are directed to result in 40-degree marginal metal and 140-degree marginal enamel.

and more accessible to finishing procedures during the inlay insertion appointment, and does so with conservation of dentin. (2) The direction of the flare results in 40-degree marginal metal (see Fig. 17-13, **J**). Metal with this angular design is burnishable; however, metal shaped at a larger angle is unsatisfactory for burnishing; metal with an angle less than 30 degrees is too thin and weak, with a corresponding enamel margin that is too indefinite and ragged. (3) A more blunted and stronger enamel margin is produced because of the secondary flare.

In a later section, the secondary flare is omitted for esthetic reasons on the mesiofacial proximal wall of preparations on premolars and first molars of the maxillary dentition. In this location, the wall is completed with minimal extension by using either hand instruments (straight or bin-angle chisel) followed by a fine-grit sandpaper disk or very thin rotary instruments.

The flame-shaped, fine-grit diamond instrument also is used for occlusal bevels. The width of the cavosurface bevel on the occlusal margin should be approximately one-fourth the depth of the respective wall (Fig. 17-14, **A** and **B**). The exception to the rule is when a wider bevel is desired to include an enamel defect (see Fig. 17-14, **G** and **H**). The resulting occlusal marginal metal of the inlay should be 40-degree metal; the occlusal marginal enamel is 140-degree enamel (see Fig. 17-14, **B** and **E**). Beveling the occlusal margins

in this manner increases the strength of the marginal enamel and helps seal and protect the margins. While beveling the occlusal margins, a guide to diamond positioning is to maintain an approximate 40-degree angle between the side of the instrument and the external enamel surface; this also indicates when an occlusal bevel is necessary (see Fig. 17-14, **A**). If the cusp inclines are so steep that the diamond instrument, when positioned at a 40-degree angle to the external enamel surface, is parallel with the enamel preparation wall, no bevel is indicated (see Fig. 17-14, **C**). By using this technique, it can be seen that margins on the proximal marginal ridges always require a cavosurface bevel (see Fig. 17-14, **D** and **I**). Failure to apply a bevel in these regions leaves the enamel margin weak and subject to injury by fracture before the inlay insertion appointment and during the try-in of the inlay when burnishing the marginal metal. Also, failure to bevel the margins on the marginal ridges results in metal alloy that is difficult to burnish because it is too bulky (see Fig. 17-14, **F**). Similarly, the importance of extending the occlusal bevel to include the portions of the occlusal margin that cross over the marginal ridge cannot be overemphasized (see Fig. 17-14, **H** and **I**). These margins are beveled to result in 40-degree marginal metal. Otherwise, fracture of the enamel margin in such stress-vulnerable regions may occur in the interim between the preparation and the cementation appointment.

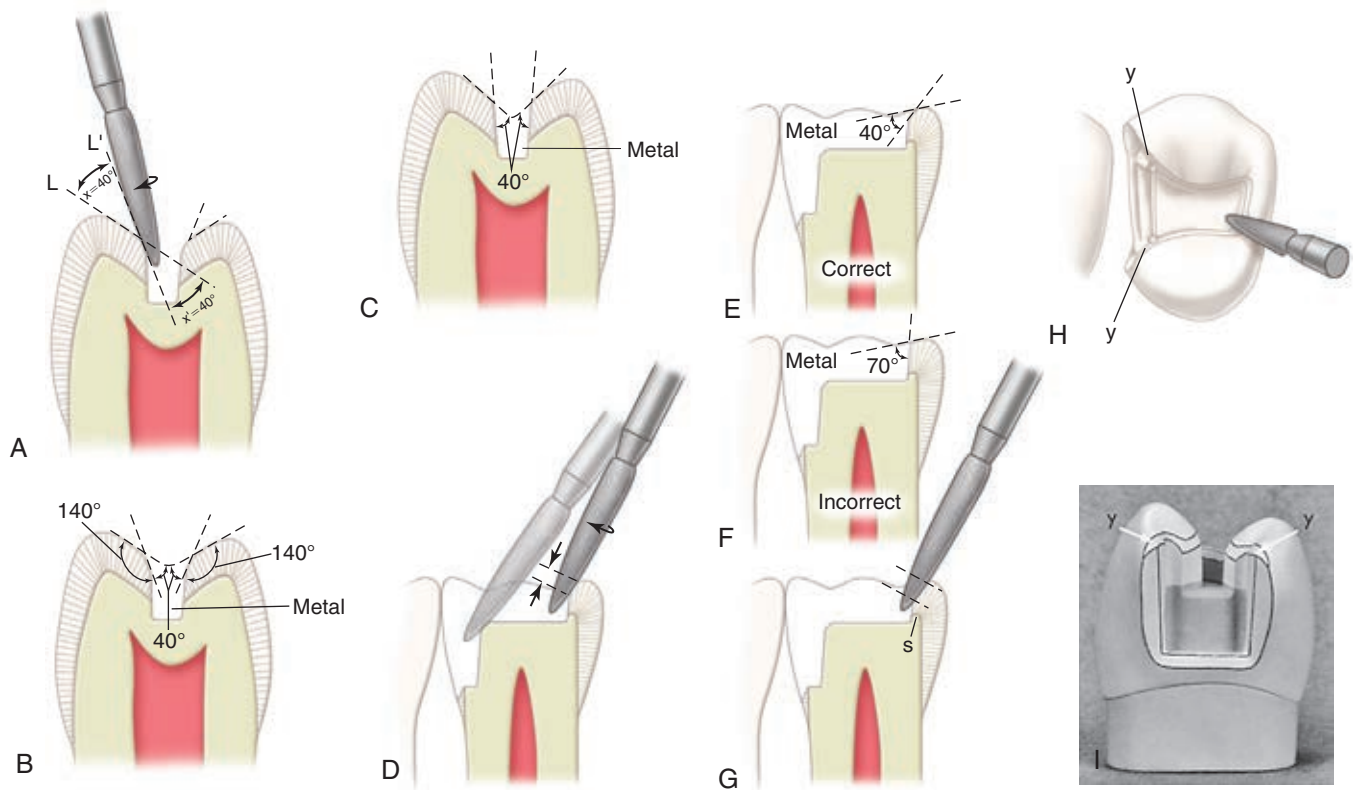


Fig. 17-14 **A**, The diamond instrument beveling the occlusal margin when it is indicated to result in 40-degree marginal metal, as shown in **B**. Angles x and x are equal because the opposite angles are equal when two lines (L and L') intersect. The diamond instrument is always directed such that an angle of 40 degrees is made by the side of the instrument and the external enamel surface. **B**, Occlusal marginal metal is approximately 40 degrees in cross-section, making the enamel angle 140 degrees. **C**, When the cuspal inclines are steep, no beveling is indicated considering that 40-degree metal would result without beveling. **D**, Beveling the mesial margin and the axiopulpal line angle. **E**, The mesial bevel is directed correctly to result in 40-degree marginal metal. **F**, An unbeveled mesial margin is incorrect because it results in a weak enamel margin and unburnishable marginal metal. **G**, To conserve dentinal support (s), occlusal defects on the marginal ridge are included in the outline form by applying a cavosurface bevel, which may be wider than usual, when necessary. **H**, Occlusal view of **G**. Preparing a 140-degree cavosurface enamel angle at regions labeled y usually dictates that the occlusal bevel be extended over the marginal ridges into the secondary flares. **I**, Distal view of **H**.

The diamond instrument also is used to bevel the axiopulpal line angle lightly (see Fig. 17-14, **D**). Such a bevel provides a thicker and stronger wax pattern at this critical region. The desirable metal angle at the margins of inlays is 40 degrees except at the gingival margins, where the metal angle should be 30 degrees. The completed preparation is illustrated in Figure 17-15, **A**.

Modifications in Inlay Tooth Preparations

Because the indications for small inlays are rare, the following sections provide procedural information that may promote better understanding of their applications in more complex and larger inlay or onlay restorations.

MESIO-OCCLUSO-DISTAL PREPARATION

If a marginal ridge is severely weakened because of excessive extension, the preparation outline often should be altered to include the proximal surface. The disto-occlusal preparation illustrated in the previous section would be extended to a mesio-occluso-distal preparation (Fig. 17-16, **A through C**; see also Fig. 17-15, **B through D**). The decision to extend the

preparation in this manner calls for clinical judgment as to whether the remaining marginal ridge would withstand occlusal forces without fracture. A fortunate factor in favor of not extending the preparation is that such ridge enamel usually is composed of gnarled enamel and is stronger than it appears. Caries present on both proximal surfaces would result in a mesio-occluso-distal preparation and restoration. The only difference in technique as described previously is the inclusion of the other proximal surface.

MODIFICATIONS OF CLASS II PREPARATION FOR ESTHETICS

For esthetic reasons, minimal flare is desired for the mesiofacial proximal wall in maxillary premolars and first molars in Class II cast metal preparations (see Fig. 17-15, **D**). The mesiofacial margin is minimally extended facially of the contact to such a position that the margin is barely visible from a facial viewing position. To accomplish this, the secondary flare is omitted, and the wall and margin are developed with (1) a chisel or enamel hatchet and final smoothing with a fine-grit paper disk or (2) a narrow diamond or bur when access permits.

FACIAL OR LINGUAL SURFACE GROOVE EXTENSION

Sometimes, a faulty facial groove (fissure) on the occlusal surface is continuous with a faulty facial surface groove (mandibular molars), or a faulty distal oblique groove on the occlusal surface is continuous with a faulty lingual surface groove (maxillary molar). This situation requires extension of the preparation outline to include the fissure to its termination (Fig. 17-17; see also Fig. 17-19, C). Occasionally, the operator may extend further gingivally than the fissure length to improve retention form. Such groove extensions, when sufficiently long, are effective for increasing retention. Likewise, this extension may be indicated to provide sufficient retention form even though the facial or lingual surface grooves are not fissured.

For extension onto the facial surface, the dentist uses the No. 271 carbide bur held parallel to the line of draw and extends through the facial ridge (see Fig. 17-17, A and B). The depth of the cut should be 1.5 mm. The floor (pulpal wall) should be continuous with the pulpal wall of the occlusal portion of the preparation (see Fig. 17-17, D).

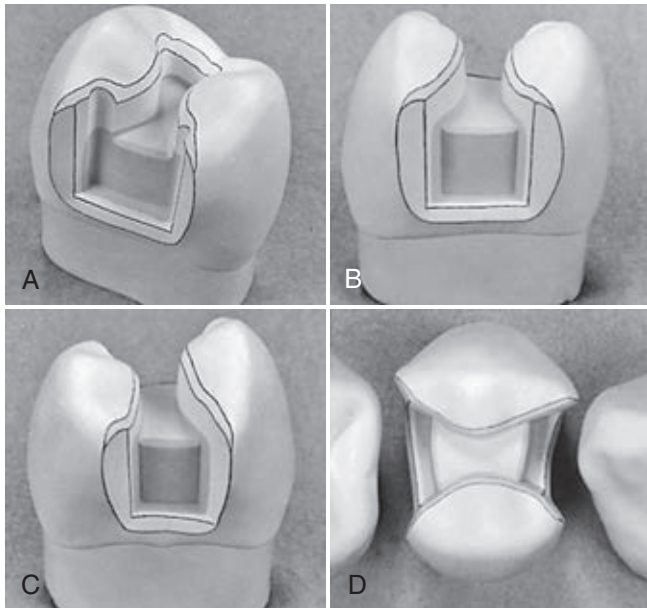


Fig. 17-15 A, Completed disto-occlusal preparation for the inlay. B, Mesio-occluso-distal preparation for the inlay on the maxillary right first premolar, disto-occlusal view. C, Same preparation as in B, mesio-occlusal view. D, Same preparation as in B, occlusal view. Note the absence, for esthetic reasons, of secondary flare on the mesiofacial aspect and minimal extension of the mesiofacial margin.

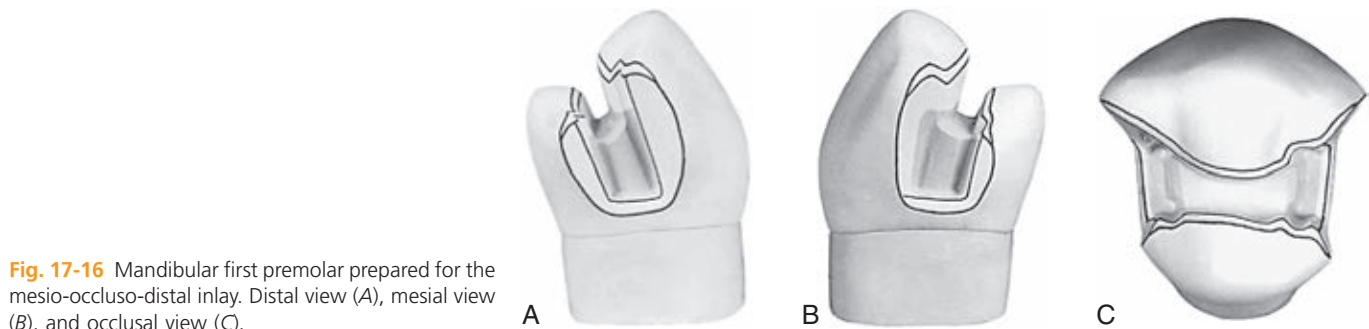


Fig. 17-16 Mandibular first premolar prepared for the mesio-occluso-distal inlay. Distal view (A), mesial view (B), and occlusal view (C).

With the bur still aligned with the path of draw, the dentist uses the side of the bur to cut the facial surface portion of this extension (see Fig. 17-17, C). The diameter of the bur serves as a depth gauge for the axial wall, which is in dentin. The blade portion of the No. 271 bur is 0.8 mm in diameter at its tip end and 1 mm at the neck; the axial wall depth should approximate 1 mm or slightly more. The bur should be tilted lingually as it is drawn occlusally, to develop the uniform depth of the axial wall (see Fig. 17-17, D). The same principles apply for the extension of a lingual surface groove.

When a facial or lingual groove is included, it also must be beveled. With the flame-shaped, fine-grit diamond instrument, the operator bevels the gingival margin (using no more than one third the depth of the gingival floor) to provide for 30-degree marginal metal (see Fig. 17-17, E). The operator applies a light bevel on the mesial and distal margins that is continuous with the occlusal and gingival bevels and results in 40-degree metal at these margins (see Fig. 17-17, F and G). The bevel width around the extended groove is approximately 0.5 mm.

CLASS II PREPARATION FOR ABUTMENT TEETH AND EXTENSION GINGIVALLY TO INCLUDE ROOT-SURFACE LESIONS

Extending the facial, lingual, and gingival margins may be indicated on the proximal surfaces of abutments for removable partial dentures to increase the surface area for the development of guiding planes. In addition, the occlusal outline form must be wide enough faciolingually to accommodate any contemplated rest preparation without involving the margins of the restoration. These extensions may be accomplished by simply increasing the width of the bevels.

The following modified preparation is recommended when further gingival extension is indicated to include a root lesion on the proximal surface. The gingival extension should be accomplished primarily by lengthening the gingival bevel, especially when preparing a tooth that has a longer clinical crown than normal as a result of gingival recession. It is necessary to extend (gingivally) the gingival floor only slightly, and although the axial wall consequently must be moved pulpally, this should be minimal. If additional extension of the gingival floor is necessary, it should not be as wide pulpally as when the floor level is at a normal position (Fig. 17-18, A). These considerations are necessary because of the draft requirement and because the tooth is smaller apically. Extending the preparation gingivally without these modifications would result in a dangerous encroachment of the axial wall on the pulp (see Fig. 17-18, B).

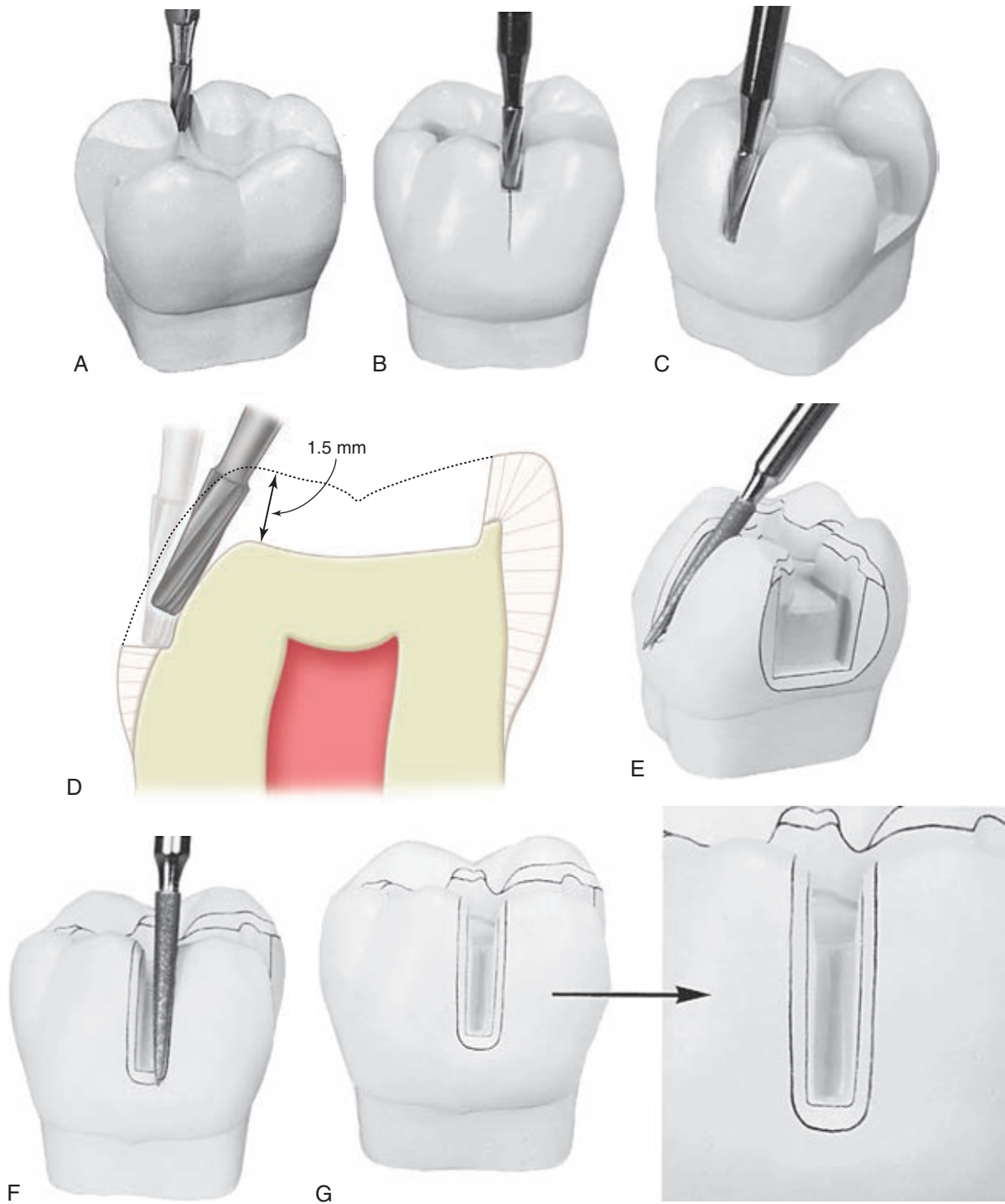


Fig. 17-17 A–C, Extending to include the occlusal fissure that is continuous with the facial fissure on the facial surface. D, Section of C. E and F, Beveling the gingival margin (E) and the mesial and distal margins (F) of fissure extension. G, Beveling completed.

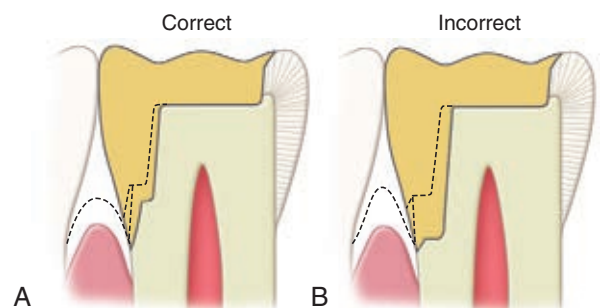


Fig. 17-18 Modifications of the preparation when extending to include the proximal root-surface lesions after moderate gingival recession. A, Correct. B, Incorrect. Note the decreased dentinal protection of the pulp compared with the management depicted in A.

MAXILLARY FIRST MOLAR WITH UNAFFECTED, STRONG OBLIQUE RIDGE

When a maxillary first molar is to be restored, consideration should be given to preserving the oblique ridge if it is strong and unaffected, especially if only one proximal surface is carious. A mesio-occlusal preparation for an inlay is illustrated

in Figure 17-19, *A* and *B*. If a distal surface lesion appears subsequent to the insertion of a mesio-occlusal restoration, the tooth may be prepared for a disto-occluso-lingual inlay (see Fig. 17-19, *H* and *I*). The disto-occluso-lingual restoration that caps the distolingual cusp is preferable to the disto-occlusal restoration because it protects the miniature

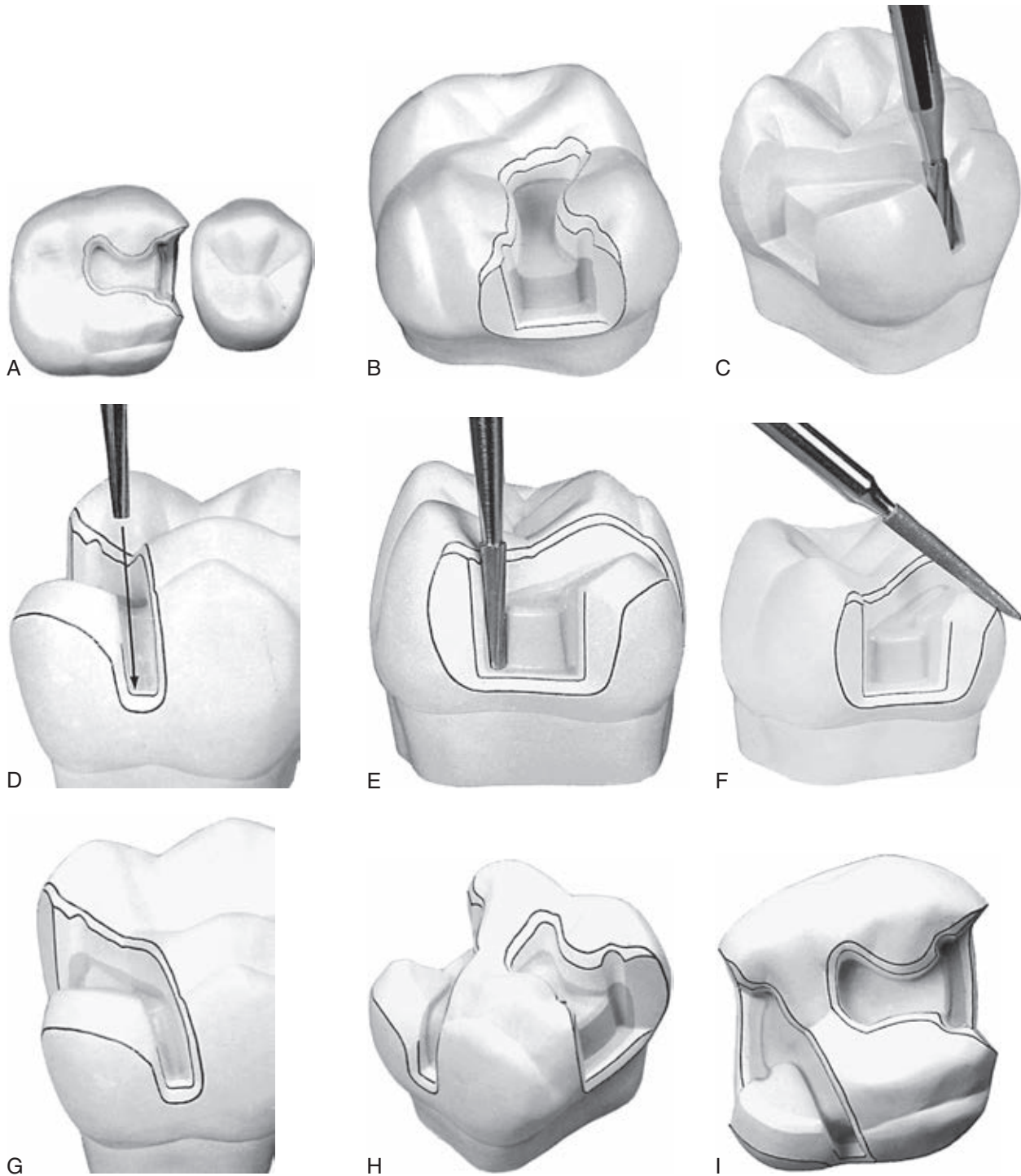


Fig. 17-19 *A* and *B*, Mesio-occlusal preparation on the maxillary molar having an unaffected oblique ridge. *C*, Preparing the lingual groove extension of the disto-occluso-lingual preparation. *D* and *E*, Cutting retention grooves in the lingual surface extension (*D*) and the distal box (*E*). *F* and *G*, Completed disto-occluso-lingual preparation on the maxillary molar having an unaffected oblique ridge. *H* and *I*, Preparations for treating both proximal surfaces of the maxillary molar having a strong, unaffected oblique ridge.

distolingual cusp from subsequent fracture. The disto-occluso-lingual preparation requires diligent application to develop satisfactory retention and resistance forms. Retention form is attained by (1) creating a maximum of 2-degree occlusal divergence of the vertical walls, (2) accentuating some line angles, and (3) extending the lingual surface groove to create an axial wall height in this extension of at least 2.5 mm occlusogingivally. The proper resistance form dictates (1) routine capping of the distolingual cusp and (2) maintaining sound tooth structure between the lingual surface groove extension and the distolingual wall of the proximal boxing.

To prepare the disto-occluso-lingual preparation, the operator first reduces the distolingual cusp with the side of the No. 271 carbide bur. The cusp should be reduced a uniform 1.5 mm. Next, the operator completes the remaining occlusal step of the preparation with the No. 271 carbide bur. The operator prepares the proximal box portion of the preparation. The lingual groove extension is prepared only after the position of the distolingual wall of the proximal boxing is established. This permits the operator to judge the best position of the lingual surface groove extension to maintain a minimum of 3 mm of sound tooth structure between this extension and the distolingual wall; if this is not possible because of extensive caries, a more extensive type of preparation may be indicated (one that crosses the oblique ridge). One can use the side of the No. 271 carbide bur to produce the lingual surface groove extension (see Fig. 17-19, C). The diameter of the bur is the gauge for the depth (pulpally) of the axial wall in this extension, and the occlusogingival dimension of this axial wall is a minimum of 2.5 mm. With the end of this bur, the operator also establishes a 2-mm depth to the portion of the pulpal floor that connects the proximal boxing to the lingual surface groove extension. This additional depth to the pulpal floor helps strengthen the wax pattern and casting in later steps of fabrication. This should create a definite 0.5-mm step from the reduced distolingual cusp to the pulpal floor. Using the No. 169L carbide bur, the operator increases retention form in the disto-occluso-lingual preparation by (1) creating mesioaxial and distoaxial grooves in the lingual surface groove extension (see Fig. 17-19, D) and (2) preparing facial and lingual retention grooves in the distal boxing (see Fig. 17-19, E).

The dentist uses the flame-shaped, fine-grit diamond instrument to bevel the proximal gingival margin and to prepare the secondary flares on the proximal enamel walls and to bevel the lingual margins. A lingual counterbevel is prepared on the distolingual cusp that is generous in width and results in 30-degree metal at the margin (see Fig. 17-19, F). Occlusion should be checked at this point because the counterbevel should be sufficiently wide to extend beyond any occlusal contacts, either in maximum intercuspation or during mandibular movements. The bevel on the gingival margin of the lingual extension should be 0.5 mm wide and should provide for a 30-degree metal angle. The bevels on the mesial and distal margins of the lingual extension also are approximately 0.5 mm wide and result in 40-degree marginal metal.

FISSURES IN THE FACIAL AND LINGUAL CUSP RIDGES OR MARGINAL RIDGES

In the preparation of Class II preparations for inlays, facial and lingual occlusal fissures may extend nearly to, or through, the respective facial and lingual cusp ridges, but not onto the

facial or lingual surface. The proper outline form dictates that the preparation margin should not cross such fissures but should be extended to include them. For the occlusal step portion of the preparation, the dentist initially extends along the lingual fissure with the No. 271 carbide bur until only 2 mm of tooth structure remains between the bur and the lingual surface of the tooth. Additional lingual extension at this time is incorrect because it may remove the supporting dentin unnecessarily (Fig. 17-20, A and B). If this extension almost includes the length of the fissure, additional extension is achieved later by using the occlusal bevel; this bevel may be wider than conventional if the remaining fissure can be eliminated by such a wider bevel (see Fig. 17-20, C). Enameloplasty sometimes may eliminate the end portion of the fissure and provide a smooth enamel surface where previously a fault was present, thus reducing the extent of the required extension (see Fig. 17-20, D). If possible, the fissure should be included in the preparation outline without extending the margin to the height of the ridge. If the occlusal bevel places the margin on the height of the ridge, however, the marginal enamel likely is weak because of its sharpness and because of the inclination of the enamel rods in this region. The preparation outline should be extended just onto the facial or lingual surface (see Fig. 17-20, I and J). Such extension onto the facial or lingual surface also would be indicated if the fissure still remains through the ridge after enameloplasty (see Fig. 17-20, E).

When necessary, extension through a cusp ridge is accomplished by cutting through the ridge at a depth of 1 mm with the No. 271 carbide bur (see Fig. 17-20, F and G). The dentist bevels the margins of the extension with the flame-shaped, fine-grit diamond instrument to provide for the desired 40-degree marginal metal on the occlusal, mesial, and distal margins and for 30-degree marginal metal on the gingival margin (see Fig. 17-20, C, D, I, and J). In the same manner, the operator should manage the fissures that may extend into or through a proximal marginal ridge, assuming that the proximal surface otherwise was not to be included in the outline form and that such fissure management does not extend the preparation outline near the adjacent tooth contact. This treatment particularly applies to a mesial fissure of the maxillary first premolar (Fig. 17-21). If this procedure extends the margin near or into the contact, the outline form on the affected proximal surface must be extended to include the contact, as for a conventional proximal surface preparation.

CUSP-CAPPING PARTIAL ONLAY

The term *partial onlay* is used when a cast metal restoration covers and restores at least one but not all of the cusp tips of a posterior tooth. The facial and lingual margins on the occlusal surface frequently must be extended toward the cusp tips to the extent of the existing restorative materials and to uncover caries (Fig. 17-22, B and C). Undermined occlusal enamel should be removed because it is weak; removing such enamel provides access for the proper excavation of caries. When the occlusal outline is extended up the cusp slopes more than half the distance from any primary occlusal groove (central, facial, or lingual) to the cusp tip, covering (capping) the cusp should be considered. If the preparation outline is extended two thirds of this distance or more, capping the cusp is usually necessary to (1) protect the weak, underlying cuspal structure from fracture caused by masticatory force and

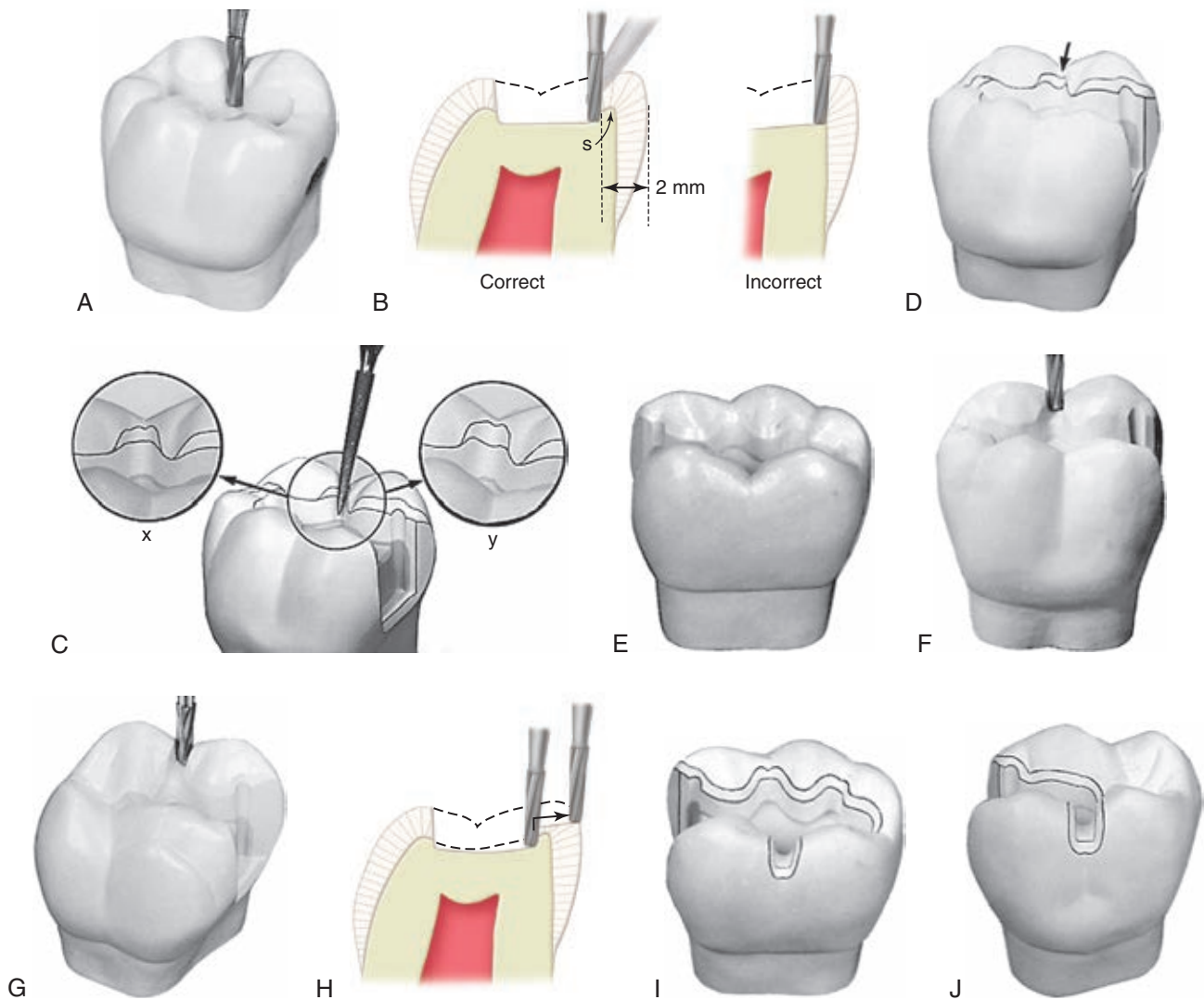


Fig. 17-20 **A**, Extending to include the lingual (occlusal) fissure. **B**, Section of **A**. The dentinal support (*s*) of the lingual cusp ridge should not be removed. A bevel can provide additional extension to include the fissure that does not extend to the crest of the ridge. **C**, Completed preparations with standard width bevel (*x*) and with wider bevel to include a groove defect that nearly extends to the ridge height (*y*). **D**, Completed preparation illustrating enameloplasty for the elimination of a shallow fissure extending to or through the lingual ridge height. (Compare the smooth, saucer-shaped lingual ridge contour with **C**, in which no enameloplasty has been performed.) **E**, Fissure remaining through the lingual ridge after unsuccessful enameloplasty. This indicates procedures subsequently illustrated. **F** and **G**, Extending the preparation if enameloplasty has not eliminated the fissure in the lingual ridge (**F**) or the facial ridge (**G**). **H**, Section of **F**. **I** and **J**, Completed preparations after beveling the margins of the extensions through the lingual ridge (**I**) and the facial ridge (**J**).

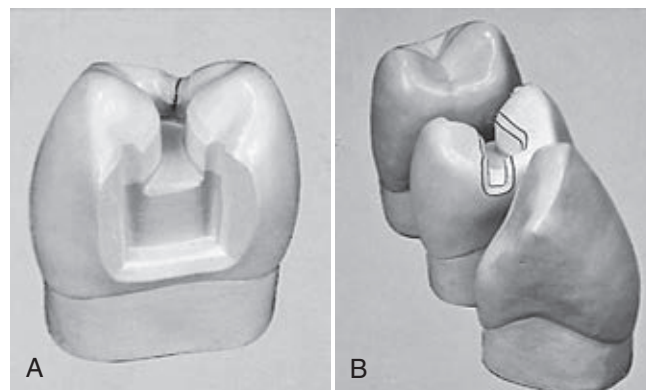


Fig. 17-21 The fissure that remains on the mesial marginal ridge after unsuccessful enameloplasty (**A**) is treated (**B**) in the same manner as lingual or facial ridge fissures (see **Fig. 17-20, I and J**).

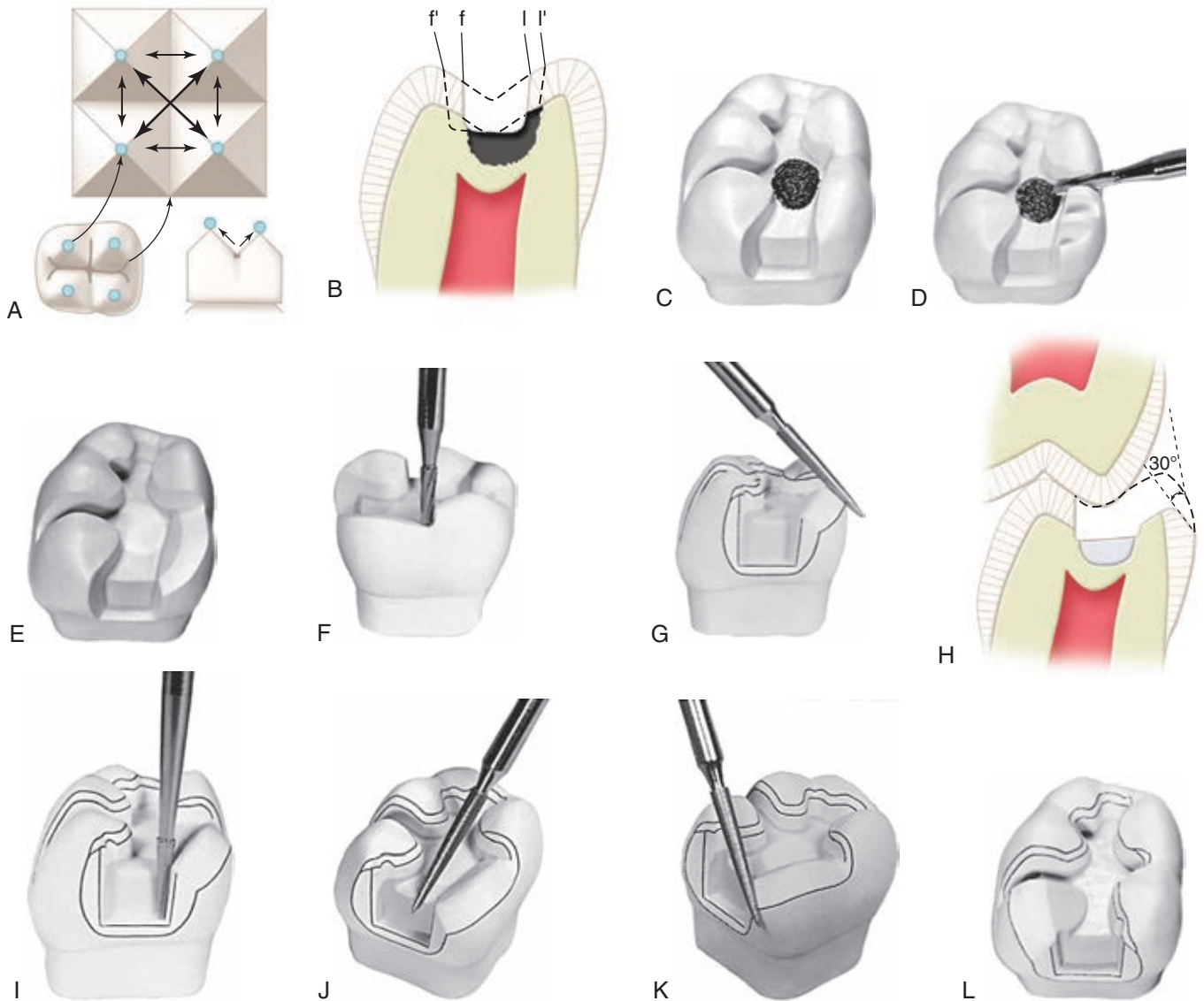


Fig. 17-22 **A**, When the extension of the occlusal margin is one half the distance from any point on the primary grooves (*cross*) toward the cusp tip (*dot*), capping of the cusp should be considered; when this distance is two thirds or more, capping of the cusp is usually indicated. **B**, *l* is midway between the central groove and the lingual cusp tip; *f* is midway between the central groove and the facial cusp tip. When enamel at *l* and *f* is undermined by caries, the respective walls must be extended to the dotted lines *l* and *f* to uncover caries. Cusps should be reduced for capping. **C**, Extension to uncover caries indicates that the mesiolingual cusp should be reduced for capping. **D**, Depth cuts. **E**, Reduced mesiolingual cusp. Caries has been removed, and the cement base has been placed. **F**, Applying the bur vertically helps establish the vertical wall that barely includes the lingual groove. **G**, Counterbeveling reduced cusp. **H**, Section of the counterbevel. **I**, Improving the retention form by cutting the proximal retention grooves. **J** and **K**, The preparation is complete except for the rounding of the axiopulpal line angle (*J*) and the rounding of the junction of the counterbevel and the secondary flare (*K*). Facial surface groove extension improves the retention and resistance forms. **L**, Preparation when reducing one of two facial cusps on the mandibular molar.

(2) remove the occlusal margin from a region subjected to heavy stress and wear (see Fig. 17-22, *A* and *B*). At this point in the preparation of the pulpal floor, depth can be increased from 1.5 mm to 2 mm. This additional pulpal depth ensures sufficient reduction in an area that is often under-reduced and results in imparting greater strength and rigidity to the wax pattern and cast restoration.

Reduce the cusps for capping as soon as the indication for such capping is determined because this improves access and visibility for the subsequent steps in the preparation. If a cusp is in infraocclusion of the desired occlusal plane before

reduction, the amount of cusp reduction is less and needs to be only that which provides the required clearance with the desired occlusal plane. Before reducing the surface, the operator prepares depth gauge grooves (depth cuts) with the side of the No. 271 carbide bur (see Fig. 17-22, *D*). Such depth cuts should help to prevent thin spots in the restoration. With the depth cuts serving as guides, the operator completes the cusp reduction with the side of the carbide bur (see Fig. 17-22, *E*). The reduction should provide for a uniform 1.5 mm of metal thickness over the reduced cusp. On maxillary premolars and first molars, the reduction should be minimal (i.e.,

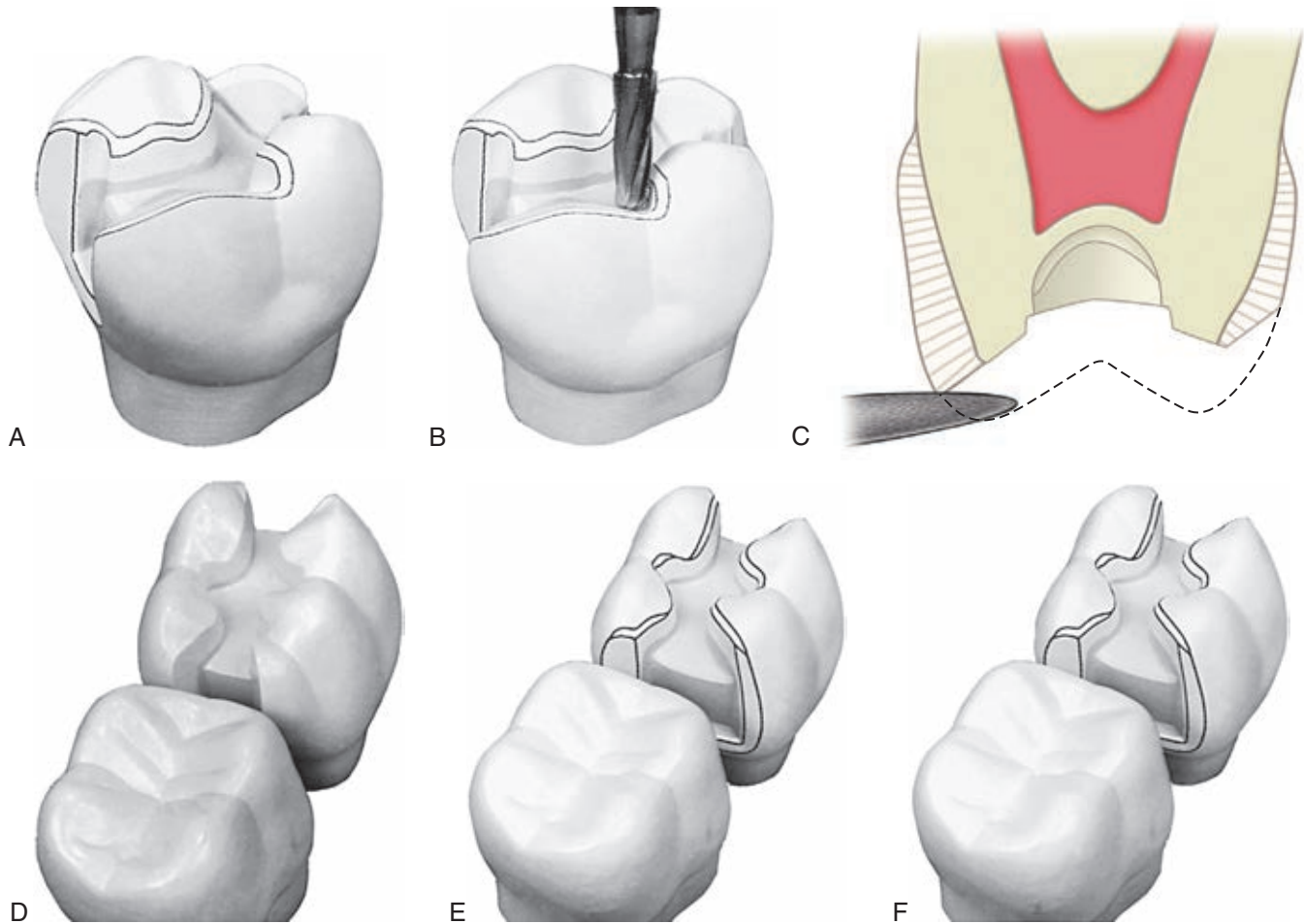


Fig. 17-23 **A** and **B**, Capping one of two facial cusps on the maxillary molar. **C**, Blunting the margin of the reduced cusp when esthetics is a major consideration. **D–F**, The margin shown crossing the distal cusp in **D** indicates treatment illustrated in **E** or **F**.

0.75–1 mm) on the facial cusp ridge to decrease the display of metal. This reduction should increase progressively to 1.5 mm toward the center of the tooth to help impart rigidity to the capping metal (Fig. 17-23, **A** and **C**).

If only one of the two lingual cusps of a molar is reduced for capping, the reduction must extend to include just the lingual groove between the reduced and unreduced cusps. This reduction should terminate with a distinct vertical wall that has a height that is the same as the prescribed cusp reduction. Applying the bur vertically (see Fig. 17-22, **F**) should help establish a vertical wall of proper depth and direction. Similar principles apply when only one of the facial cusps is to be reduced (see Figs. 17-22, **L**, and 17-23, **B**).

A bevel of generous width is prepared on the facial (lingual) margin of a reduced cusp with the flame-shaped, fine-grit diamond instrument (with the exception of esthetically prominent areas). This bevel is referred to as *reverse bevel* or *counterbevel*. The width varies because it usually should extend beyond any occlusal contact with opposing teeth, either in maximum intercuspation or during mandibular movements (see Fig. 17-24, **C**). It should be at an angle that results in 30-degree marginal metal (see Fig. 17-22, **G** and **H**). The exception is the facial margin on maxillary premolars and the first molar, where esthetic requirements dictate only a

blunting and smoothing of the enamel margin (a stub margin) by the light application of a fine-grit sandpaper disk or the fine-grit diamond instrument (flame-shaped) held at a right angle to the facial surface (see Fig. 17-23, **C**). Any sharp external corners should be rounded slightly to strengthen them and reduce the problems they may generate in future steps (see Fig. 17-22, **J** and **K**).

Cusp reduction appreciably decreases the retention form because it decreases the height of the vertical walls. Therefore, proximal retention grooves usually are recommended (see Fig. 17-22, **I**). It may be necessary to increase the retention form by extending facial and lingual groove regions of the respective surfaces or by collar and skirt features (see later). These additional retention features also provide the desired resistance form against forces tending to split the tooth (see Figs. 17-22, **K**, and 17-28).

The principles stated in the preceding paragraphs may be applied in the treatment of the distal cusp of the mandibular first molar when preparing a mesio-occluso-distal preparation (see Fig. 17-23, **D**). Proper extension of the distofacial margin usually places the occlusal margin in a region subjected to heavy masticatory forces and wear. Satisfactory treatment usually dictates either extending the distofacial margin (and wall) slightly mesial of the distofacial groove (see Fig. 17-23,

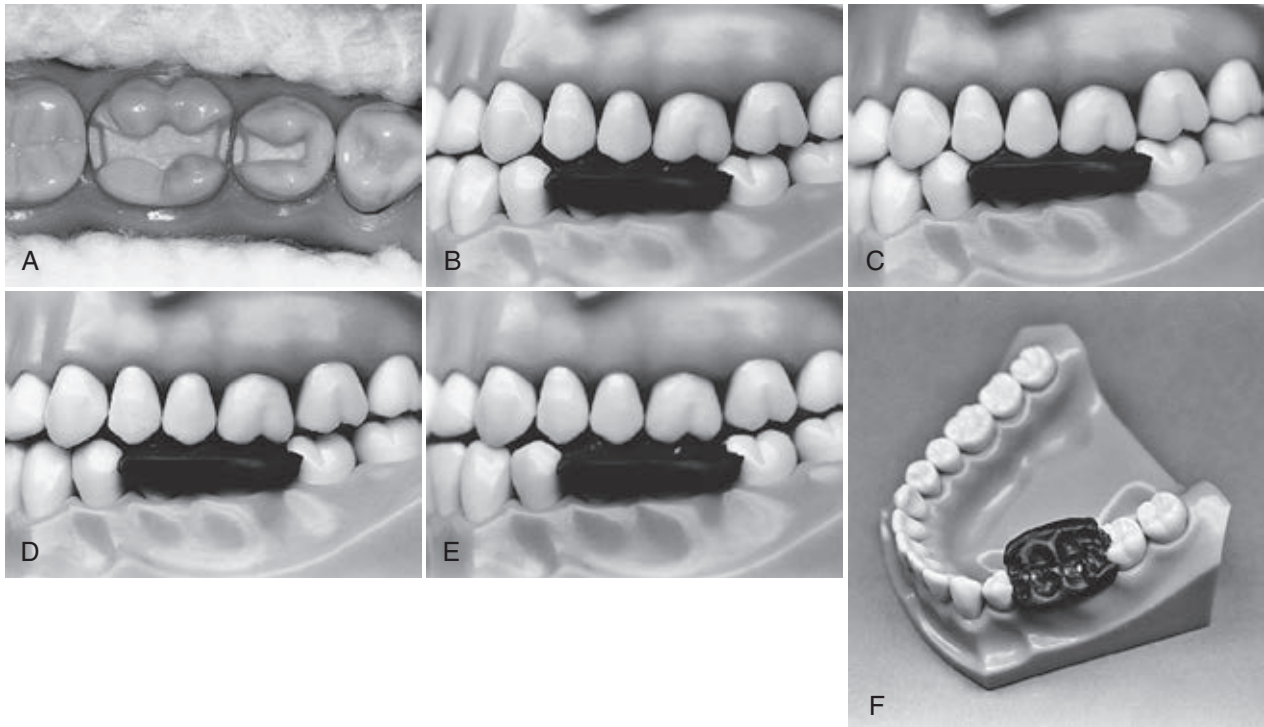


Fig. 17-24 Verifying sufficient cusp reduction by forming a wax interocclusal record. **A**, The walls of the preparations (disto-occlusal for the second premolar, and mesio-occluso-distal for the first molar) are air-dried of visible moisture. The low-fusing inlay wax that is the same length as the mesio-distal length of the inlay preparations is softened and pressed over the prepared teeth. **B–E**, The patient moves the mandible into all occlusal positions, left lateral (**B**), through maximum intercuspation (**C**), to right lateral (**D**), and protrusive (**E**). **F**, Completed interocclusal record.

E) or capping the remaining portion of the distal cusp (see Fig. 17-23, *F*).

After cusp reduction, the dentist visually verifies that the occlusal clearances are sufficient. A wax interocclusal record is helpful when checking the occlusal clearances, especially in areas that are difficult to visualize, for example, in the central groove and lingual cusp regions. To make a wax “bite,” the dentist first dries the preparation free of any visible moisture; however, dentin should not be desiccated (Fig. 17-24, *A*). Next, the dentist lightly presses a portion of softened, low-fusing inlay wax over the prepared tooth; the dentist immediately requests the patient to close into the soft wax and slide the teeth in all directions (see Fig. 17-24, *B* through *F*). During the mandibular movements, the dentist observes to verify that (1) the patient performs right lateral, left lateral, and protrusive movements; (2) the adjacent unprepared teeth are in contact with the opposing teeth; (3) the wax in the preparation is stable (not loose and rocking); and (4) the wax is not in infraocclusion. The dentist cools the wax and carefully removes it, holds it up to a light, and notes the degree of light transmitted through it. With experience, this is a good indicator of the thickness of the wax. An alternative method is to use wax calipers or to section the wax to verify its thickness. Insufficient thickness calls for more reduction in the indicated area before proceeding. As an alternative to wax, an interocclusal record can be made in maximum intercuspation with a quick-setting polyvinyl impression material. Once set, this interocclusal record can be measured with wax calipers to evaluate the reduction. If wax calipers are not available, the interocclusal record can be sectioned with a knife to see the

thickness in cross-section. However, a polyvinyl interocclusal record will not offer as much information as would the softened inlay wax technique, since the lateral and protrusive paths are not registered in the former.

INCLUDING PORTIONS OF THE FACIAL AND LINGUAL SMOOTH SURFACES AFFECTED BY CARIES OR OTHER INJURY

When portions of a facial (lingual) smooth surface and a proximal surface are affected by caries or some other factor (e.g., fracture) (Fig. 17-25, *A* and *I*), the treatment may be a large inlay, an onlay, a three-quarter crown, a full crown, or multiple amalgam or composite restorations. Generally, if carious portions are extensive, the choice between the previously listed cast metal restorations is determined by the degree of tooth circumference involved. A full crown is indicated if the lingual and the facial smooth surfaces are defective, especially if the tooth is a second or third molar. When only a portion of the facial smooth surface is carious, and the lingual surfaces of the teeth are conspicuously free of caries, a mesio-occlusal, distofacial, and distolingual inlay or onlay with a lingual groove extension is chosen over the crown because the former is more favorable to the health of the gingival tissues and more conservative in the removal of tooth structure. Often, this is the treatment choice for the maxillary second molar, which may exhibit caries or decalcification on the distofacial surface as a result of poor oral hygiene (owing to poor access) in this region.

In the preparation of the maxillary molar referred to in the preceding paragraph, the mesiofacial and distolingual cusps

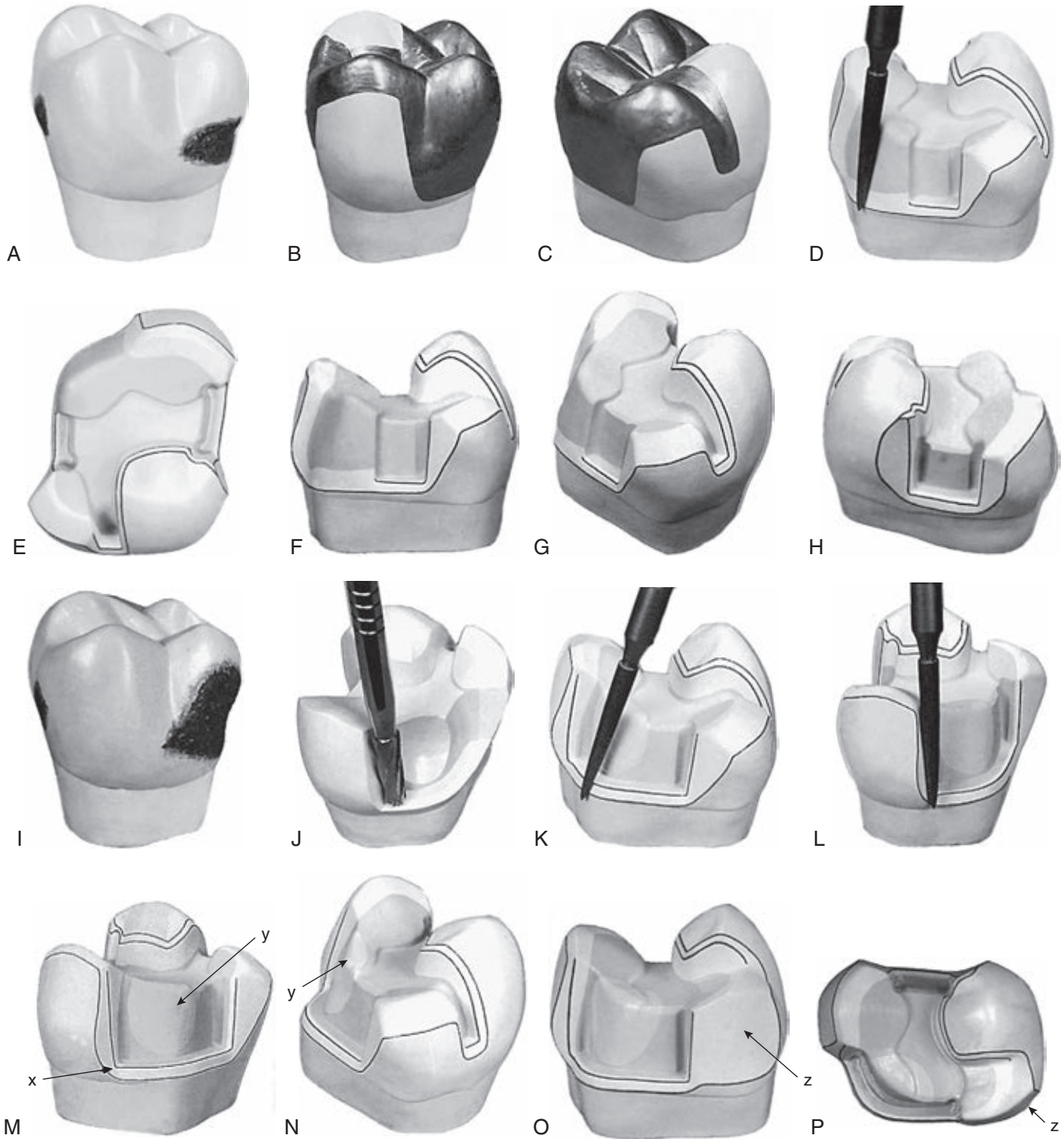


Fig. 17-25 **A**, Maxillary molar with caries on the distofacial corner and the mesial surface. **B** and **C**, Completed mesio-occlusal, distofacial, and distolingual inlay for treating caries shown in **A**, facio-occlusal view (**B**) and disto-linguo-occlusal view (**C**). **D–H**, Preparation for treating caries illustrated in **A**, disto-occlusal view with diamond instrument being applied (**D**), occlusal view (**E**), distal view (**F**), disto-linguo-occlusal view (**G**), and mesio-occlusal view (**H**). **I**, Maxillary molar with deeper caries on the distofacial corner and with mesial caries. **J**, Preparation (minus bevels and flares) for mesio-occlusal, distofacial, and distolingual inlay to restore the carious molar shown in **I**. A No. 271 carbide bur is used to prepare the gingival shoulder and the vertical wall. **K** and **L**, Beveling margins. **M** and **N**, Completed preparation for treating the caries shown in **I**. Gingival and facial bevels blend at **x**, and **y** is the cement base. **O** and **P**, When the lingual surface groove has not been prepared and when the facial wall of the proximal box is mostly or totally missing, forces directed to displace the inlay facially can be opposed by lingual skirt extension (**z**).

and the distofacial cusp are usually reduced for capping. If the distofacial cusp defect is primarily shallow decalcification, the flame-shaped diamond instrument is used to reduce the involved facial surface and distofacial corner approximately to the depth of enamel and to establish the gingival margin of this reduction apical to the affected area (see Fig. 17-25, *D*). This instrument also is used to terminate the facial surface reduction in a definite facial margin running gingivooclusally and in a manner to provide for 40-degree metal at this margin (see Fig. 17-25, *E*).

If the distofacial defect is more extensive and deeper into the tooth (see Fig. 17-25, *I*), eliminating the opportunity for an effective distal box or groove (no facial wall possible), the No. 271 carbide bur should be used to cut a gingival shoulder extending from the distal gingival floor around to include the affected facial surface. This shoulder partially provides the desired resistance form. (A gingival floor, perpendicular to occlusal force, has been provided in lieu of the missing pulpal wall in the distofacial cusp region.) The No. 271 bur is used to create a nearly vertical wall in the remaining facial enamel (see Fig. 17-25, *J*). The width of the shoulder should be the diameter of the end of the cutting instrument. The vertical walls should have the appropriate degree of draft to contribute to retention form. Then, the faciogingival and facial margins are beveled with the flame-shaped, fine-grit diamond instrument to provide 30-degree metal at the gingival margin (see Fig. 17-25, *K*) and 40-degree metal along the facial margin (see Fig. 17-25, *L*). These two bevels should blend together (see *x* in Fig. 17-25, *M*), and the faciogingival bevel should be continuous with the gingival bevel on the distal surface. Additional retention and resistance forms are indicated for this preparation and can be developed by an arbitrary lingual groove extension (see Fig. 17-25, *N*) or a distolingual skirt extension (see Fig. 17-25, *O* and *P*). These preparation features resist forces normally opposed by the missing distofacial wall and help protect the restored tooth from fracture injury.

Tooth Preparation for Full Cast Metal Onlays

The preceding sections have presented basic tooth preparation principles and techniques for small, simple cast metal inlays and for partial onlays that cap less than all the cusps. This section presents the tooth preparation principles and techniques for *full onlay* restorations that cover the entire occlusal surface. Onlay restorations have many clinical applications and may be desired by many patients. These restorations have a well-deserved reputation for providing excellent service.

The cast metal onlay restoration spans the gap between the inlay, which is primarily an intracoronal restoration, and the full crown, which is a totally extracoronal restoration. The full onlay by definition caps all of the cusps of a posterior tooth and can be designed to help strengthen a tooth that has been weakened by caries or previous restorative experiences. It can be designed to distribute occlusal loads over the tooth in a manner that greatly decreases the chance of future fracture.^{4,6} It is more conservative of the tooth structure than the full crown preparation, and its supragingival margins, when possible, are less irritating to the gingiva. Usually, an onlay diagnosis is made pre-operatively because of the tooth's status. Sometimes, the diagnosis is deferred until the extension of the occlusal step of an inlay preparation facially and lingually to

the limits of the caries lesion shows that cusp reduction is mandatory. The mandibular first molar is used to illustrate one mesio-occluso-distal preparation for a full cast metal onlay.

Initial Preparation

OCCUSAL REDUCTION

As soon as the decision is made to restore the tooth with a full cast metal onlay, the cusps should be reduced because this improves the access and the visibility for subsequent steps in tooth preparation. With the cusps reduced, the efficiency of the cutting instrument and the air-water cooling spray is improved. Also, when the cusps are reduced, it is easier to assess the height of the remaining clinical crown of the tooth, which determines the degree of occlusal divergence necessary for adequate retention form. Using the No. 271 carbide bur held parallel to the long axis of the tooth crown, a 2-mm deep pulpal floor is prepared along the central groove (Fig. 17-26, *A*). To verify the pre-operative diagnosis for cusp reduction, this occlusal preparation is extended facially and lingually just beyond the caries to sound tooth structure (see Fig. 17-26, *B*). The groove should not be extended farther, however, than two thirds the distance from the central groove to the cusp tips because the need for cusp reduction is verified at this point. With the side of the No. 271 carbide bur, uniform 1.5-mm deep depth cuts are prepared on the remaining occlusal surface (see Fig. 17-26, *C* and *D*). Depth cuts usually are placed on the crest of the triangular ridges and in the facial and lingual groove regions. These depth cuts help prevent thin spots in the final restoration. If a cusp is in infraocclusion of the desired occlusal plane before reduction, the amount of cusp reduction is less and needs only that which provides the required clearance with the desired occlusal plane. Caries and old restorative material that is deeper in the tooth than the desired clearance are not removed at this step in preparation.

With the depth cuts serving as guides for the amount of reduction, the cusp reduction is completed with the side of the No. 271 bur. When completed, this reduction should reflect the general topography of the original occlusal surface (see Fig. 17-26, *E*). The operator should not attempt to reduce the mesial and distal marginal ridges completely at this time to avoid hitting an adjacent tooth. The remainder of the ridges are reduced in a later step when the proximal boxes are prepared.

Throughout the next steps in the initial preparation, the cutting instruments used to develop the vertical walls are oriented continually to a single draw path, usually the long axis of the tooth crown, so that the completed preparation has draft (i.e., no undercuts). For mandibular molars and second premolars whose crowns tilt slightly lingually, the bur should be tilted slightly (5–10 degrees) lingually to help preserve the strength of the lingual cusps (see Fig. 17-4, *D*). The gingival-to-occlusal divergence of these preparation walls may range from 2 to 5 degrees from the line of draw, depending on their heights. If the vertical walls are unusually short, a minimum of 2 degrees occlusal divergence is desirable for retentive purposes. Cusp reduction appreciably decreases the retention form because it decreases the height of the vertical walls, so this minimal amount of divergence is often indicated in the preparation of a tooth for a cast metal onlay. As the

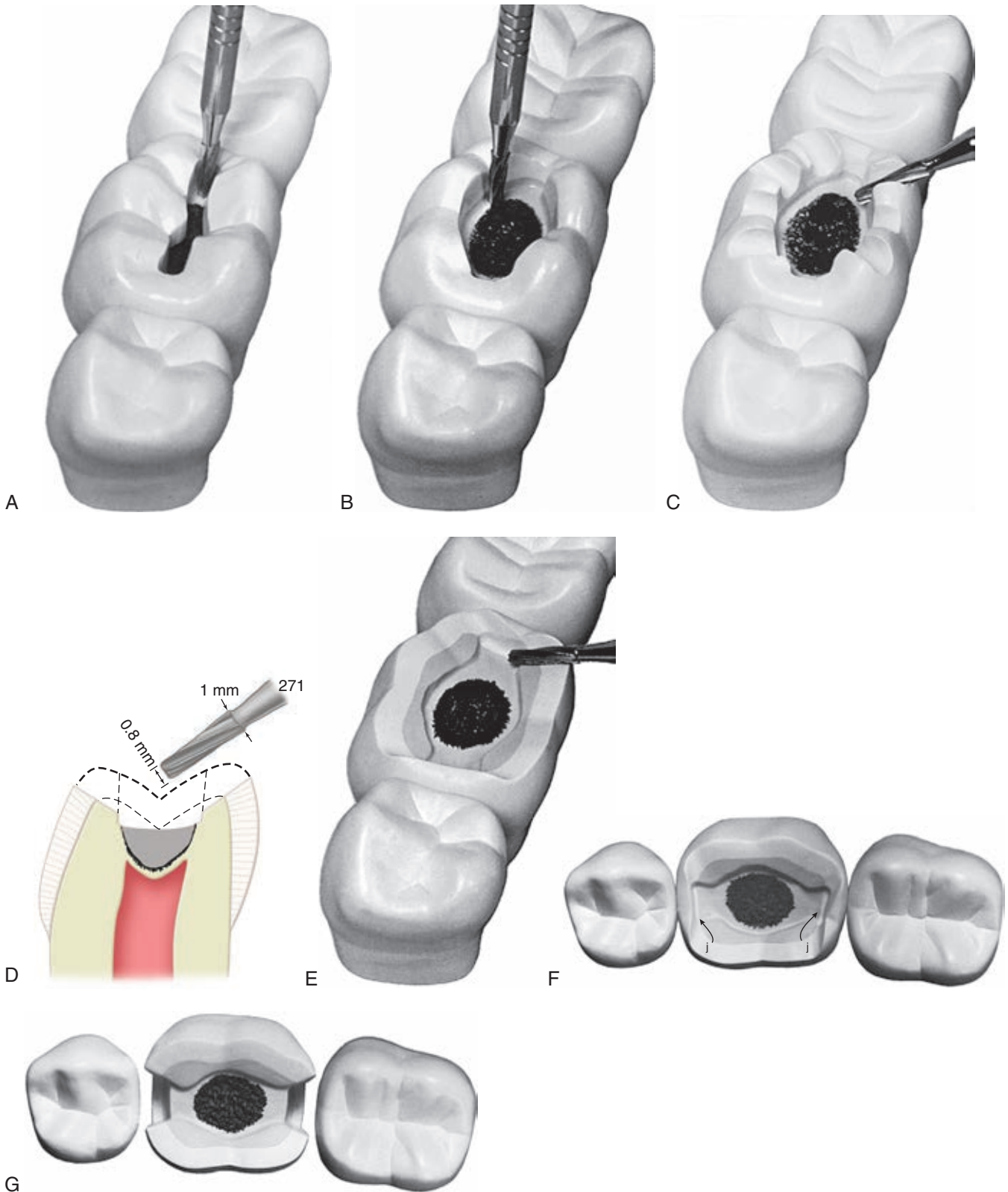


Fig. 17-26 **A**, Cutting a 2-mm deep central groove. **B**, Extending the central groove cut facially and lingually to verify any need for cusp capping. **C**, Depth cuts. **D**, Section of **C**. **E**, Completion of cusp reduction. Small portions of the mesial and distal marginal ridges are left unreduced to avoid scarring the adjacent teeth. **F**, The occlusal step is extended facially and lingually past any carious areas and is extended to expose the proximal dentinoenamel junction (DEJ) (*j*) in anticipation of proximal boxing. **G**, Preparation with proximal boxes prepared. Note the clearances with the adjacent teeth.

gingivo-occlusal height of the vertical walls increases, the occlusal divergence should increase, allowing 5 degrees in the preparation of the greatest gingivo-occlusal length. The latter preparations present difficulties during pattern withdrawal, trial seating and withdrawal of the casting, and cementing, unless this maximal divergence is provided.

OCCLUSAL STEP

After cusp reduction, a 0.5-mm deep occlusal step should be present in the central groove region between the reduced cuspal inclines and the pulpal floor. Maintaining the pulpal depth (0.5 mm) of the step, it is extended facially and lingually just beyond any carious areas, to sound tooth structure (or to sound base or restorative material if certain conditions, discussed subsequently, have been met). Next, the operator extends the step mesially and distally far enough to expose the proximal DEJ (see Fig. 17-26, *F*). The step is extended along any remaining facial (and lingual) occlusal fissures as far as they are faulty (fissured). The facial and lingual walls of the occlusal step should go around the cusps in graceful curves, and the isthmus should be only as wide as necessary to be in sound tooth structure or sound base or restorative material. Old restorative material or caries that is deeper pulpally than this 0.5-mm step is not removed at this stage of tooth preparation.

As the occlusal step approaches the mesial and distal surfaces, it should widen faciolingually in anticipation of the proximal box extensions (see Fig. 17-26, *F*). This 0.5-mm occlusal step contributes to the retention of the restoration and provides the wax pattern and cast metal onlay with additional bulk for rigidity.⁷

PROXIMAL BOX

Continuing with the No. 271 carbide bur held parallel to the long axis of the tooth crown, the proximal boxes are prepared as described in the inlay section. Figure 17-26, *G*, illustrates the preparation after the proximal boxes are prepared.

Final Preparation

REMOVAL OF INFECTED CARIOUS DENTIN AND DEFECTIVE RESTORATIVE MATERIALS AND PULP PROTECTION

If the occlusal step and the proximal boxes have been extended properly, any caries or previous restorative materials remaining on the pulpal and axial walls should be visible. They should be removed as described previously.

PREPARATION OF BEVELS AND FLARES

After the cement base (when indicated) is completed (Fig. 17-27, *A*), the slender, flame-shaped, fine-grit diamond instrument is used to place counterbevels on the reduced cusps, to apply the gingival bevels, and to create secondary flares on the facial and lingual walls of the proximal boxes. First, a gingival retraction cord is inserted, as described in the previous inlay section. During the few minutes required for the cord's effect on the gingival tissues, the diamond instrument is used to prepare the counterbevels on the facial and lingual margins of the reduced cusps. The bevel should be of generous width and should result in 30-degree marginal metal. The best way to judge this is to always maintain a 30-degree angle between the

side of the instrument and the external enamel surface beyond the counterbevel (see Fig. 17-27, *B* and *C*). The counterbevel usually should be wide enough so that the cavosurface margin is beyond (gingival to) any contact with the opposing dentition. If a facial (lingual) surface fissure extends slightly beyond the normal position of the counterbevel, it may be included (removed) by deepening the counterbevel in the region of the fissure (see Fig. 17-27, *D*). If the fissure extends gingivally more than 0.5 mm, however, the fissure is managed as described later.

A counterbevel is not placed on the facial cusps of maxillary premolars and first molars where esthetic considerations may dictate using a stubbed margin by blunting and smoothing the enamel margin by the light application of a fine-grit sandpaper disk or the fine-grit diamond instrument (flame-shaped) held at a right angle to the facial surface (see Fig. 17-23, *C*). The surface created by this blunting should be approximately 0.5 mm in width. For beveling the gingival margins and flaring (secondary) the proximal enamel walls, refer to the inlay section.

After beveling and flaring, any sharp junctions between the counterbevels and the secondary flares are rounded slightly (see Fig. 17-27, *E*). The fine-grit diamond instrument also is used to bevel the axiopulpal line angles lightly (see Fig. 17-27, *F*). Such a bevel produces a stronger wax pattern at this critical region by increasing its thickness. Any sharp projecting corners in the preparation are rounded slightly because these projections are difficult to reproduce without voids when developing the working cast and often cause difficulties when seating the casting. The desirable metal angle at the margins of onlays is 40 degrees except at the gingivally directed margins, where the metal angle should be 30 degrees.

When deemed necessary, shallow (0.3 mm deep) retention grooves may be cut in the facioaxial and the linguoaxial line angles with the No. 169L carbide bur (see Fig. 17-27, *G*). These grooves are especially important for retention when the prepared tooth is short, which is often the case after reducing all the cusps. When properly positioned, the grooves are entirely in dentin near the DEJ and do not undermine enamel. The direction of cutting (translation of the bur) is parallel to the DEJ. The long axis of the No. 169L bur must be held parallel to the line of draw, and the tip of the bur must be positioned in the gingival box internal point angles. If the axial walls are deeper than ideal, however, the correct reference for placing retention grooves is just inside the DEJ to minimize pulpal impacts but avoids undermining enamel. The model showing the completed preparation is illustrated in Figure 17-27, *H*.

Modifications in Full Onlay Tooth Preparations

FACIAL OR LINGUAL SURFACE GROOVE EXTENSION

A facial surface fissure (mandibular molar) or a lingual surface fissure (maxillary molar) is included in the outline in the same manner as described in the section on inlays. This extension sometimes is indicated to provide additional retention form, even though the groove is not faulty. A completed mesio-occluso-disto-facial onlay preparation on a mandibular first molar is illustrated in Figure 17-27, *I*.

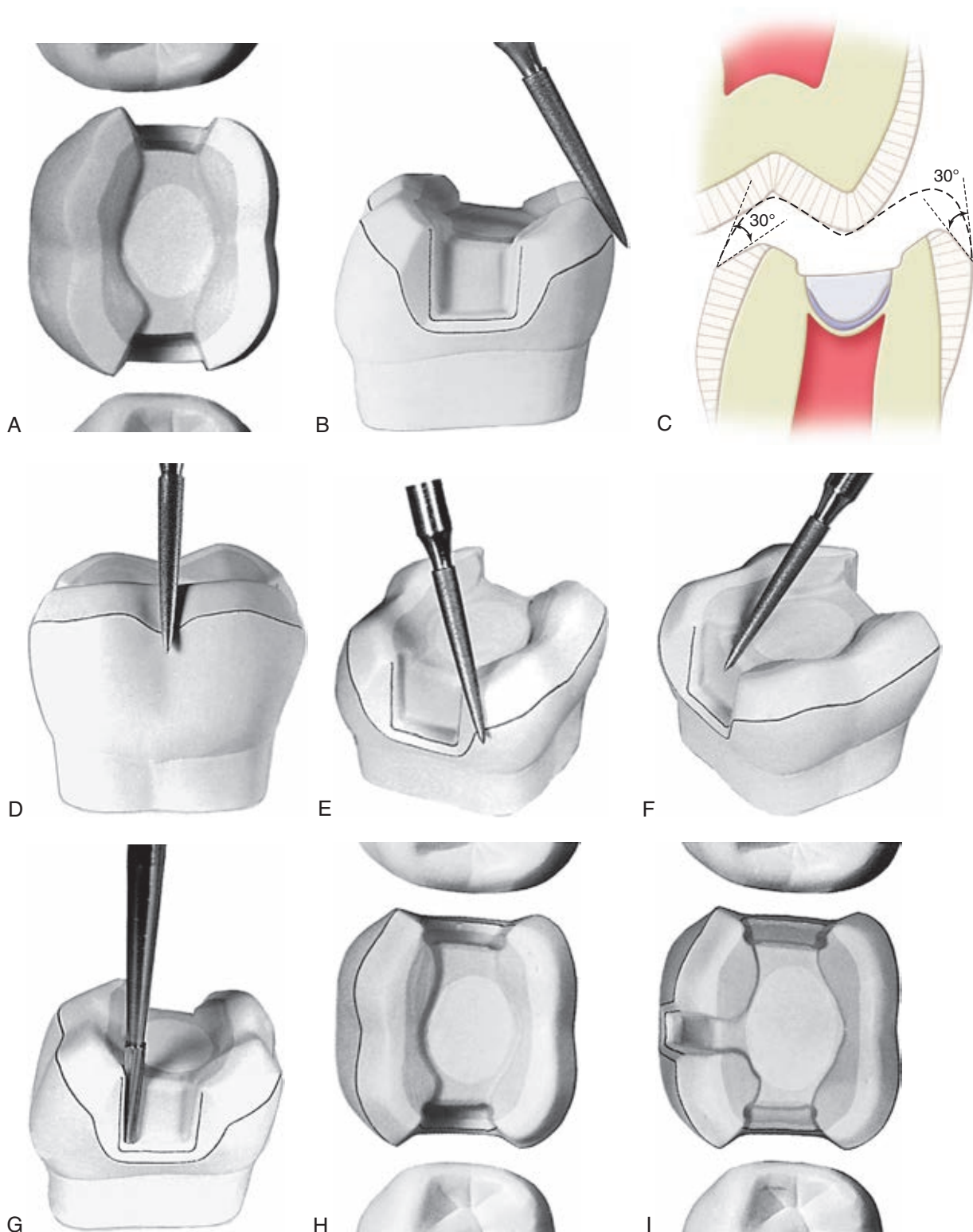


Fig. 17-27 **A**, Caries has been removed, and the cement base has been inserted. **B**, Counterbeveling facial and lingual margins of reduced cusps. **C**, Section of **B**. **D**, The fissure that extends slightly gingival to the normal position of the counterbevel may be included by slightly deepening the counterbevel in the fissured area. **E**, The junctions between the counterbevels and the secondary flares are slightly rounded. **F**, The axiopulpal line angle is lightly beveled. **G**, Improving the retention form by cutting proximal grooves. **H**, Completed mesio-occluso-distal onlay preparation. **I**, Completed mesio-occluso-disto-facial onlay preparation showing the extension to include the facial surface groove or fissure.

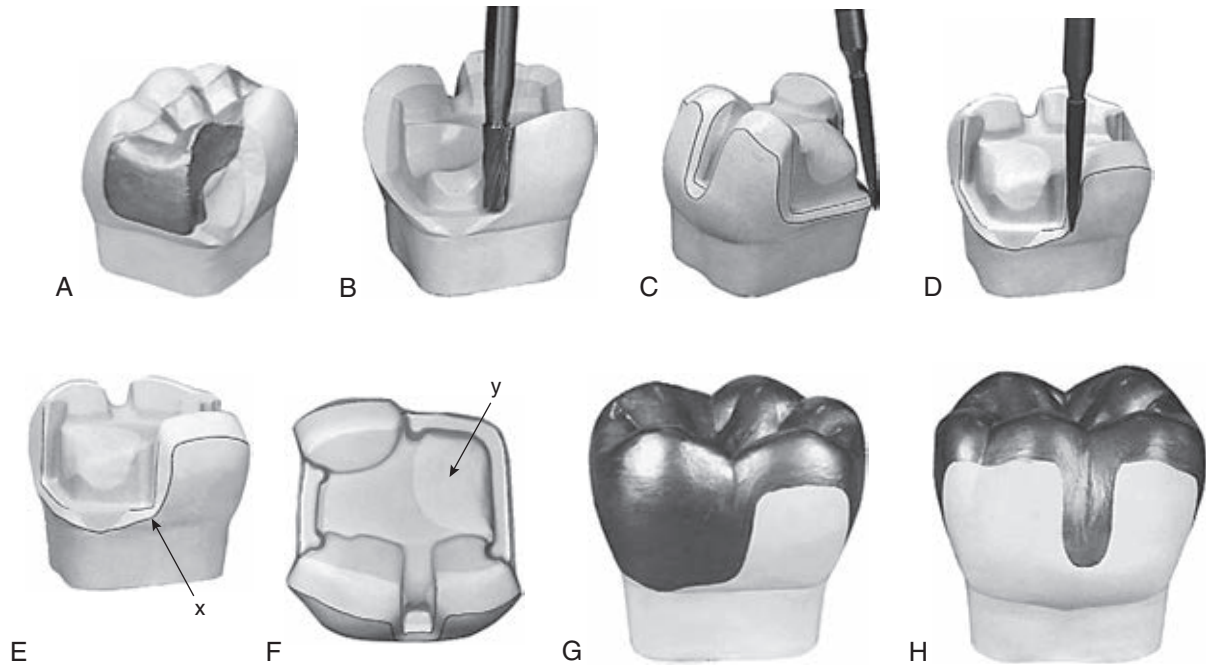


Fig. 17-28 **A**, Mandibular first molar with large mesio-occluso-distal amalgam and fractured mesiolingual cusp. **B**, Preparation (minus bevels and flares) for mesio-occlusal, distofacial, and distolingual onlay to restore the fractured molar shown in **A**. A No. 271 carbide bur is used to prepare the gingival shoulder and the vertical lingual wall. Reducing cusps for capping and extending out the facial groove improve the retention and resistance forms. **C** and **D**, Beveling of margins. **E** and **F**, Completed preparation. The gingival and lingual bevels blend at *x*, and *y* is the cement base. **G** and **H**, Completed onlay.

INCLUSION OF PORTIONS OF THE FACIAL AND LINGUAL SMOOTH SURFACES AFFECTED BY CARIES, FRACTURED CUSPS, OR OTHER INJURY

For inclusion of shallow to moderate lesions on the facial and lingual smooth surfaces, refer to the section on inlays. A mandibular molar with a fractured mesiolingual cusp is used to illustrate the treatment of a fractured cusp of a molar (Fig. 17-28, **A**). The dentist uses a No. 271 carbide bur to cut a shoulder perpendicular to occlusal force by extending the proximal gingival floor (adjacent to the fracture) to include the affected surface. This shoulder partially provides the desired resistance form by being perpendicular to gingivally directed occlusal force. This instrument also is used to create a vertical wall in the remaining lingual enamel (see Fig. 17-28, **B**). The width of the gingival floor should be the diameter of the end of the cutting instrument. The vertical walls should have the degree of draft necessary for the retention form. If the clinical crown of the tooth is short, it is advisable to cut proximal grooves for additional retention with the No. 169L bur. The linguogingival and lingual margins are beveled with the flame-shaped, fine-grit diamond instrument to provide 30-degree metal at the gingival margin (see Fig. 17-28, **C**) and 40-degree metal along the lingual margin (see Fig. 17-28, **D**).

These two bevels should blend together (see *x* in Fig. 17-28, **E**), and the linguogingival bevel is continuous with the gingival bevel on the mesial surface. Additional features to improve the retention and resistance forms are indicated and can be developed by a mesiofacial skirt extension or by a facial groove extension. These preparation features (discussed in the following section) improve the retention form, resist forces normally

opposed by the missing mesiolingual wall, and help protect the restored tooth from further fracture injury.

ENHANCEMENT OF RESISTANCE AND RETENTION FORMS

When the tooth crown is short (which is often the case when all cusps are reduced), the operator must strive to maximize the retention form in the preparation. Retention features that already have been presented are as follows:

1. Minimal amount of taper (2 degrees per wall) on the vertical walls of the preparation
2. Addition of proximal retention grooves
3. Preparation of facial (or lingual) surface groove extensions

In the preparation of a tooth that has been grossly weakened by caries or previous filling material and is judged to be prone to fracture under occlusal loads, the resistance form that cusp capping provides should be augmented by the use of skirts, collars, or facial (lingual) surface groove extensions. When properly placed, these features result in onlays that distribute the occlusal forces over most or all of the tooth and not just a portion of it, reducing the likelihood of fractures of teeth (Fig. 17-29, **A** and **B**). The lingual “skirt” extension (see Fig. 17-29, **C** through **E**), the lingual “collar” preparation (see Fig. 17-29, **F**), or the lingual surface groove extension on a maxillary molar protects the facial cusps from fracture. The facial skirt extension, the facial collar preparation, or the facial surface groove extension on a mandibular molar protects the lingual cusp from fracture.

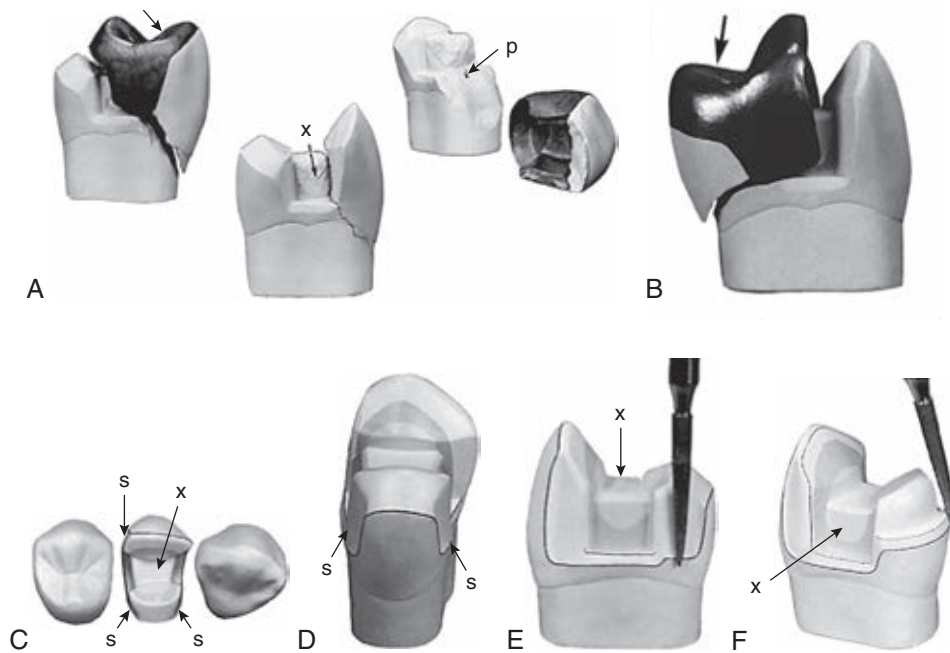


Fig. 17-29 The large cement base *x* indicates severely weakened tooth crown. Occlusal force (*thick arrow*) may fracture the facial cusp (*A*) or the lingual cusp (*B*), which may expose the pulp (*p*). **C** and **D**, Skirt extensions (*s*) on the mesiolingual, distolingual, and distofacial transitional line angles prevent the fractures shown in *A* and *B*. Esthetic consideration contraindicates skirting the mesiofacial line angle. **E**, Distal view of the preparation shown in *D*. Skirt extensions are prepared with a fine-grit diamond instrument. **F**, A collar preparation around the lingual cusp prevents the fracture shown in *A*.

SKIRT PREPARATION

Skirts are thin extensions of the facial or lingual proximal margins of the cast metal onlay that extend from the primary flare to a termination just past the transitional line angle of the tooth. A skirt extension is a conservative method of improving the retention and resistance forms of the preparation. It is relatively atraumatic to the tooth because it involves removing very little (if any) dentin. Usually, the skirt extensions are prepared entirely in enamel.

When the proximal portion of a Class II preparation for an onlay is being prepared and the lingual wall is partially or totally missing, the retention form normally provided by this wall can be developed with a skirt extension of the facial margin (Fig. 17-30, *A* through *C*). Similarly, if the facial wall is not retentive, a skirt extension of the lingual margin supplies the desired retention form (see Fig. 17-25, *O* and *P*). When the lingual and facial walls of a proximal box are inadequate, skirt extensions on the respective lingual and facial margins can satisfy the retention and resistance form requirements. The addition of properly prepared skirts to three of four line angles of the tooth virtually eliminates the chance of post-restorative fracture of the tooth because the skirting onlay is primarily an extracoronal restoration that encompasses and braces the tooth against forces that might otherwise split the tooth. The skirting onlay is often used successfully for many teeth that exhibit split-tooth syndrome.

The addition of skirt extensions also is recommended when the proximal surface contour and contact are to be extended more than the normal dimension to develop a proximal contact. Extending these proximal margins onto the respective facial and lingual surfaces aids in recontouring the proximal surface to this increased dimension. Also, when improving the

occlusal plane of a mesially tilted molar by a cusp-capping onlay, reshaping the mesial surface to a satisfactory contour and contact is facilitated when the mesiofacial and mesiolingual margins are extended generously.

Skirting also is recommended when splinting posterior teeth together with onlays. The added retention and resistance forms are desirable because of the increased stress on each unit. Because the facial and lingual proximal margins are extended generously, the ease of soldering the connector and finishing of the proximal margins is increased.

A disadvantage of skirting is that it increases the display of metal on the facial and lingual surfaces of the tooth. For this reason, skirts are not placed on the mesiofacial margin of maxillary premolars and first molars. Skirting the remaining three line angles of the tooth provides ample retention and resistance forms.

The preparation of a skirt is done entirely with the slender, flame-shaped, fine-grit diamond instrument. Skirt preparations follow the completion of the proximal gingival bevel and primary flares. Experienced operators often prepare the skirt extensions at the same time that the gingival bevel is placed, however, working from the lingual toward the facial, or vice versa. Maintaining the long axis of the instrument parallel to the line of draw, the operator translates the rotating instrument into the tooth to create a definite vertical margin, just beyond the line angle of the tooth, providing at the same time a 140-degree cavosurface enamel angle (40-degree metal angle) (see Fig. 17-30, *D* through *F*). The occlusogingival length of this entrance cut varies, depending on the length of the clinical crown and the amount of extracoronal retention and resistance forms desired. Extending into the gingival third of the anatomic crown is usually necessary for an effective

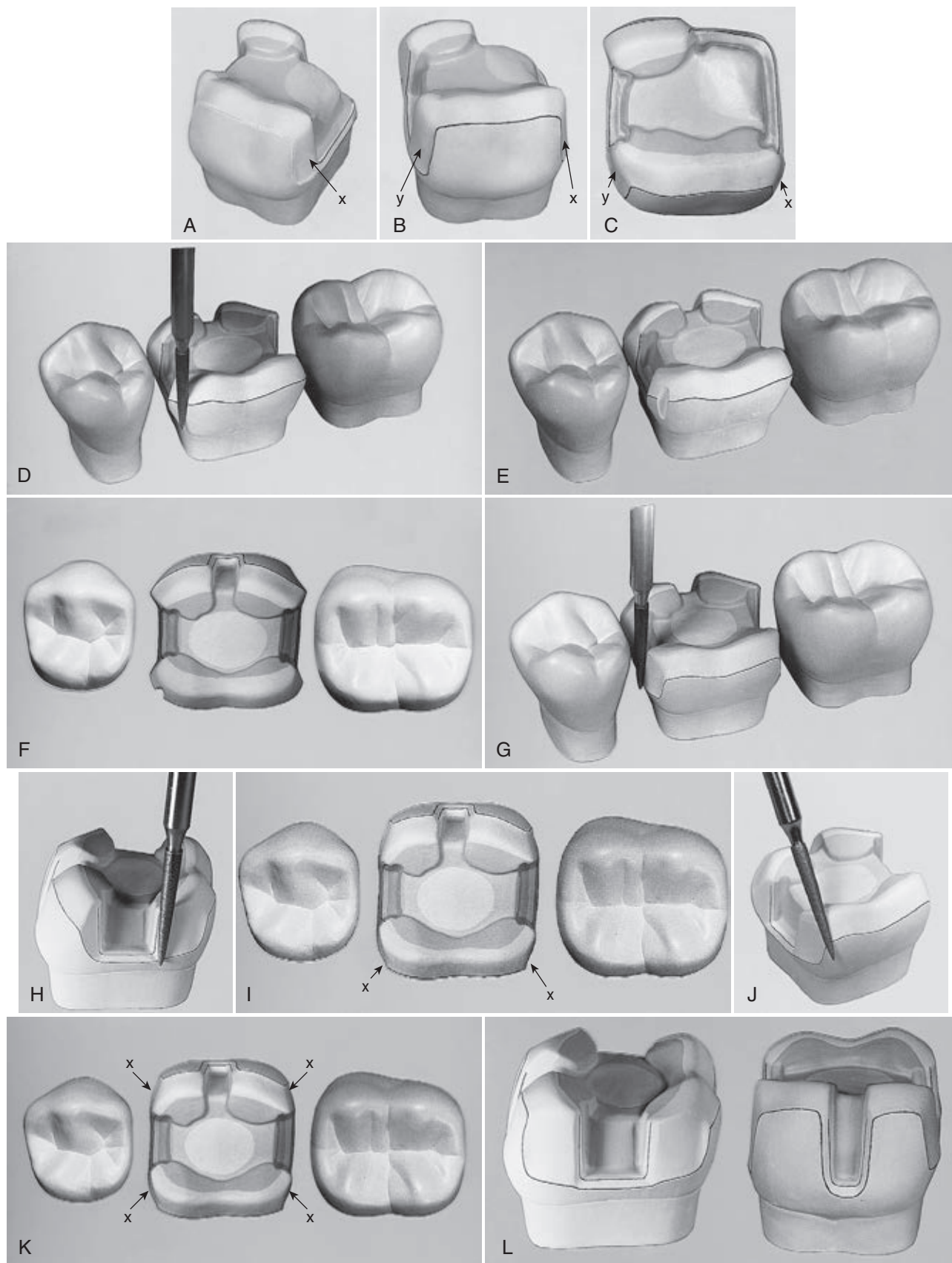


Fig. 17-30 **A**, When the lingual wall of the proximal box is inadequate or missing, the retention form can be improved by facial skirt extension (x). **B**, Facio-occlusal view of **A**. Maximal resistance form is developed by skirting the distofacial (y) and mesiofacial (x) transitional line angles. **C**, Occlusal view of **B**. **D–F**, The initial cut for the skirt is placed just past the transitional line angle of the tooth. **G** and **H**, Blending the skirt into the primary flare. **G** and **H**, Blending the skirt into the primary flare. **I**, Occlusal view showing the mesiolingual and distolingual skirts. Caution is exercised to prevent the over-reduction of transitional line angles (x). Facial surface groove extension also improves the retention and resistance forms. **J**, The junction of the skirt and the counterbevel is slightly rounded. **K**, Skirting all four transitional line angles of the tooth further enhances the retention and resistance forms. Caution is exercised to prevent the over-reduction of transitional line angles (x). **L**, Mesial and facial views of the preparation shown in **K**.

resistance form. In most instances, the gingival margin of the skirt extension is occlusal to the position of the gingival bevel of the proximal box (see Fig. 17-30, *H* and *L*).

The operator should use less than half the tip diameter of the flame-shaped diamond instrument to avoid creating a ledge at the gingival margin of the skirt extension. Using high speed and maintaining the long axis of the diamond instrument parallel with the line of draw, the operator translates the instrument from the entrance cut toward the proximal box to blend the skirt into the primary flare and the proximal gingival margin (see Fig. 17-30, *G* and *H*). The operator must ensure that the line angle of the tooth is not over-reduced when preparing skirt extensions (see *x* in Fig. 17-30, *I* and *K*). If the line angle of the tooth is over-reduced, the bracing effect of the skirt is diminished. Holding the diamond instrument at the same angle that was used for preparing the counterbevel, the operator rounds the junction between the skirt and the counterbevel (see Fig. 17-30, *J*). Any sharp angles that remain after preparation of the skirt need to be rounded slightly because these angles often lead to difficulties in the subsequent steps of the restoration.

COLLAR PREPARATION

To increase the retention and resistance forms when preparing a weakened tooth for a mesio-occluso-distal onlay to cap all cusps, a facial or lingual “collar” or both may be provided (Fig. 17-31). To reduce the display of metal, however, the facial surfaces of maxillary premolars and first molars usually are not prepared for a collar. The operator uses a No. 271 carbide bur at high speed parallel to the line of draw to prepare a 0.8 mm–deep shoulder (equivalent to the diameter of the tip end of the bur) around the lingual (or facial) surface to provide for a collar about 2 to 3 mm high occlusogingivally (see Fig. 17-31, *A* and *B*). To provide for a uniform thickness of metal, the occlusal 1 mm of this reduction should be prepared to follow the original contour of the tooth (see Fig. 17-31, *C*), and any undesirable sharp line angle formed by the union of the prepared lingual and occlusal surfaces should be

rounded. This aspect of the preparation is completed by lightly beveling the gingival margin of the shoulder with the flame-shaped, fine-grit diamond instrument to achieve a 30-degree metal angle at the margin (see Fig. 17-31, *D*).

SLOT PREPARATION

Occasionally, the use of a slot in dentin is helpful in creating the necessary retention form. An example is the mandibular second molar that has no molar posterior to it and requires a mesio-occlusal onlay restoration that caps all of the cusps (Fig. 17-32, *A* through *C*). The distal, facial, and lingual surfaces are free of caries or other injury, and these surfaces also are judged not to be prone to caries. After cusp reduction, the vertical walls of the occlusal step portion of the preparation have been reduced so as to provide very little retention form. The necessary retention can be achieved by cutting a distal slot. Such a slot is preferred over preparing a box in the distal surface because (1) the former is more conserving of the tooth structure and of the strength of the tooth crown, and (2) the linear extent of marginal outline is less.

To form this slot, the dentist uses a No. 169L carbide bur with its long axis parallel to the line of draw (this must be reasonably close to a line parallel with the long axis of the tooth) (see Fig. 17-32, *A*). The slot is cut in dentin so that it would pass midway between the pulp and the DEJ if it were to be extended gingivally (see Fig. 17-32, *C*). The position and direction of the slot thus avert (1) the exposure of the pulp, (2) the removal of the dentin supporting the distal enamel, and (3) the perforation of the distal surface of the tooth at the gingival termination of the slot. The slot should have the following approximate dimensions: (1) the width (diameter) of the bur mesiodistally; (2) 2 mm faciolingually; and (3) a depth of 2 mm gingival of the normally positioned pulpal wall. To be effective, the mesial wall of the slot must be in sound dentin; otherwise, the retention form obtained is insufficient.

A comparable situation occurs occasionally: The maxillary first premolar requires a disto-occlusal onlay restoration to

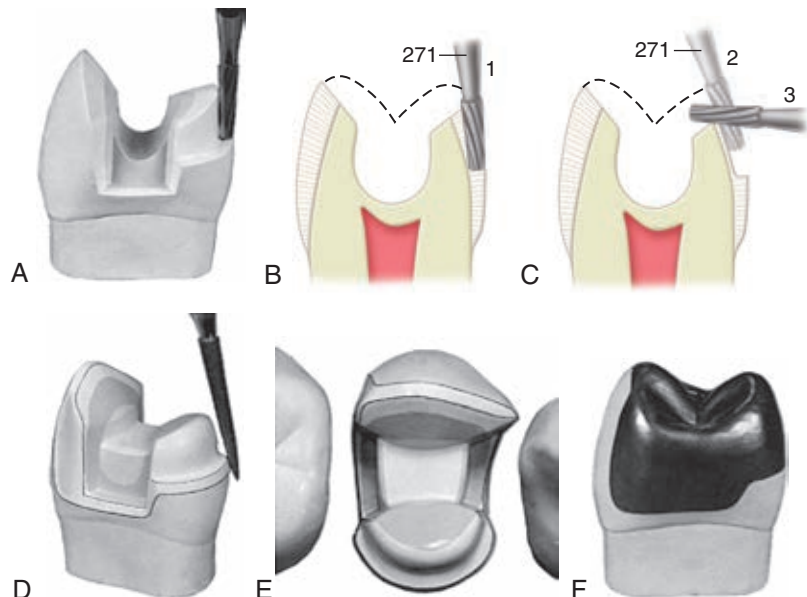


Fig. 17-31 **A**, First position of the bur in preparing for the lingual collar on a weakened maxillary premolar. **B** and **C**, Section drawings of the first position of the bur (*B*) and the second and third positions (*C*). **D**, Beveling the lingual margin. Note the distofacial skirt extension. **E**, Completed preparation. **F**, Completed onlay.

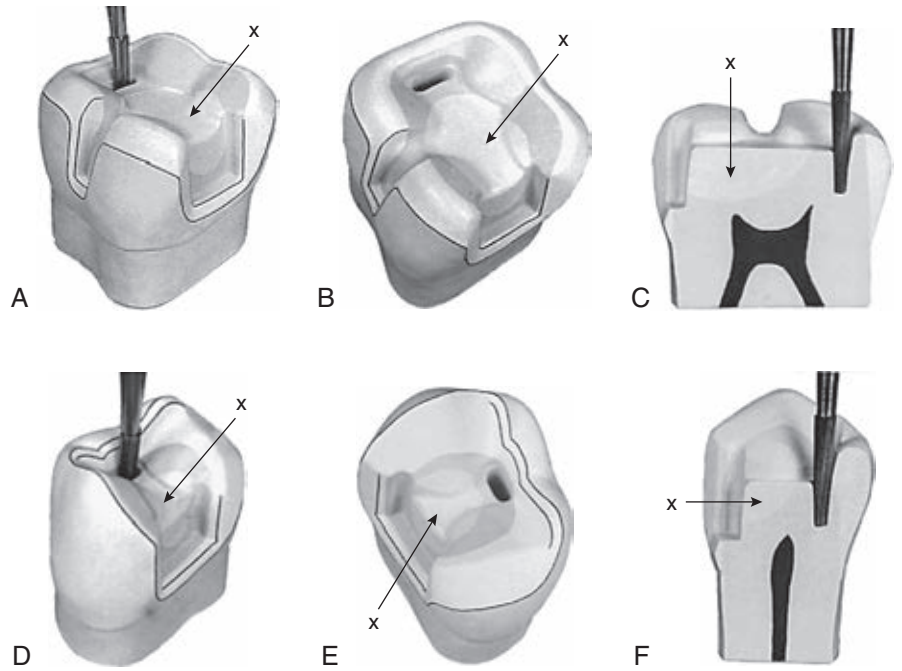


Fig. 17-32 **A** and **B**, Cutting a distal slot for the retention for the mesio-occlusal onlay to treat the terminal molar having a large cement base (x) resulting from extensive occlusal and mesial caries. **C**, Section of **A**. **D** and **E**, Preparing a mesial slot for the retention for the disto-occlusal onlay to treat the maxillary first premolar that has a large cement base (x). **F**, Section of **D**.

cap the cusps, and the mesial surface is non-carious and deemed not prone to caries (see Fig. 17-32, *D* through *F*). To reduce the display of metal and to conserve the tooth structure, a slot similar to that described in the preceding paragraph (except that it is mesially positioned and 1.5 mm wide faciolingually) may be used for the production of adequate retention. The mesio-occlusal marginal outline in this preparation should be distal of the height of the mesial marginal ridge.

MODIFICATIONS FOR ESTHETICS ON MAXILLARY PREMOLARS AND FIRST MOLARS

To minimize the display of metal on maxillary premolars and first molars, several modifications for esthetics are made to the basic onlay preparation. On the facial cusps of maxillary premolars and on the mesiofacial cusp of the maxillary first molar, the occlusal reduction should be only 0.75 to 1 mm on the facial cusp ridge to minimize the display of metal. This thickness should increase progressively to 1.5 mm toward the center of the tooth to provide rigidity to the capping metal. These cusps do not receive a counterbevel but are “stubbed” or blunted by the application of a sandpaper disk or the fine-grit diamond instrument held at a right angle to the facial surface (see Fig. 17-23, *C*). The surface created by this blunting should be approximately 0.5 mm in width.

To further decrease the display of metal on maxillary premolars and first molars, the mesiofacial margin is minimally extended facially of the contact to such a position that the margin is barely visible from a facial viewing position. To accomplish this, the secondary flare is omitted, and the wall and margin are developed with a chisel or enamel hatchet. Final smoothing with the fine-grit paper disk is recommended when access permits. The cavosurface margin should result in a gold angle of 40 to 50 degrees, if possible.

When more than ideal extension of the mesiofacial margin is necessary because of caries or previous restorations, and as dictated by the esthetic desires of the patient, the operator may

choose to place a composite insert at this margin. This is a more conservative option than preparing the tooth to receive a porcelain-veneered metal crown. When preparing the mesiofacial margin, no attempt is made to develop a straight mesiofacial wall past the point of ideal extension. After caries excavation, a glass ionomer cement base is inserted to temporarily form the missing portion of the wall. The cement is contoured to the ideal form, and the preparation can continue, terminating the mesiofacial onlay margin in the ideal position in the cement. After cementation, the operator removes (with small round burs) the glass ionomer cement to a depth of 1 mm for a composite insert. Small undercuts should be prepared in the wall formed by the cast metal onlay (see Fig. 17-57, *A*). (It is best to carve the undercut in the wall formed by the onlay during the wax pattern stage.) After beveling the enamel cavosurface margin and preparing a gingival retention groove where, and if, enamel is thin or missing, the composite veneer is inserted (see Fig. 17-62, *A*).

ENDODONTICALLY TREATED TEETH

Routinely, teeth that have had endodontic treatment are weak and subject to fracture from occlusal forces. These teeth require restorations designed to provide protection from this injury (see Fig. 17-30, *K* and *L*). This particularly applies to posterior teeth, which are subjected to greater stress. The need for such protection is accentuated when much of the strength of the tooth has been lost because of extensive caries or previous restorations. When the facial and lingual surfaces of an endodontically treated tooth are sound, it is more conservative, for the health of the facial and lingual gingival tissue, to prepare the tooth not for a full crown, but for a full occlusal coverage onlay that has been designed with adequate resistance form to prevent future tooth fracture. Such features include skirt extensions and collar preparations. These features make the onlay more of an extracoronal restoration that encompasses the tooth such that the tooth is better

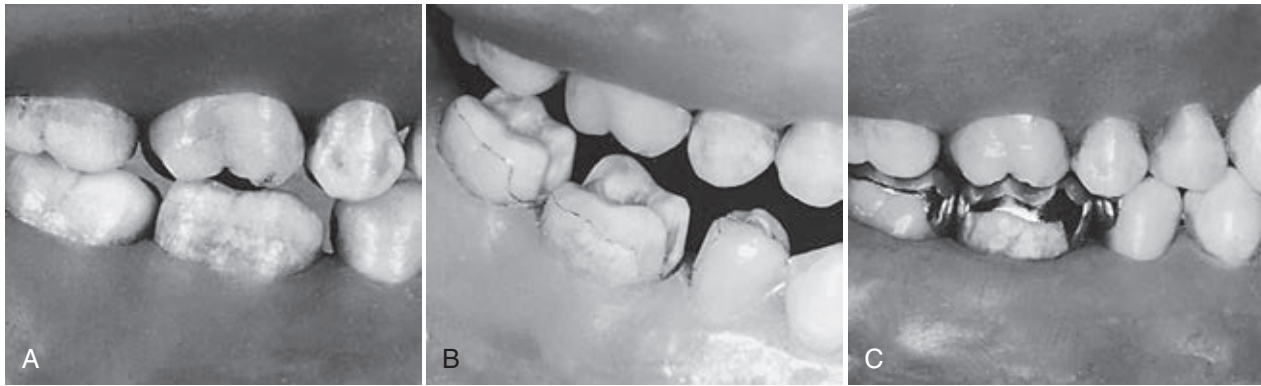


Fig. 17-33 **A**, The mandibular second and third molars being tilted mesially often is the result of failure to replace a lost first molar by bridgework. Note the poor contact relationship between the molars and between the molar and the second premolar. **B**, The second premolar is prepared for an inlay, and the molars are prepared for onlays. The margins of the preparations are well extended on the facial and lingual surfaces to aid in recontouring teeth to improve the occlusal relationship and to improve the proximal contours and contacts. **C**, Completed restorations. Note the improvement in the occlusal plane and in the proximal contacts.

able to resist lateral forces that otherwise might fracture the tooth.

Before starting the preparation of an endodontically treated posterior tooth, the pulp chamber should be excavated to the chamber floor and usually into the canals (1–2 mm), and an amalgam or composite foundation should be placed; this gives the onlay a firm base on which to rest. In the preparation of an endodontically treated premolar that has had extensive damage, the root canal may be prepared for a cast metal or fiber-reinforced composite post, which is cemented before the onlay preparation is completed. This post helps the tooth resist forces that otherwise might cause a horizontal fracture of the entire tooth crown from the root. The post should extend roughly two thirds the length of the root and should terminate, leaving at least 3 mm of the root canal filling material at the apical portion of the root.

RESTORING THE OCCLUSAL PLANE OF A TILTED MOLAR

An onlay is excellent for restoring the occlusal plane of a mesially tilted molar (Fig. 17-33). When the unprepared occlusal surface (mesial portion) is less than the desired occlusal plane, a corresponding decrease in occlusal surface reduction is indicated. To facilitate increasing the height of the tooth, while maintaining the desirable faciolingual dimension of the restored occlusal surface and good contour of the facial and lingual surfaces, the counterbevels on the latter surfaces often should be extended gingivally more than usual (see Fig. 17-33, B).

Often, the mesiofacial and mesiolingual margins (on the “submerged” proximal surface) should be well extended onto the respective facial and lingual surfaces to help in recontouring the mesial surface to desirable proximal surface contour and contact. This extension can be accomplished with a minimal loss of the tooth structure by preparing facial and lingual skirt extensions on the respective proximal margins, which improves retention and resistance forms. In contrast, achieving extension by preparing the mesiofacial and mesiolingual walls facially and lingually does not improve retention or resistance forms and is less conservative of the tooth structure. Verification of appropriate cusp reduction is the same as

presented for the inlay tooth preparation and is illustrated in Figure 17-24.

Restorative Techniques for Cast Metal Restorations

Interocclusal Record

Before preparation of the tooth, the occlusal contacts in maximum intercuspation and in all lateral and protrusive movements should have been carefully evaluated. If the patient has sufficient canine guidance to provide disocclusion of posterior teeth, the necessary registration of the opposing teeth can be obtained by (1) making a maximum intercuspation interocclusal record with commercially available bite registration pastes or (2) making full-arch impressions and mounting the casts made from these impressions on a simple hinge articulator. The interocclusal record works well when preparing one tooth; the full-arch casts are preferred when two or more prepared teeth are involved.

The maximum intercuspation interocclusal record can be made from one of several commercially available bite registration pastes. The most commonly used bite registration pastes are composed of heavily filled PVS impression materials. Several materials are available in cartridge systems that automatically mix the base and accelerator pastes together as they are expressed through a special disposable mixing tip (Fig. 17-34, A). The mixed impression material is dispensed directly onto the prepared teeth and their opponents, then the patient closes completely (Fig. 17-34 B, C). The dentist observes teeth not covered by the bite registration paste to verify that teeth are in maximum intercuspation. When the material has set, the dentist removes the interocclusal record and inspects it for completeness. When held up to a light, areas where the adjacent unprepared teeth have penetrated through the material should be seen (Fig. 17-34, D). The interocclusal record is set aside for later use in the laboratory.

The maximum intercuspation interocclusal records described in the previous paragraph provide information on the shape and position of the opposing teeth in maximum intercuspation. Such records give the laboratory technician

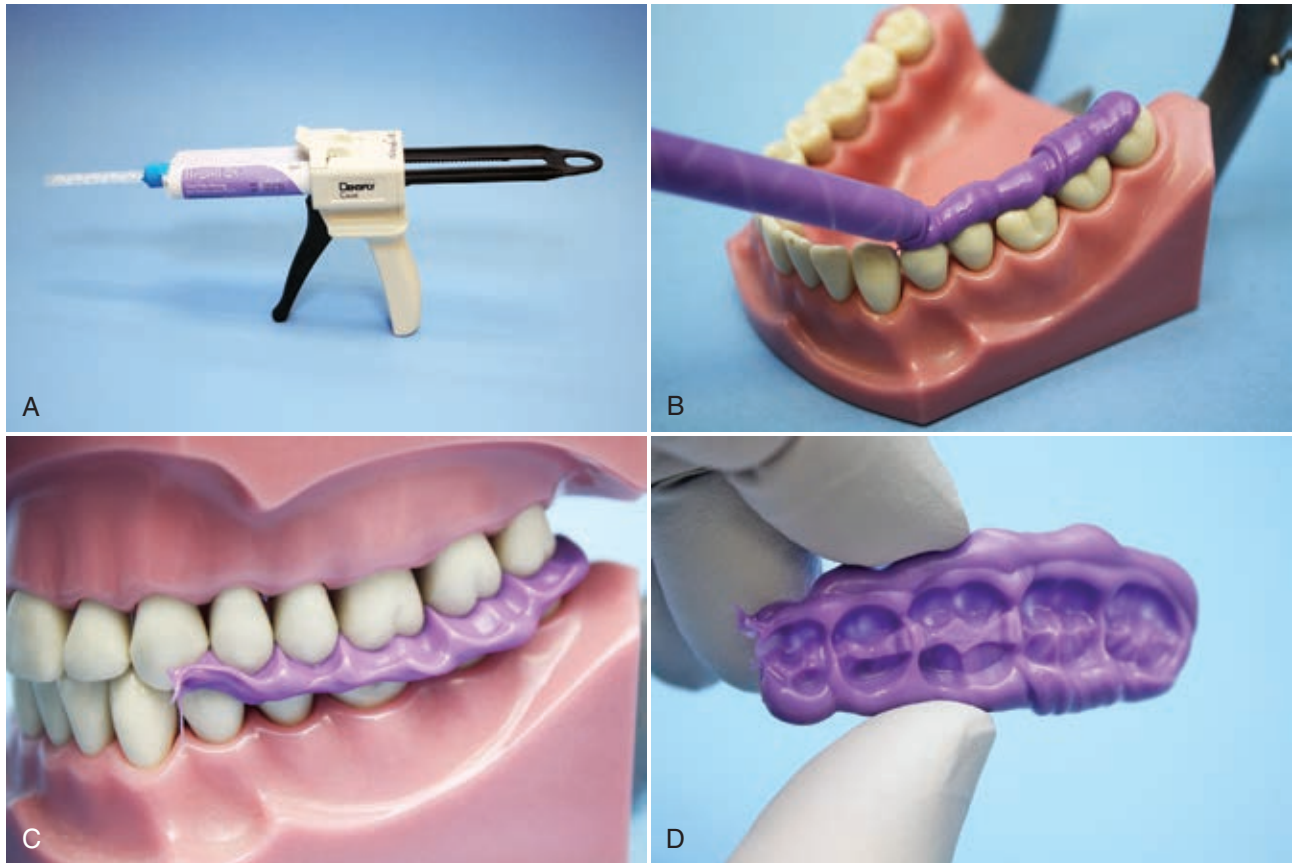


Fig. 17-34 Maximum intercuspation interocclusal record made with polyvinyl siloxane bite registration paste. **A**, One of many commercially available bite registration materials used in this technique. **B**, Using a cartridge dispenser and a disposable automixing tip, the base and accelerator pastes are automatically mixed and applied to the prepared teeth, their neighbors, and the opposing teeth. **C**, Have the patient close into maximum intercuspation position. Be sure that the adjacent unprepared teeth are touching in their normal relationships. **D**, Remove the maximum intercuspation interocclusal record carefully after it has set, and inspect it for completeness. Areas where the adjacent, unprepared teeth have penetrated through paste should be seen.

some information about how to form the occlusal surface and position the occlusal contacts on the restoration, but they supply no data on how these structures and contacts might function during mandibular movements. This is also true when full-arch casts are mounted on a simple hinge articulator. Cast metal restorations made with these simple bite registration techniques often require adjustments in the mouth to alleviate interferences during mandibular movements.

If information is desired in the laboratory about the pathways of cusps during mandibular movements (such as when the tooth is to be restored in group function), an excellent technique involves making full-arch impressions and mounting casts made from these impressions on a properly adjusted semi-adjustable articulator (Fig. 17-35). The use of full-arch casts mounted on a semi-adjustable articulator is recommended when restoring a large portion of the patient's posterior occlusion with cast metal restorations. It involves only a little extra chairtime and gives the laboratory technician much more information about the general occlusal scheme, pathways of cusps, opposing cusp steepness and groove direction, and the anatomy of other teeth in the mouth. The technique uses a full-arch tray when making the final impression, which requires mixing more material, especially when using stock trays. The opposing arch is impressed with alginate

impression material, and the appropriate mandibular movement and face-bow transfer records are made. The reader is referred to Chapter 1 for principles regarding the use of the semi-adjustable articulator in developing proper occlusal relationships for cast metal restorations.

Temporary Restoration

Between the time the tooth is prepared and the cast metal restoration is delivered, it is important that the patient be comfortable and the tooth be protected and stabilized with an adequate temporary restoration. The temporary restoration should satisfy the following requirements:

1. It should be nonirritating and protect the prepared tooth from injury.
2. It should protect and maintain the health of the periodontium.
3. It should maintain the position of the prepared, adjacent, and opposing teeth.
4. It should provide for esthetic, phonetic, and masticatory function, as indicated.
5. It should have adequate strength and retention to withstand the forces to which it will be subjected.

When properly made, the custom temporary restoration can satisfy these requirements and is the preferred temporary restoration. Temporaries can be fabricated intraorally directly on the prepared teeth (direct technique) or outside of the mouth using a post-operative cast of the prepared teeth (indirect technique). The indirect technique is not as popular as the direct technique because of the increased number of steps and complexity in the former; however, it is useful when

making temporaries that might become “locked on” (e.g., intracoronal inlays) when using the direct technique.

Technique for Indirect Temporary Restoration

The indirect temporary technique has the following advantages:

1. The indirect technique avoids the possibility of “locking on” the set temporary material into undercuts on the prepared tooth or the adjacent teeth.
2. The indirect technique avoids placing polymerizing temporary material directly on freshly prepared dentin and investing soft tissue, reducing potential irritation to these tissues.⁸⁻¹⁰
3. The post-operative cast made in the indirect technique affords an opportunity to evaluate the preparation (before the final impression) and serves as an excellent guide when trimming and contouring the temporary restoration.
4. Fabrication of the temporary restoration can be delegated to a well-trained dental auxiliary.

To form the indirect temporary, first, an impression of the prepared tooth is made with fast-setting impression material. A stock, plastic impression tray that has been painted with tray adhesive is used (Fig. 17-36, A). If using alginate, it is ensured that teeth are slightly moistened by saliva, then some alginate is applied over and into the preparation with a fingertip to avoid or to minimize trapping air (see Fig. 17-36, B); and the tray is seated over the region (see Fig. 17-36, C). After the material has become elastic, the impression is removed with a quick pull in the direction of the draw of the preparation and is inspected for completeness (see Fig. 17-36, D). The impression is poured with fast-setting plaster or stone (see Fig. 17-36, E).

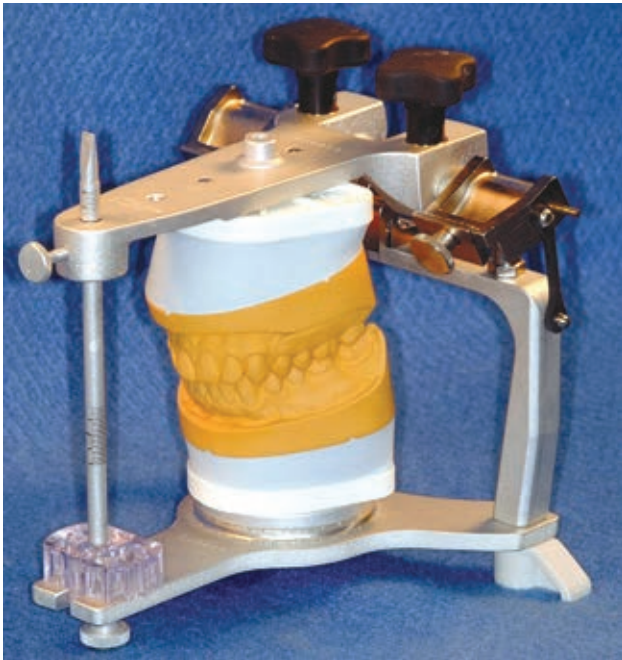


Fig. 17-35 Full-arch casts mounted via a facebow transfer on a semi-adjustable articulator provide maximal information in the laboratory on how to position cusps to prevent undesirable contacts.

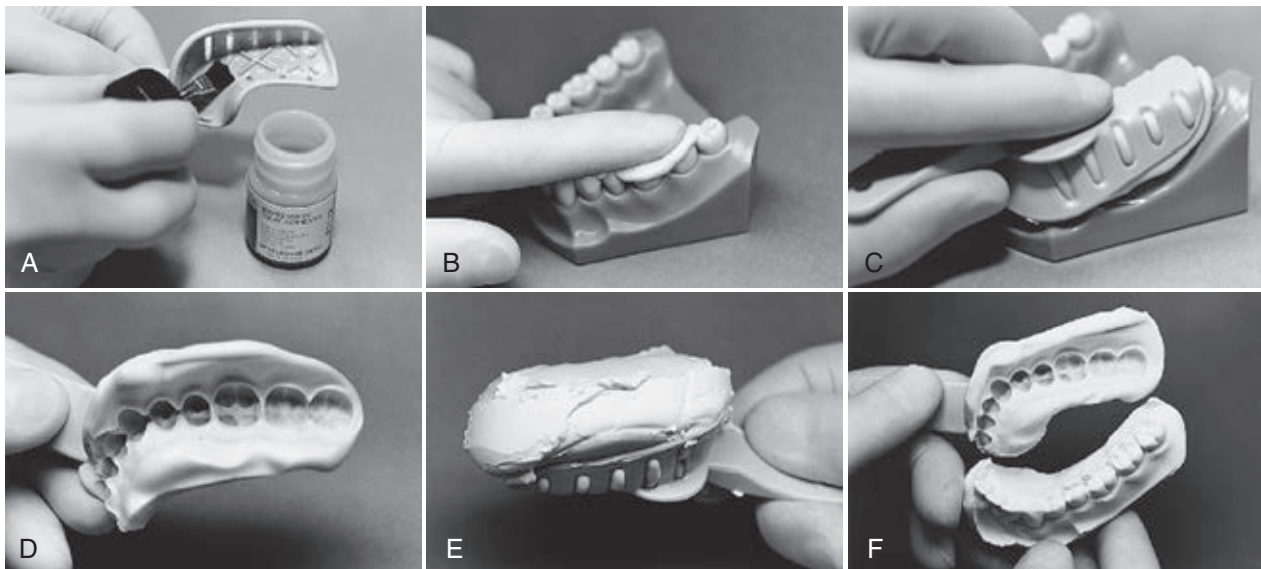


Fig. 17-36 Making a post-operative plaster cast for indirectly forming a temporary restoration. **A**, The interior of the tray is coated with alginate tray adhesive. **B**, Some alginate is applied over and into the preparations with the fingertip to avoid trapping air. **C**, Alginate-filled tray in place. **D**, Alginate impression. **E**, The alginate impression is poured with fast-setting plaster. **F**, Plaster cast of the preparations shown in Figure 17-24, A.

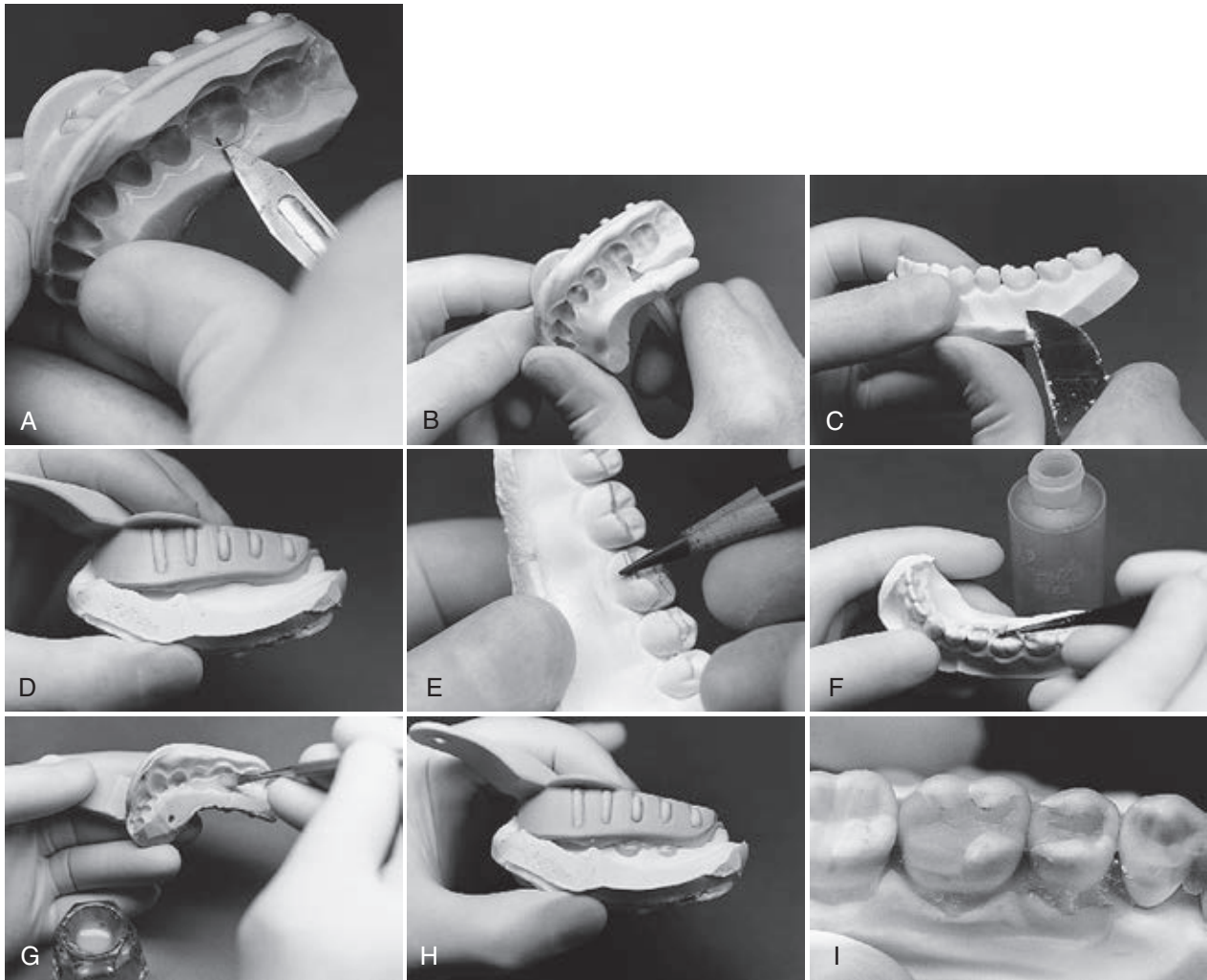


Fig. 17-37 Forming indirect temporary restorations for the preparations initially shown in Figure 17-24, A. **A**, Thin edges of the pre-operative impression material that record the gingival sulcus should be cut away because these are apt to tear when seating the post-operative cast in the impression. **B** and **C**, Trimming away much of the soft tissue areas recorded by the impression and the cast also facilitates seating. **D**, Trial seating the post-operative cast into the pre-operative impression. **E**, Marking the margins with red pencil. **F**, Applying the release agent to the cast. **G**, Filling the pre-operative impression with temporary material in the area of the tooth preparation. **H**, Seating the cast into impression, taking care not to over-seat or tilt the cast. **I**, Formed temporary restoration.

As soon as the post-operative cast has been recovered from the impression, the dentist inspects the cast for any negative or positive defects (see Fig. 17-36, F). Small voids on the cast may be filled in with utility wax. Large voids indicate re-pouring the impression. Positives (blebs) on the cast should be removed carefully with a suitable instrument.

The post-operative cast is seated into the pre-operative impression (Fig. 17-37, A through D). If using alginate, the operator must remember that the pre-operative impression has been wrapped in wet paper towels from the time it was made (see Fig. 17-2, D). The thin edges of the post-operative alginate impression material that record the gingival sulcus must be cut away (see Fig. 17-37, A). If these thin edges are not removed, they may tear off and keep the post-operative cast from seating completely in the impression. The post-operative cast is trial-seated into the pre-operative impression to verify that it seats completely. Soft tissue around the perimeter of the impression or the cast or in both areas may have to be relieved to allow full seating (see Fig. 17-37, B and C).

When satisfied that the gypsum cast seats completely in the pre-operative impression (see Fig. 17-37, D), the dentist removes the cast and marks the margins of the preparations on the cast with a red pencil to facilitate trimming (see Fig. 17-37, E). A release agent is brushed on the preparations and adjacent teeth (see Fig. 17-37, F). The dentist mixes tooth-colored temporary material (following the manufacturer's instructions) and pours it into the pre-operative impression in the area of the prepared teeth (see Fig. 17-37, G). When adjacent teeth are prepared, the temporary material is continuous from one tooth to the next. The cast is seated into the pre-operative impression, and the dentist ensures that it seats completely (see Fig. 17-37, H). Too much pressure should not be applied on the cast, or the temporary restoration becomes distorted and too thin in some areas. When the cast is seated, the cast and the impression are wrapped passively with a rubber band (too much pressure from the rubber band can distort the temporary restoration), and the assembly is submerged in hot water to accelerate the setting

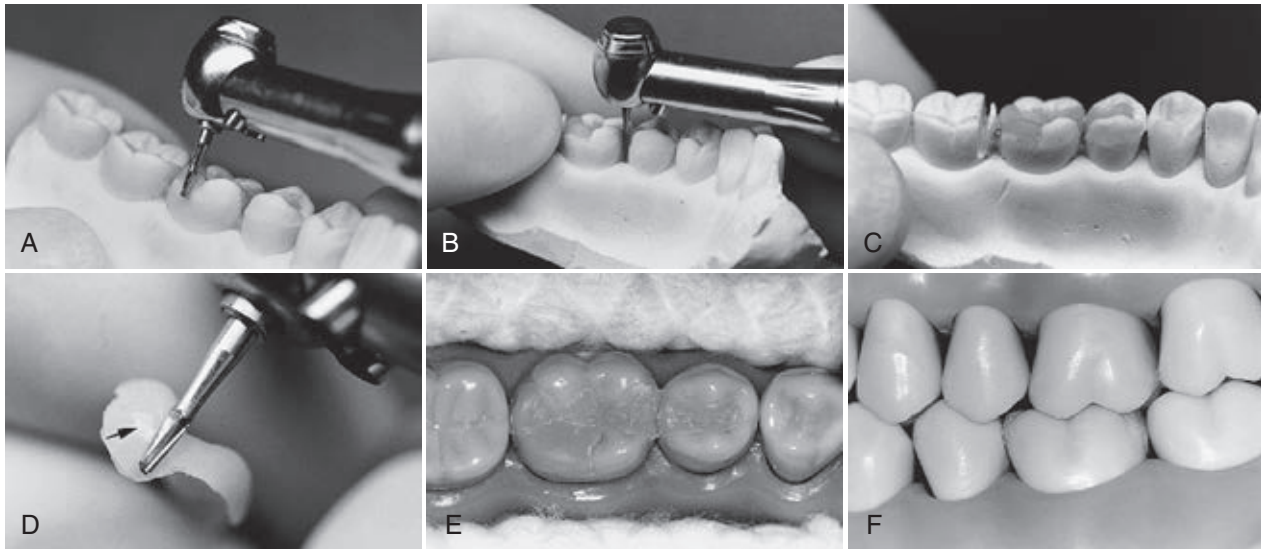


Fig. 17-38 Trimming and adjusting the indirect temporary restorations. **A**, Trimming the excess material back to the accessible facial and lingual margins (marked by red line on the plaster cast). **B**, On multiple-unit temporaries, a slender bur or diamond instrument can be used to refine the interproximal embrasure form. **C**, On the cast, any tooth adjacent to the temporary restoration is cut away. **D**, Trimming the proximal surface of the temporary restoration to the proper contour. Care should be taken to avoid removing the proximal contact (c). **E** and **F**, After the final impression is made, the temporary restoration is cemented with temporary cement. Note the anatomic contour and fit (**E**) and the functional occlusion of the temporary restoration (**F**).

reaction. The formed temporary restoration is shown in [Figure 17-37, I](#).

With suitable burs (No. 271, small acrylic bur, or diamond), the excess temporary material along the facial and lingual margins is trimmed away. The red line previously placed helps in the trimming, especially if it is performed by an auxiliary ([Fig. 17-38, A](#)). On multiple-unit temporary restorations, a thin diamond instrument or the slender No. 169L bur or diamond can be used to refine the interproximal embrasures (see [Fig. 17-38, B](#)). After the excess temporary material has been removed from the facial and lingual embrasures, the dentist cuts through the adjacent unprepared tooth 1 mm away from the proximal contact (see [Fig. 17-38, C](#)). A knife is inserted into the cut and the temporary restoration is pried off from the cast. Access to improve the contour of the proximal surface that will contact the adjacent, unprepared tooth is now available (see [Fig. 17-38, D](#)). The contact area on the temporary restoration that was accurately formed on the gypsum cast should not be disturbed.

Trial-fit the temporary restoration on the patient's teeth (see [Fig. 17-38, E](#)). It should fit well, make desirable contact with the adjacent teeth, and meet occlusal requirements with minimal adjustments (see [Fig. 17-38, F](#)). If occlusal adjustments are indicated, the prematurities are marked with articulating paper and reduced with an appropriate rotary instrument. After correcting the occlusion, any roughness or undesirable sharp edges are smoothed with a rubber point or wheel. The temporary restoration is removed from the mouth and set aside for cementation with temporary cement after the final impression has been made.

Technique for Direct Temporary Restoration

The direct temporary technique involves forming the temporary restoration directly on the prepared tooth and has the

following advantages ([Fig. 17-39](#)): (1) The direct technique involves fewer steps and materials because no post-operative impression and gypsum cast are required, and (2) it is much faster than the indirect technique. The main disadvantages of the direct temporary technique include the following: (1) There is a chance of locking hardened temporary materials into small undercuts on the prepared tooth and the adjacent teeth, (2) the marginal fit may be slightly inferior to the indirect technique, and (3) it is more difficult to contour the temporary restoration without the guidelines offered by the post-operative cast.¹¹

Forming the temporary restoration directly on the prepared tooth requires the pre-operative impression (see [Fig. 17-2, C](#)). Trial-fitting seats the pre-operative impression onto teeth to verify that it seats completely. Because a potential for locking the temporary restoration on the tooth exists, it is necessary to eliminate undercuts in the preparation and occasionally in the proximal areas. Undercuts in the preparation should be “blocked out” using a light-cured glass ionomer cement base (see [Fig. 17-39, B](#)). A light film of a water-based lubricant over any exposed base prevents adherence and facilitates removal.

When using the direct technique with inlay and onlay preparations (preparations that gain their retention primarily through internal retention features), it is helpful to select temporary material systems that become elastic before the final set, allowing removal from undercuts without permanent distortion. The temporary material is mixed, following the manufacturer's instructions. Temporary materials that use automixing tips are especially convenient (see [Fig. 17-39, C](#)). The dentist places the material into the pre-operative impression in the area of the prepared tooth, taking care not to entrap any air (see [Fig. 17-39, D](#)). The impression is placed on teeth, and the dentist ensures that it seats completely (see [Fig. 17-39, E](#)). The manufacturer's instructions for gauging the



Fig. 17-39 Forming the direct temporary restoration with pre-operative impression. Mesio-occluso-distal preparation for the mandibular first molar is used for illustration. **A**, Pre-operatively, this patient had symptoms indicating an incomplete fracture of a vital tooth. **B**, After preparation for an onlay, an incomplete fracture (*f*) of dentin is seen extending mesiodistally along the pulpal floor. To maximize the retention and resistance forms, all the cusps are reduced for capping, a facial surface groove extension is prepared, and all four transitional line angles have skirt extensions. Glass ionomer cement bases are inserted into excavations on axial walls (*g*). Cement bases should have a light coat of water-soluble lubricant to prevent adhesion. **C**, Automixing the temporary resin material. **D**, The mixed temporary material is poured into the pre-operative impression of the prepared tooth. **E**, The pre-operative impression is seated with the temporary material onto the prepared tooth. **F**, The formed temporary restoration is removed from the preparation (note the contact area *c*, which must not be removed during trimming). **G**, Thin excess can be removed by using scissors. **H**, The internal surface of the temporary restoration has record of the cavosurface margin that is used as guide for final trimming. **I**, After the final impression is made, the temporary restoration is cemented with temporary cement. The temporary material over the skirt extensions is left slightly over-contoured for additional strength.

setting time should be followed. Most temporary systems recommend monitoring the setting by rolling some excess material into a small ball and holding it between two fingers. When the temporary material has set to a firm stage, the impression is removed. The formed temporary restoration should remain

on the prepared tooth. The operator tests the temporary restoration by pressing on the occlusal surface slightly, and when the material is sufficiently strong, the operator removes it from the tooth (see Fig. 17-39, *F*). Excess material is trimmed away (see Fig. 17-39, *G*). The cavosurface margins of the

preparation can be seen inside the temporary restoration and are used as a guide for trimming the critical external areas near the margins (see Fig. 17-39, *H*). The techniques for try-in, adjustment, and finishing the direct temporary restoration are identical to those described in the previous section (see Fig. 17-39, *I*).

Final Impression

The indirect technique for making cast metal restorations is accurate and dependable. Fabrication of the cast metal restoration occurs in the laboratory, using a gypsum cast made from an impression of the prepared and adjacent unprepared teeth. The impression material used for the final impression should have the following qualities:

1. It must become elastic after placement in the mouth because it must be withdrawn from undercut regions that usually exist on the prepared and adjacent teeth. Note the shaded portions in Figure 17-40, which are undercut areas with regard to the line of draw of the preparation. A satisfactory impression must register some of this undercut surface to delineate the margin sharply and to signify the desirable contour of the restoration in regions near the margin.
2. It must have adequate strength to resist breaking or tearing on removal from the mouth.
3. It must have adequate dimensional accuracy, stability, and reproduction of detail so that it is an exact negative imprint of the prepared and adjacent unprepared teeth.
4. It must have handling and setting characteristics that meet clinical requirements.
5. It must be free of toxic or irritating components.
6. It must be possible to disinfect it without distorting it.

In addition to the absolute requirements listed above, the choice of impression material is usually made by comparisons of cost; ease of use; working time; shelf life; and pleasantness of odor, taste, and color. The most common impression material used for the indirect casting technique is PVS. The technique for the use of this material is discussed in detail in the following sections.

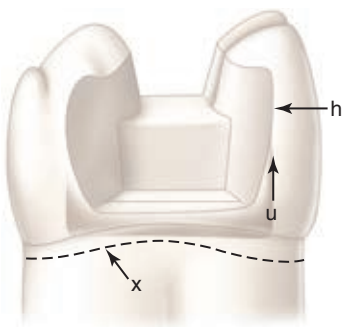


Fig. 17-40 The shaded area on the prepared tooth is undercut in relation to the line of withdrawal of the impression. The impression material that is in the position of greatest undercut (*u*) must be withdrawn in the direction of the vertical arrow and flexed over the greatest heights of contour (*h*). The position of the gingival attachment is indicated by *x*.

Tissue Retraction

Final impression materials make accurate impressions only of tooth surfaces that are visible, clean, and dry. When margins are subgingival, it is necessary to use retraction cords to displace the free gingiva temporarily away from the tooth and to control the flow of any gingival hemorrhage and sulcular fluids. The objective of gingival retraction is to widen the gingival sulcus to provide access for the impression material to reach the subgingival margins in adequate bulk to resist tearing during impression withdrawal (see Fig. 17-40). The objective of control of hemorrhage and moisture is met by the use of retraction cord impregnated with appropriate styptics (e.g., aluminum chloride), vasoconstrictors (e.g., epinephrine), or both. The use of vasoconstrictors in retraction cord is contraindicated in some patients, especially those who have cardiac arrhythmias, severe cardiovascular disease, uncontrolled hyperthyroidism, or diabetes and patients taking drugs such as β -blockers, monoamine oxidase inhibitors, or tricyclic anti-depressants.¹²

All sensory nerves to the region should be anesthetized, cotton rolls applied, and the saliva ejector inserted. Profound local anesthesia substantially reduces salivation to facilitate a dry field and allows tissue retraction without causing discomfort to the patient. The dentist selects and cuts a retraction cord of suitable diameter that is slightly longer than the length of the gingival margin. The cord may be cut long enough to extend from one gingival margin to another if they are on the same tooth or on adjacent teeth. In Figure 17-41, *A* and *B*, the cord is inserted into the gingival sulcus only in areas where the cavosurface margin is prepared subgingivally. Using the edge of a paddle-tipped instrument or the side of an explorer, one end of the cord is gently placed into the sulcus, about 2 mm facial to the point where the facial margin passes under the free gingiva. Then, the cord is inserted progressively into the remainder of the sulcus, with the end of the cord left exposed, to be grasped with tweezers later in the technique (see Fig. 17-41, *A* through *C*, *H*). The cord is placed to widen the sulcus and not to depress soft tissue gingivally (although some temporary retraction does occur apically).

Occasionally, when the gingival margin is deep, it is helpful to insert a second cord of the same or larger diameter over the first. When the free gingiva is thin and the sulcus is narrow (e.g., facial surface of the maxillary or mandibular canine), a cord of very small diameter must be selected to prevent undue trauma to the tissue. In instances when a small-diameter cord is used, layering a second cord on top of the first may be necessary to keep the sulcus from narrowing at the gingival crest.

In Figure 17-41, *D*, the cord is incorrectly placed because it is tucked too deeply into the sulcus, as its depth permitted such positioning. When the cord is withdrawn before the injection of the impression material, the sulcus is wide at the bottom but narrow at the top. If the impression material is injected successfully into such a sulcus, the material is likely to tear in the region of *x* during the removal of the impression from the mouth. Correct application of the retraction cord is shown in Figure 17-41, *C*.

Occasionally, the retraction cord becomes displaced from the sulcus during its insertion in the presence of slight hemorrhage or seepage, but this can be controlled if an assistant repeatedly touches the cord with dry cotton pellets or dries

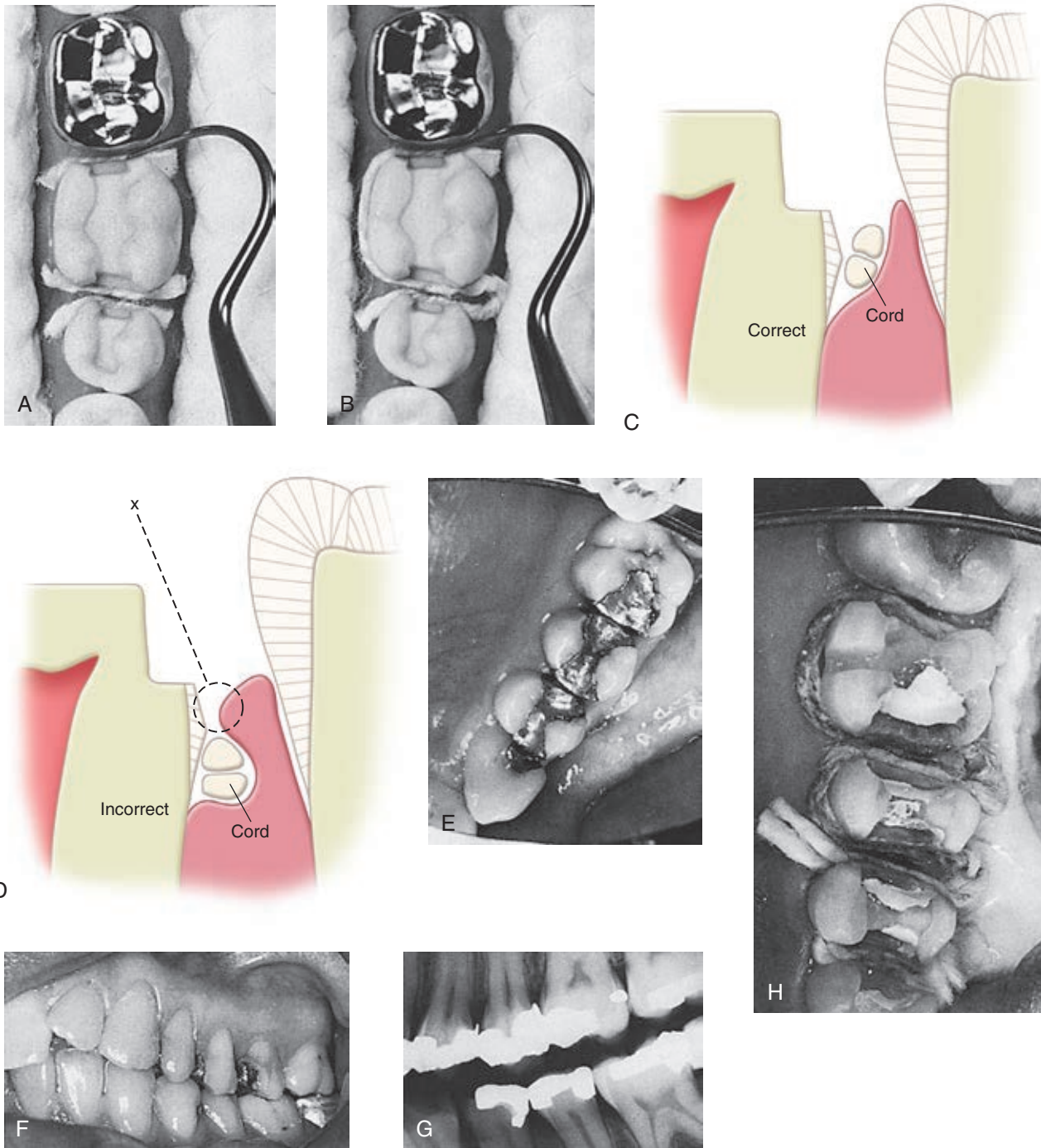


Fig. 17-41 **A** and **B**, Inserting the retraction cord to widen the gingival sulcus to expose the gingival margin. Separate lengths of cord can be inserted (one for each gingival margin) (**A**), or a cord long enough to run from one gingival margin to another can be inserted (**B**). Where the margin is not subgingival, as on the lingual surface of the molar, the cord should not be in the sulcus. **C**, Correct application of the retraction cord. **D**, Incorrect application of the retraction cord causing the impression material to tear at *x*. **E**, Maxillary quadrant before preparing teeth for onlays. Note the fracture of the mesiofacial cusp of the molar. **F**, Facial view of **E**. **G**, Bitewing radiograph of **E**. **H**, Teeth prepared for onlays and ready for making the final impression. The lingual and distofacial transitional line angles of premolars are prepared for skirting.

the area with a gentle stream of air. When excessive hemorrhage from the interproximal tissue occurs, first a cotton pellet is moistened with aqueous aluminum chloride solution, and the pellet is wedged between teeth so that it presses on the bleeding tissue. This pellet is left in for several minutes before it is removed and the cord is inserted. The widening

or opening of the gingival sulcus by the earlier insertion of the retraction cord before the beveling of the gingival margin also should minimize or eliminate hemorrhage of the gingiva. For retracting a large mass of tissue, first a suitably shaped, large-diameter cotton pack is made by rolling cotton fibers between fingertips, and the pack is then moistened with a

drop or two of aqueous aluminum chloride and inserted into the sulcus.

The cords remain in place for several minutes. When hemorrhage or excessive tissue is present, more time is recommended. The region must remain free of saliva during this interval, and the patient should be cautioned not to close or allow the tongue to wet the teeth. Placing cotton rolls over teeth and having the patient close lightly to relax while the teeth remain isolated is sometimes helpful.

Caution: Some brands of latex gloves and some hemostatic agents contain chemicals that can inhibit the setting of PVS impression materials. Meticulous cleaning of teeth and the retraction cord to remove any chemicals that could prevent the setting of the impression material may be necessary. After cleaning, the prepared teeth should not be excessively dried with compressed air. The patient should be asked to close lightly on cotton rolls until the impression material is ready to be applied.

Polyvinyl Siloxane Impression

The PVS impression is discussed in detail here because it is widely used, and the technique for its use can be readily applied to most other impression materials. PVS impression materials have many advantages over other impression materials used for final impressions. They have excellent reproduction of detail and dimensional stability over time. They are user-friendly because they are easy to mix and have no unpleasant odor or taste. PVS impressions can withstand disinfection routines without significant distortion. These impression materials come in the form of two pastes (base and catalyst) that are mixed in disposable, automix, cartridge-dispensing systems. These automix systems provide excellent mixing of the accelerator and base pastes (Fig. 17-42, A).

TRAY SELECTION AND PREPARATION

The impression tray must be sufficiently rigid to avoid deformation during the impression technique. If the tray bends or flexes at any time, the accuracy of the impression may be affected. Two types of trays, commercial stock and custom made, are suitable. Use of stock plastic trays is convenient and saves time. The custom resin tray made over a 2- to 3-mm wax spacer on the study cast is an excellent tray. A thickness of impression material greater than 3 mm increases shrinkage and the chance of voids; a thickness less than 2 mm may lead to distortion or tear of the impression material or to breakage of narrow or isolated teeth on the cast during withdrawal from the impression. Adequate bonding of impression material to the tray is accomplished with the application of a special adhesive to the tray (see Fig. 17-42, B).

IMPRESSION TECHNIQUE

Most dental manufacturers offer their PVS impression materials in automix dispensing systems. The automixing systems have many advantages, including (1) speed, (2) consistent and complete mixing of accelerator and base pastes, and (3) incorporation of very few air voids during mixing and delivery to teeth. The technique demonstrated requires two viscosities of impression material, a light-bodied material to inject around the preparation and a heavy-bodied material to fill the tray.

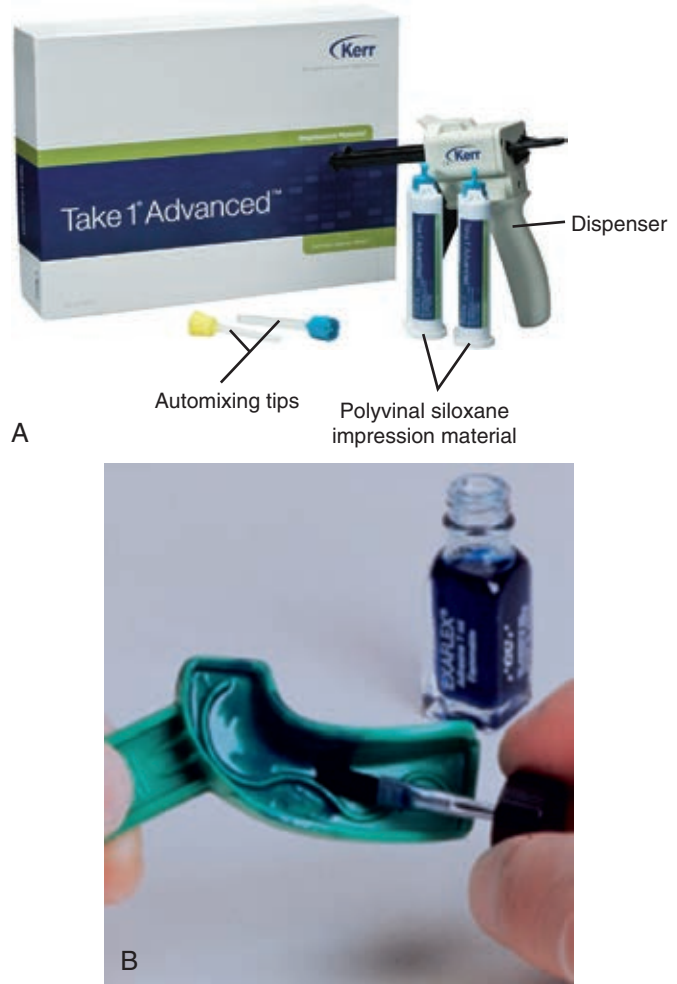


Fig. 17-42 A, Light-bodied (low viscosity), medium-bodied, and heavy-bodied (high viscosity) polyvinyl siloxane impression material; dispenser; automixing tip; and putty (very high viscosity). B, Painting adhesive on stock tray. (A, Courtesy of Kerr Corp., Orange, CA. B, From Rosenstiel SF, Land MF, Fujimoto J: Contemporary fixed prosthodontics, ed 4, St. Louis, Mosby, 2006.)

Two dispensing guns are needed (Fig. 17-43, A). The dispensers are loaded with cartridges that contain the accelerator and base pastes (see Fig. 17-43, B). A disposable automixing tip fits onto the end of each cartridge (see Fig. 17-43, C). The light-bodied mixing tip has an accessory curved tip that is small enough to gain access to the smallest, most remote areas of the preparation (see Fig. 17-43, D).

The first dispenser is used to mix and fill the impression tray with the heavy-bodied impression material (see Fig. 17-43, E). The dispensing tip should be kept embedded in the impression material as it is expressed into the tray so that the chance of trapping air is decreased. The second dispenser is then used to mix and inject the light-bodied impression material on the prepared teeth (see Fig. 17-43, F). Teeth should be examined to ensure that the field is still clean and dry. Any visible moisture on teeth is removed with compressed air. The retraction cord is gently removed with operative pliers. All preparation surfaces should be clean, dry, and exposed to view. Next, the opened gingival sulci and preparations are

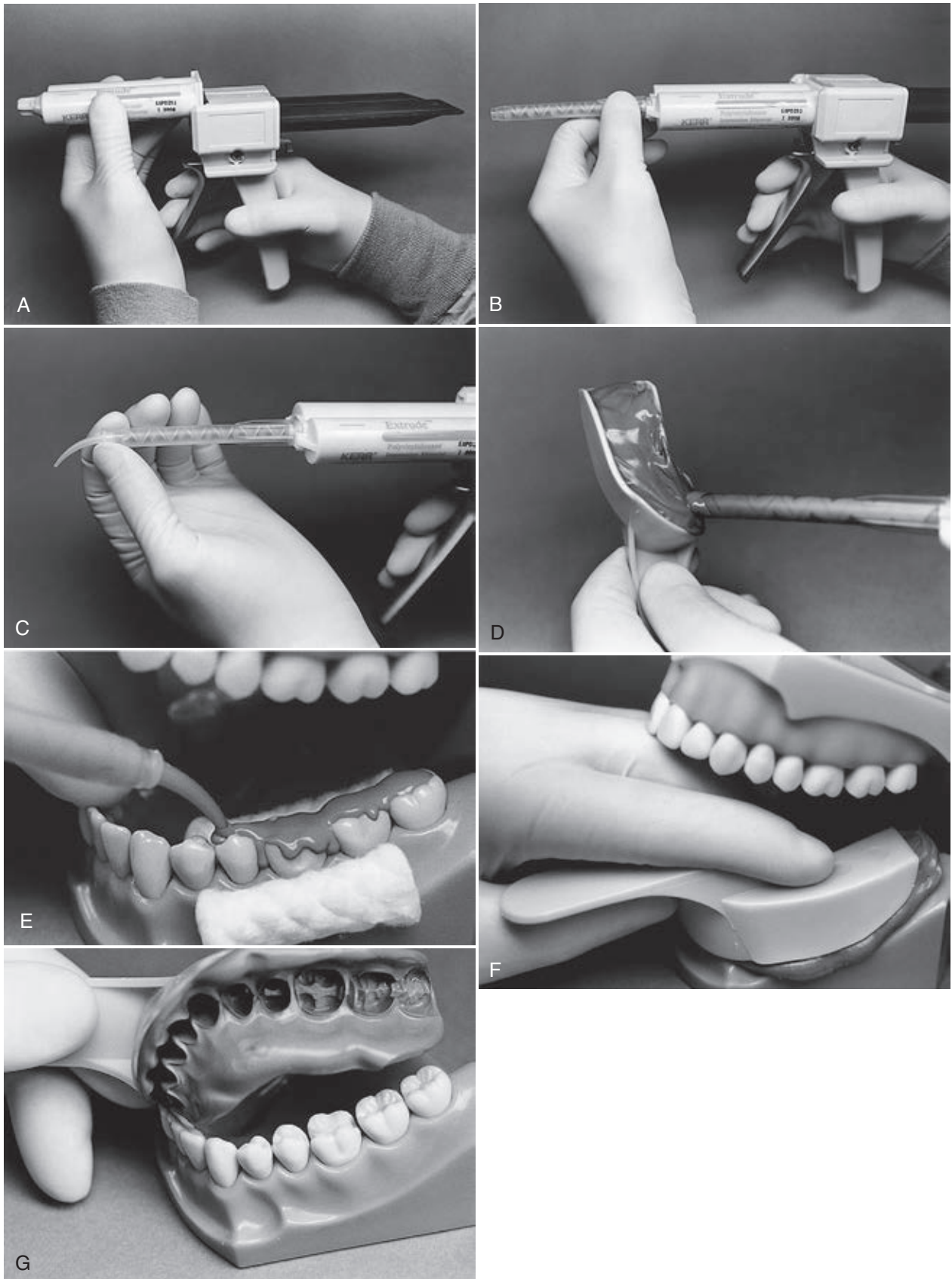


Fig. 17-43 **A**, One dispenser is loaded with light-bodied impression material, and the other dispenser is loaded with heavy-bodied impression material. **B**, The disposable automixing tip fits onto the end of the cartridge. **C**, An accessory curved tip is added to the end of the automixing tip for the light-bodied material. **D**, The impression tray is filled with heavy-bodied material. **E**, The retraction cord is removed, and the opened sulci and preparations are progressively filled over and beyond the cavosurface margins without trapping air. The occlusal surfaces of the adjacent unprepared teeth are covered with light-bodied impression material. **F**, The cotton rolls are removed, and the impression tray is seated. **G**, Completed automixed polyvinyl siloxane impression.

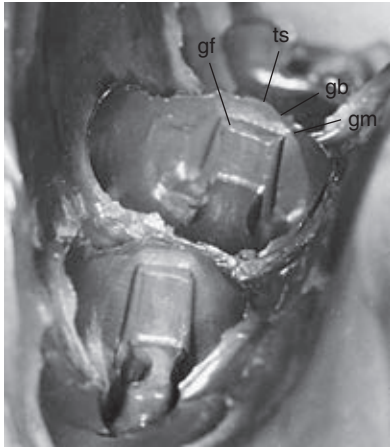


Fig. 17-44 Close-up view of the impression shows sharp details of record of the gingival floor (*gf*), gingival bevel (*gb*), and margin (*gm*) and a small amount of unprepared tooth surface (*ts*) beyond the margin.

deliberately and progressively (moving from distal to mesial) filled over and beyond the margins with material from the syringe. To avoid trapping air, the tip is kept directly on the gingival and pulpal walls, filling the preparations from the gingival to the occlusal aspect, and the flow is regulated so that the material is not extruded too fast ahead of the tip. Light-bodied material also is injected on the occlusal surfaces of the unprepared adjacent teeth to eliminate the trapping of air on the occlusal grooves.

After filling and covering teeth with material from the syringe, the cotton rolls are immediately removed and the loaded tray seated over the region. The manufacturer's product instructions should be followed with regard to how long the material should be allowed to set before removal. As an additional safeguard, the operator should test the set of the impression material wherever it is accessible at the periphery of the tray. When it recovers elastically from an indentation made by the tips of the operative pliers, it is ready for removal.

REMOVING AND INSPECTING THE IMPRESSION

After the PVS impression has properly polymerized, it is removed from the mouth by a quick, firm pull that is directed as much as possible in line with the draw of the preparation. Removal is aided by inserting a fingertip at the junction of the facial border of the impression and the vestibule fornix, disrupting the vacuum that occasionally occurs during withdrawal, especially with full-arch impressions. The impression should be inspected carefully with good lighting and magnification. It should register every detail of the teeth and the preparation (Fig. 17-44).

Working Casts and Dies

The working cast is an accurate replica of the prepared and adjacent unprepared teeth that allows the cast metal restoration to be fabricated in the laboratory. During this fabrication procedure, it is most helpful if the replicas of the prepared teeth and of the adjacent unprepared teeth, called *dies*, are individually removable. The most used methods for creating a working cast with removable dies from an elastic impression require two pours. The first pour is made to produce the



Fig. 17-45 Cast poured from the die stone is inspected for completeness.

removable dies, and the second pour is made to establish intra-arch relationships. Working casts made in this manner are called *split casts*. Several satisfactory methods are available for making a split cast with removable dies. The Pindex system (Coltene/Whaledent Inc., Cuyahoga Falls, OH) is illustrated because it offers many advantages, as follows:

1. The first pour becomes the die segment and can be made quickly and easily.
2. Dowel pins can be positioned precisely, where needed.
3. Dowel pins are automatically positioned parallel, which facilitates die removal.

Pouring the Final Impression

A mix of high-strength die stone is made using a vacuum mechanical mixer, and the dies are poured with the aid of a vibrator and a No. 7 spatula. The first increments are applied in small amounts, allowing the material to flow into the remote corners and angles of the preparation without trapping air. Surface tension-reducing agents that allow the stone to flow more readily into the deep, internal corners of the impression are available. The impression should be sufficiently filled so that the dies are approximately 15 to 20 mm tall occlusogingivally after trimming. This may require surrounding the impression with boxing wax before pouring. After the die stone has set, the cast is removed from the impression and inspected for completeness (Fig. 17-45). This first pour (die segment) becomes the removable dies.

Completing the Working Cast

The base of the die segment is trimmed flat on a model trimmer (Fig. 17-46, A). This trimming is approximately parallel to the occlusal surfaces of teeth. The operator must take care while doing this so that no grinding slurry is allowed to splash onto the dies. The dies should be approximately 15 mm occlusogingivally. When the base of the die segment is flat, the sides closer to the facial and lingual aspects of teeth should be trimmed (see Fig. 17-46, B). Deep scratches left by the model trimmer are removed by wet sanding the base of the die segment with 220-grit wet or dry sandpaper.

General rule: Teeth that will be removable are the prepared teeth with proximal gingival margins and any unprepared

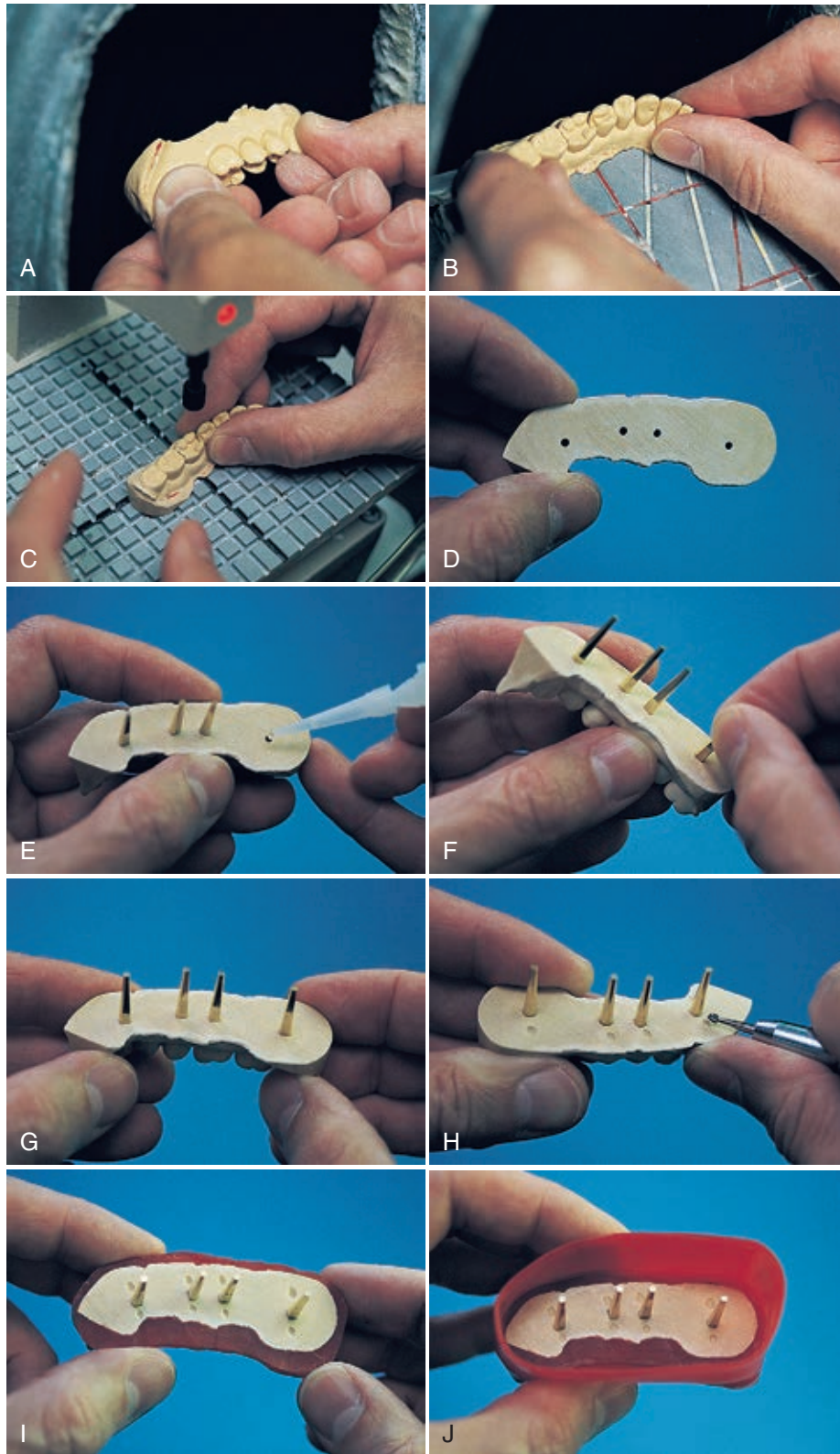


Fig. 17-46 **A**, The base of the die segment is trimmed flat and approximately parallel to the occlusal surfaces with a model trimmer. Dies should be approximately 15 mm high occlusogingivally. **B**, The die segment is trimmed on the facial and lingual surfaces to reduce the need for trimming in later steps. **C**, The die segment on the Pindex machine, ready to drill hole for first molar die. A small red dot of light helps position the cast. **D**, Holes drilled for removable dies. **E**, A drop of cyanoacrylate glue is poured into each hole. The cast must be dry for the glue to adhere. **F**, Immediately insert a dowel pin into the hole, being sure it is fully seated. **G**, The dowel pins must be parallel to one another and fully seated, and no excess glue must be present. **H**, To aid in indexing, small dimples are cut in the base of the dies, using one third the diameter of a large (No. 6) round bur. Typically, these are positioned facial and lingual to the dowel pin. **I**, Rope wax is placed around the cast, flush with the die bases. **J**, Boxing wax is placed around the rope wax to create a container for the base pour. A separating agent must be painted on the die bases to prevent adherence to the base pour.

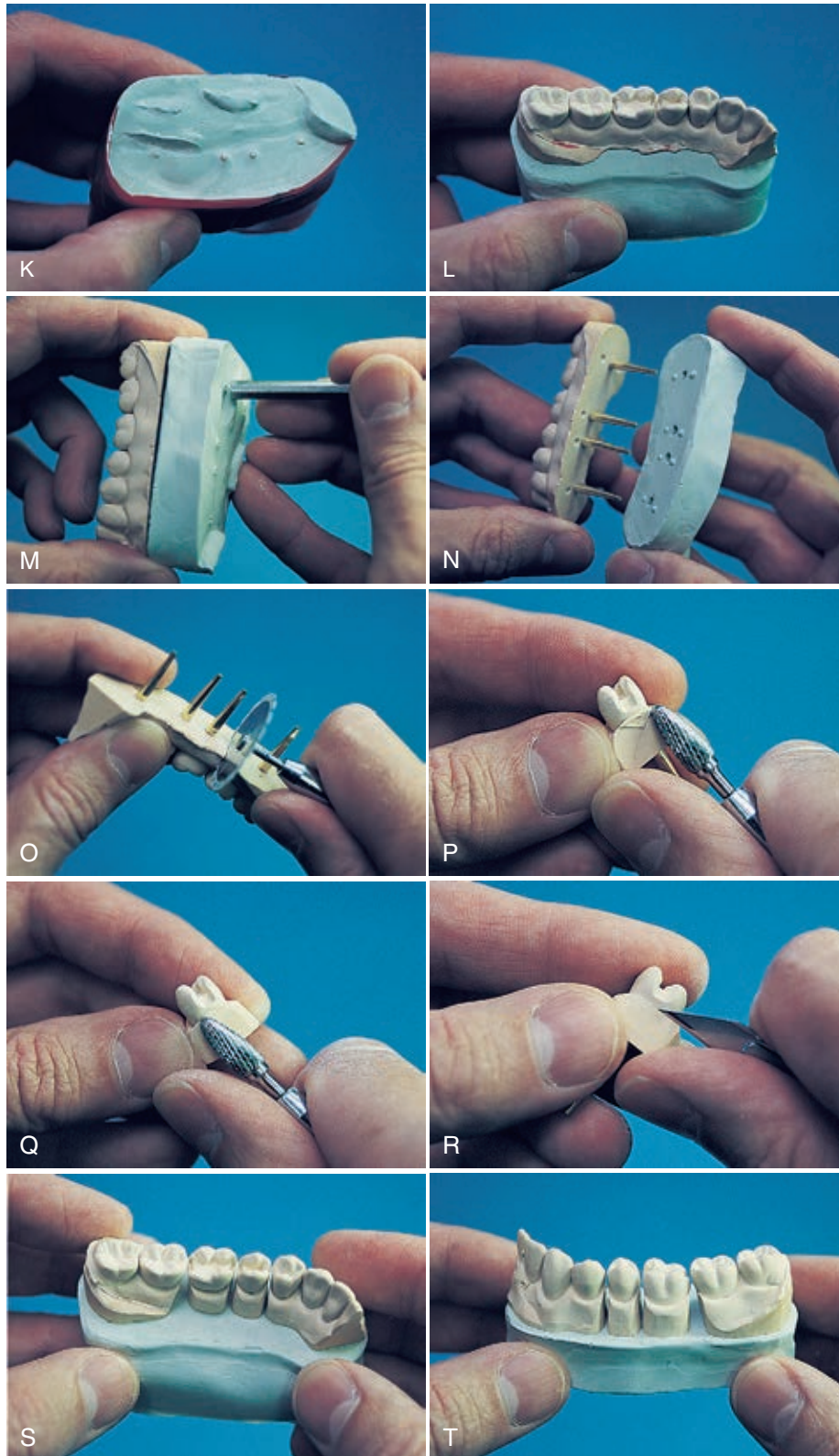


Fig. 17-46, cont'd **K**, Base pour is completed. At least 1 mm of the dowel pin should be left protruding. **L**, Cast after removing boxing and rope wax. **M**, Tapping on the end of each dowel pin until the die segment moves. **N**, Removing the die segment from base. **O**, The dies are carefully cut apart by using a saw, bur, or thin diamond abrasive disk. Eye protection and dust collection are essential. **P**, Excess die stone around the gingival margins usually prevents good access for later steps in fabrication. **Q**, Removing the excess die stone with a large crosscut carbide bur in a slow-speed handpiece. Trimming across slightly gingival of the recorded gingival contour of the tooth weakens the excess, causing it to fall away. **R**, Final trimming is completed with a sharp scalpel. **S**, Cast completed, lingual view. Note how each prepared tooth and the adjacent unprepared teeth are removable now. **T**, Cast completed, facial view. Note the full seating of the dies.

teeth adjacent to the prepared proximal surfaces. The two main advantages to making removable dies of unprepared teeth adjacent to prepared proximal surfaces are as follows: (1) The adjacent tooth will not interfere with removing the die that has the preparation, as occasionally may happen otherwise. (2) Adjusting the contacts is easier and more accurate when waxing and finishing the castings.

One dowel pin usually is placed in each prepared tooth and each adjacent tooth. When long sections of teeth are to be removable, the operator may wish to place more than one pin to increase stability and prevent rotation of the die. The cast is placed on the Pindex drilling machine, and one hole is drilled into the die base precisely in the middle of each tooth that is to be removable (Fig. 17-46, C and D). A small light beam helps position the cast correctly. When all the holes are drilled, a small drop of cyanoacrylate glue is placed in each hole, and a dowel pin is inserted (see Fig. 17-46, E and F). The cast must be dry before cementing the pins, or the cement may not adhere. Any excess glue should be removed, and the operator should ensure that the dowel pins are parallel to one another (see Fig. 17-46, G). To prevent rotation of the dies on the model base, small dimples may be placed just facial and lingual to each dowel pin with one third the diameter of a No. 6 round bur (see Fig. 17-46, H). A bead of rope wax is placed around the die segment level with the base of the dies (see Fig. 17-46, I). Then, boxing wax is added around this to form a container for the base pour (see Fig. 17-46, J). A separating medium is applied on the die segment, and a mix of dental stone is vibrated into the boxing wax container (see Fig. 17-46, K). At least 1 mm of the ends of the dowel pins should be allowed to protrude. To provide adequate strength, the base of the cast should not be less than 10 mm thick.

After the stone has hardened, the boxing and rope wax are removed. Then, the cast is removed from the impression (see Fig. 17-46, L). The operator taps the end of each dowel pin lightly with the end of an instrument handle until a different sound is heard; this indicates that the die segment has moved slightly from its seating (see Fig. 17-46, M). Next, the ends of the pins are carefully pushed conjointly, causing the die segment to move equally away from its seating (see Fig. 17-46, N). After the die segment is removed in this manner, the teeth that are to be individually removable must be cut apart from one another (see Fig. 17-46, O). This requires the use of a saw, bur, or disk. To aid in carving the wax pattern and polishing the casting, the gingival aspect of the dies is carefully trimmed to expose the gingival margins properly (see Fig. 17-46, P through R). The trimmed dies should have a positive and complete seating in the base portion of the cast (see Fig. 17-46, S and T).

Caution: Do not allow any debris between the die portion and the base, or the accuracy will be compromised. This is especially true for the walls of the dowel pin holes. A small bit of wax or gypsum can be carelessly pressed onto the wall and prevent complete seating of the pin. Such debris is difficult to detect and remove to regain accuracy.

Use of Interocclusal Records

A maximum intercuspal interocclusal record is made before making the final impression. From this interocclusal record, a gypsum cast of the opposing teeth is made; this cast

can be related accurately to the working cast, when forming the occlusal surface of the wax pattern. This step can be omitted if full-arch casts are to be used in waxing. See Chapter 1 for the principles of developing occlusion when using full-arch casts.

When using this type of interocclusal record, the working cast is mounted on a simple hinge articulator. The working cast is attached to one member of the articulator with fast-setting plaster. The interocclusal record is carefully fitted on the dies of the working cast (Fig. 17-47, A and B). The interocclusal record should seat completely without rocking. Interocclusal bite records must never touch the registrations of soft tissue areas on the cast because these contacts usually interfere with complete seating. Such areas of contact on the interocclusal record can be trimmed away easily with a sharp knife. After ensuring that the interocclusal record is completely seated, lute the record adjacent to the unprepared teeth with sticky wax to prevent dislodgment when dental stone is poured into the record. Dental stone is then poured into the record (see Fig. 17-47, C). This gypsum is attached to the opposite arm of the hinge articulator (see Fig. 17-47, D), it is allowed to set, and then the interocclusal record is removed (see Fig. 17-47, E through G).

Wax Patterns

Forming the Pattern Base

The operator lubricates the die and incrementally adds liquid wax from a No. 7 wax spatula by the “flow and press” method to form the proximal, facial, and lingual surface aspects of the pattern. A thin layer of wax should be added on the occlusal surface (Fig. 17-48, A). Wax shrinks as it cools and hardens and tends to pull away from the die. This effect can be minimized and pattern adaptation improved by applying finger pressure for at least several seconds on each increment of wax soon after surface solidification and before any subsequent wax additions (see Fig. 17-48, B). In this incremental technique, the wax that is flowed on the previously applied wax must be hot enough, as otherwise voids are formed.

Forming the Proximal Contour and Contact

The proximal contour and contact of the pattern are now formed on the pattern base (Figs. 17-49 and 17-50). The normal proximal contact relationship between teeth is that of two curved surfaces touching one another. The contact on each curved proximal surface is a point inside a small area of near-approach. Soon after eruption and the establishment of proximal contact, wear of the contact point from physiologic movements of teeth creates a contact surface. Lack of a proximal contact is usually undesirable because it creates the risk of proximal drifting of teeth, shifting occlusion, food impaction, and damage to the supporting tissues. Total lack of a proximal contact is often referred to as an *open contact* and is to be avoided.

Drawings of two maxillary premolars (see Fig. 17-50) are used to illustrate forms of contact and mesiodistal widths of interproximal spaces. Figure 17-50, A through C, shows normal conditions. In Figure 17-50, A, the position of the contact is marked with an *x*, the area of near-approach of the two surfaces is indicated with a broken line, and the position of the crest of the gingiva is indicated with a continuous line.

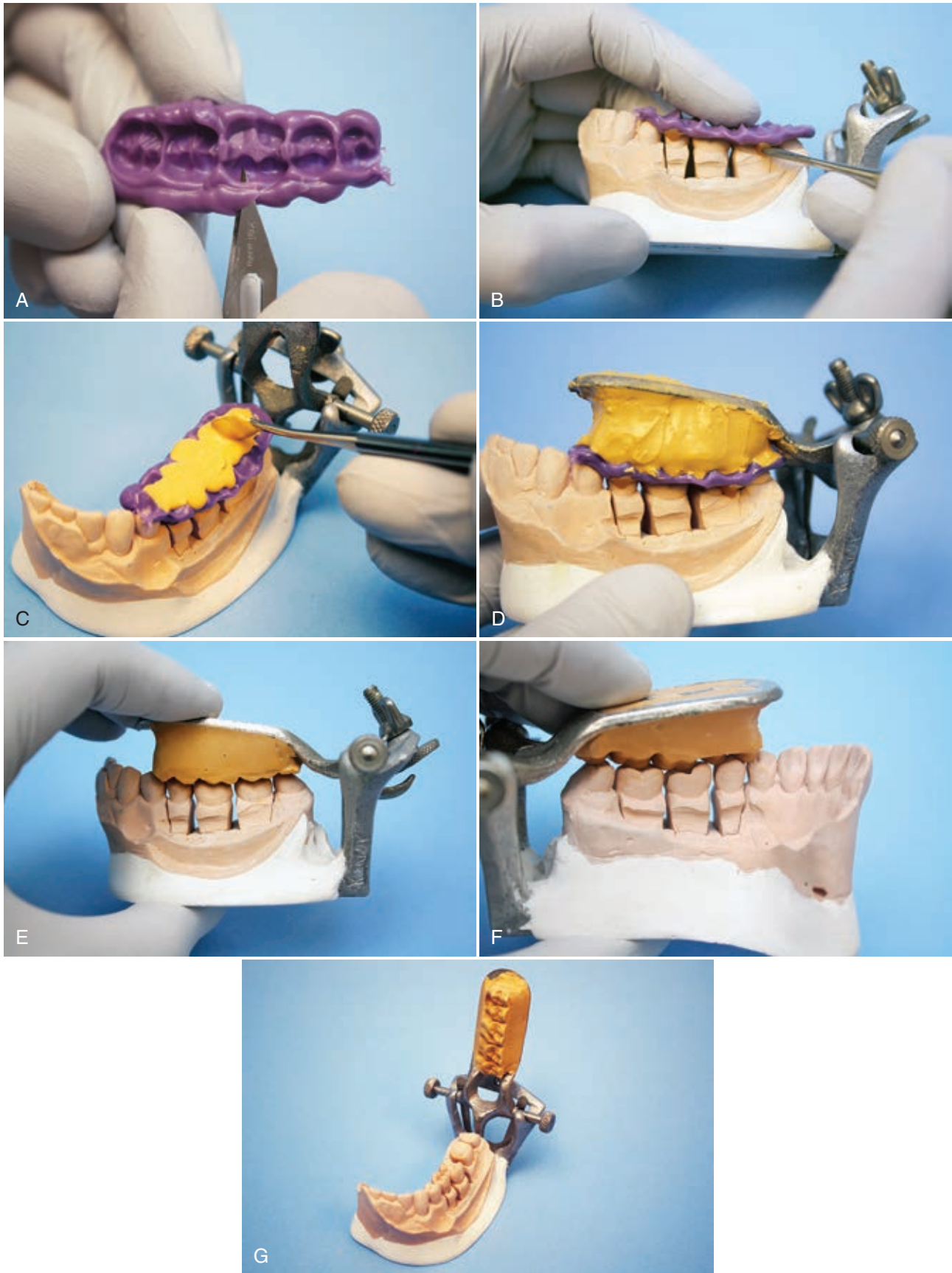


Fig. 17-47 Pouring the interocclusal record made with bite registration paste. **A**, Trimming away some of the interocclusal record (on the preparation side) with a sharp knife is often necessary to allow complete seating on the working cast. **B**, Fastening the seated interocclusal record to the working cast of preparations first shown in *Figure 17-33, A*, with small amounts of sticky wax. **C**, Pouring stone into the interocclusal record. **D**, Attaching gypsum to the upper member of the hinge articulator. **E-G**, Three views of the completed mounting.

Fig. 17-48 To ensure optimal wax adaptation to the preparation walls, a thin layer of wax is first poured (A), and then finger pressure is applied for several seconds while the wax cools (B).

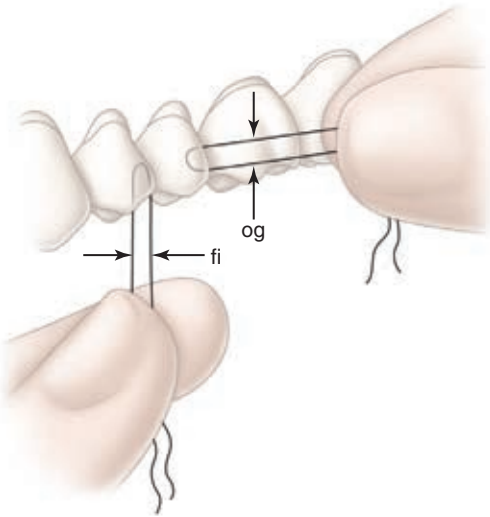
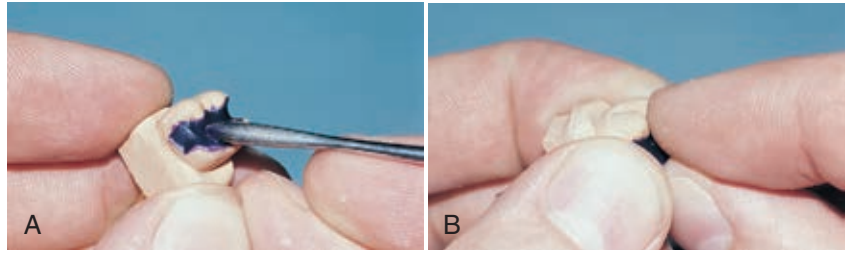


Fig. 17-49 Measuring the diameters of the proximal contact faciolingually (*fi*) and occlusogingivally (*og*) with dental floss. Two parallel strands should not be more than 1 to 2 mm apart. (Modified from Black GV: Operative dentistry, vol 2, ed 8, Woodstock, IL, 1947, Medico-Dental.)

Figure 17-50, B, is a mesiodistal section through teeth at the point of contact, and Figure 17-50, C, is an occlusal view.

A broad contact faciolingually is illustrated in Figure 17-50, D through F. In the proximal view (see Fig. 17-50, D), the position of a normal contact is marked *x*, the contact of this tooth is the outlined oblong area, and the area of near approach is the broken line. The crest of the gingiva is less arched, being almost horizontal along the area of near-approach. Viewed from the facial in the mesiodistal section (see Fig. 17-50, E), the contact appears to be the same as in Figure 17-50, B, but a comparison of the occlusal views (see Fig. 17-50, F and C) shows the extra breadth of this contact at the expense of the lingual embrasure. Figure 17-50, H, shows a contact that is too far to the gingival. Its position in comparison with normal is shown by the relation of the circle to the *x* in Figure 17-50, G. The problem with such a contact is in the inclinations of the proximal surfaces from the occlusal marginal ridges to the contact. Stringy food is likely to become packed into this space, and the contact may impinge on the interproximal tissue.

See Figure 17-50, I and J, for an illustration of a contact too close to the occlusal. This form is frequently observed in restorations (especially amalgams), seldom in virgin teeth. Such a contact allows food to fill the gingival embrasure and invites proximal caries.

A contact that is too broad in the occlusogingival direction, but narrow faciolingually, is illustrated in Figure 17-50, K and L. The principal objections to this form of contact are that stringy foods are likely to be caught and held; also, if proximal recurrent caries occurs, it is farther to the gingival, requiring a tooth preparation close to the cemento-enamel junction (CEJ). In cases of excessive proximal wear of teeth, the condition of the contact areas is similar to the combination of the areas illustrated in Figure 17-50, D and K, resulting in a facet of considerable dimensions.

Forming the Occlusal Surface

Payne developed the fundamental principles in the following method of waxing.⁷ The technique is particularly applicable when capping cusps. With practice, it has proven to be faster than the old method of building up wax, cutting away, building up again, and so on. The amount of wax desired is added in steps until the occlusal surface of the pattern is completed (Fig. 17-51).

To obtain the faciolingual position of the cusp tips, the faciolingual width of the tooth is divided in quarters. Facial cusps are located on the first facial quarter line. Lingual cusps fall on the first lingual quarter line (see Fig. 17-51, B). To obtain the mesiodistal position of the cusp tips, one notes the regions in the opposing tooth that should receive the cusp tips. The operator waxes small cones of inlay wax to the pattern to establish the cusp tips one at a time (see Fig. 20-51, C and D). Next, the operator waxes the inner and outer aspects of each cusp, being careful not to generate premature occlusal contacts (see Fig. 17-51, D through F). It is suggested that only one aspect of each cusp be waxed into occlusion at a time. On the maxillary molar (illustrated in Fig. 17-51, D), where all of the cusps are being restored, each of the nine aspects present are waxed one at a time. The operator should follow the proper angle on the inner and outer aspects (see Fig. 17-51, E).

Next, the distal slopes of the cusps are waxed (one at a time) into occlusal relation with the opposing teeth. The mesial slopes of the cusps are waxed next (one at a time) (see Fig. 17-51, G). After the cusps are formed, the operator waxes in the proximal marginal ridge areas (see Fig. 17-51, H). The same level to adjacent proximal marginal ridges should be developed, even though occasionally this may sacrifice a contact on one of the two ridges. Restoring marginal ridges to the same level avoids a “food trap” that otherwise would be created. The mesial and distal pit regions also should be carved enough to have them deeper than the respective marginal ridges. This provides appropriate spillways for the removal of food from the occlusal table and helps prevent food impaction in the occlusal embrasure area of the proximal surface.

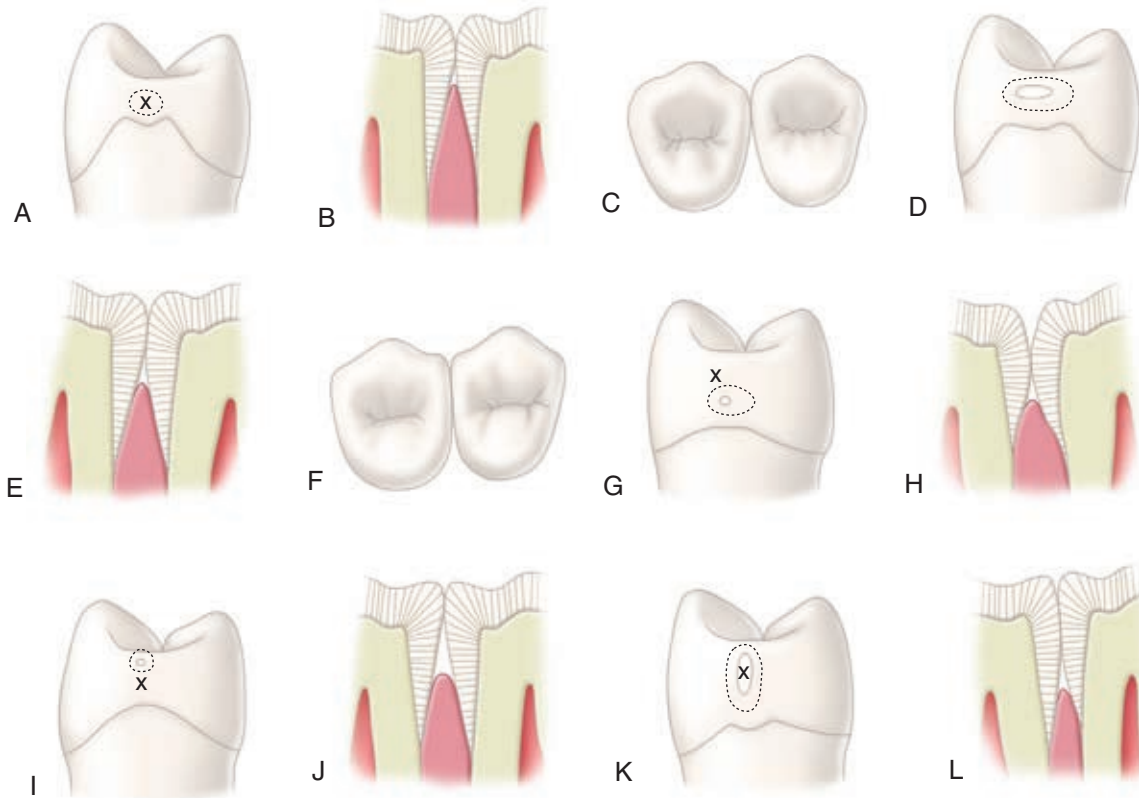


Fig. 17-50 **A–C**, Correct contact. Note the position and form of the contact and the form of the embrasures around the contact. The mesial and distal pits are below (gingival of) the proximal marginal ridges. **D–F**, Contact too broad faciolingually. **G** and **H**, Contact positioned too far gingivally. **I** and **J**, Contact too close to the occlusal surface. **K** and **L**, Contact too broad occlusogingivally. (Modified from *Black GV: Operative dentistry, vol 2, ed 8, Woodstock, IL, 1947, Medico-Dental.*)

To complete the occlusal wax-up, wax is added (where appropriate) to the fossae until they contact the opposing centric-holding cusps (see Fig. 17-51, *I*). Spillways for the movement of food are established by carving appropriately placed grooves. Flat-plane occlusal relationships are not desired.

This technique is a systematic and practical method of waxing the occlusal aspect of the pattern into proper occlusion. Forming one small portion at a time results in waxing each portion into proper occlusion before adding another, which simplifies the procedure. Building the occlusal aspect by such small increments should help develop a pattern with minimal stress and distortion. Whenever a large portion of wax is added, it creates a potential for pattern distortion caused by the large shrinkage of such an addition.

For establishing stable occlusal relationships, the operator should take care to place the cusp tips against flat plateaus or into fossae on the stone cast of the opposing teeth. In other areas, the wax is shaped to simulate normal tooth contours, using adjacent teeth as references. Some relief between the opposing cusp inclines should be provided because these incline contacts often interfere during mandibular movements. The maximum intercuspation record provides only information regarding the position of the opposing teeth in maximum intercuspation. Some adjustment to the casting may be necessary in the mouth to eliminate interferences during mandibular movements. See Chapter 1 for the

principles of cusp and fossa placement when using full-arch casts mounted on a semi-adjustable articulator.

Finishing the Wax Pattern

Careful attention to good technique is required for waxing the margins of the wax pattern. There must be a continuous adaptation of wax to the margins, with no voids, folds, or faults. If adaptation is questionable, the marginal wax should be re-melted to a distance into the pattern of approximately 2 mm. Finger pressure is applied immediately after surface solidification and before subsequent cooling of the wax, with pressure maintained for at least 4 seconds. This finger pressure helps develop close adaptation to the die by offsetting the cooling shrinkage of the wax. Additional wax should be added during the re-melting procedure to ensure a slight excess of contour and extension beyond the margin.

Wax that is along the margins is now carved back to the cavosurface outline with a warmed No. 7 wax spatula (Fig. 17-52, *A* through *E*). This warming of the spatula permits carving of the marginal wax with light pressure so that the stone margins are not damaged. A little practice helps the operator determine how much to heat the instrument for easy and effective carving. The No. 7 spatula should not have sharp edges; when it touches the die lightly, it should not abrade or injure the die surface. The operator uses the die surface just beyond the cavosurface margin to guide the position and

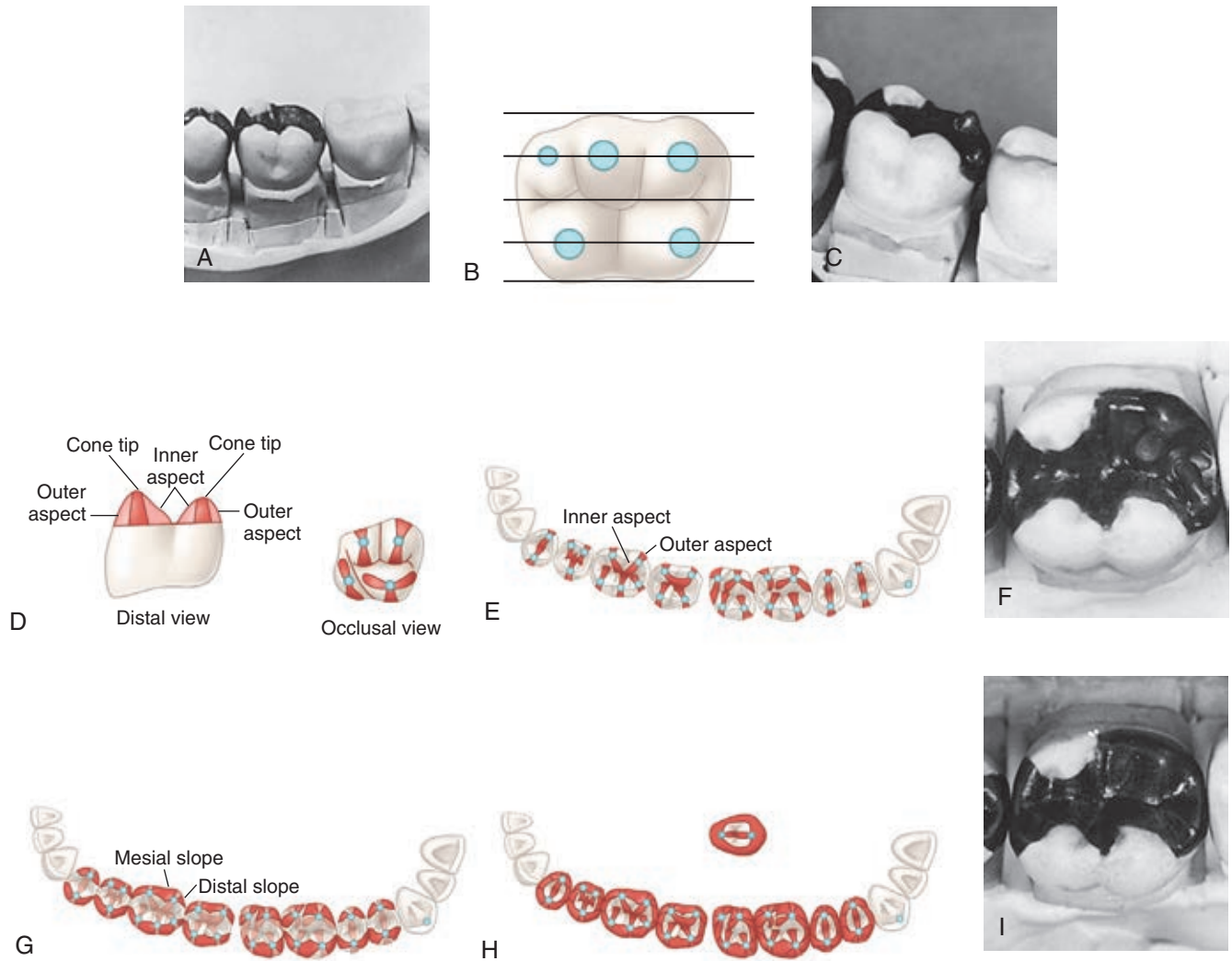


Fig. 17-51 **A**, The pattern base is completed and ready for waxing two reduced cusps (distolingual and distal) into occlusion by using Payne's waxing technique. **B**, The facial cusps are located on the first facial quarter line, and the lingual cusps fall on the first lingual quarter line. **C**, The distolingual and distal cusp tips are waxed into occlusion in the form of small cones. **D**, Cone tips and inner and outer aspects. **E**, Cone tips and inner and outer aspects of the cusps of teeth. **F**, The inner and outer aspects of the distolingual and distal cusps have been added to the pattern base. **G**, The mesial and distal slopes of the cusps of teeth. **H**, Marginal ridges of teeth. **I**, After the marginal ridge is added to the pattern base, fossae are waxed in, and grooves are carved to complete the wax pattern. (Modified from Payne E: *Reproduction of tooth form*, Ney Tech Bull 1, 1961.)

direction of the carving instrument. The direction of the instrument movement is not dictated by the margin but by the contour of the unprepared tooth (die) surface just beyond the margin. The instrument blade is held parallel to this surface and used as a guide for the contour of the pattern near the margin; this should result in a continuity of contour across the margin. This principle of carving is too often neglected, resulting in the contour errors (see *x* in Fig. 17-52, *B* through *D*); correct application of the carving instrument results in correct contours (exemplified by *y*). The completed patterns are shown in Figure 17-52, *F* through *I*.

On accessible surfaces of the carved pattern, satisfactory smoothness can be imparted by a few strokes with the end of a finger if surfaces have been carefully carved with the No. 7 spatula. Rubbing with cotton that has been twisted onto a round toothpick may smooth less accessible surfaces such as grooves.

Initial Withdrawal and Reseating of the Wax Pattern

Care must be exercised when initially withdrawing the wax pattern from the die. The wax can be dislodged by holding the die and pattern as shown in Figure 17-53. When the pattern has been dislodged, it should be removed gently from the preparation. The operator should inspect the preparation side of the pattern to see if any wrinkles or holes are present. Such voids indicate poor wax adaptation and should be corrected if they are (1) in critical regions of the preparation designed to provide the retention form, (2) numerous, or (3) closer than 1 mm to the margin. To eliminate these voids, the operator first re-lubricates the die and reseats the pattern on the die. Then, a hot instrument is passed through the wax to the unadapted area. This usually results in the air (void) rising through the liquid wax to the pattern's surface as the wax takes

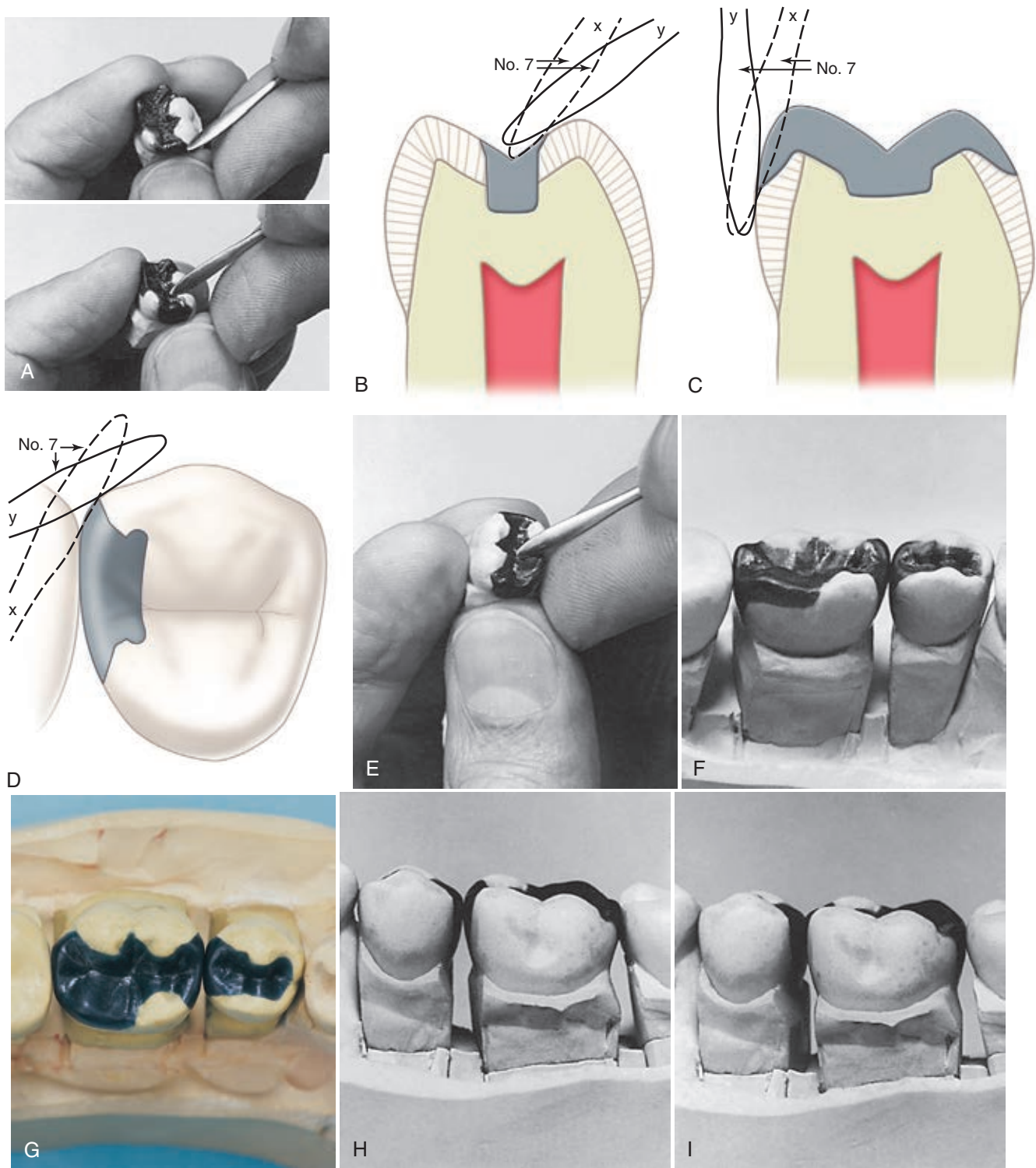


Fig. 17-52 **A**, Wax is carved to margins with a warm No. 7 spatula. **B–D**, Incorrect application of No. 7 spatula to carve the contour of the marginal wax is shown by *x*; the correct manner is labeled *y*. **E**, Carving the occlusal groove and pit anatomy. **F**, The adjacent marginal ridges should be on the same level as much as possible. **G**, Occlusal view of completed patterns. Note the shape of the facial and lingual embrasures and the position of the contact. **H** and **I**, Facial view of the completed patterns. Note the gingival and occlusal embrasures and the position of the contact.

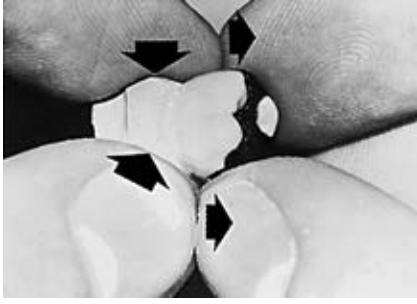


Fig. 17-53 Removing the wax pattern by using indirect finger pressure. Arrows indicate the direction of the pressure. Care must be exercised not to squeeze and distort the wax pattern as it is initially withdrawn.

the place of the air. A consequence of this correcting procedure on the occlusal surface is the obliteration of the occlusal carving in the affected region, requiring the addition of wax, re-carving, and rechecking the occlusion.

Spruing, Investing, and Casting

If a delay of several hours or more occurs between the forming of the wax pattern and the investing procedure, the pattern should remain on the die, and the margins should be inspected carefully again before spruing and investing. When such a delay is contemplated, it is suggested that the sprue be added to the pattern before the delay period. If the addition of the sprue caused the induction of enough stress to produce pattern distortion, such a condition is more evident after the rest period, and corrective waxing can be instituted before investing. The reader is referred to textbooks on dental materials for the principles and techniques of spruing, investing, casting, and cleaning the casting. All investment must be removed from the casting, and it should be properly pickled.

Seating, Adjusting, and Polishing the Casting

It is crucial to examine the casting closely, preferably under magnification, before testing the fit on the die. The internal and external surfaces should be examined with good lighting to identify any traces of investment, positive defects (blebs), or negative defects (voids). Voids in critical areas indicate rejection of the casting, unless they can be corrected by soldering. Any small positive defects on the internal surface should be carefully removed with an appropriately sized round bur in the high-speed handpiece.

The casting is then trial-fitted on the die before removing the sprue and sprue button, which serve as a handle to remove the casting, if removal is necessary. The casting should seat with little or no pressure (Fig. 17-54, A). Ideally, when being placed on the die, it should have the same feel as the feel of the wax pattern when it was seated on the die. If the casting fails to seat completely, it should be removed, and the die surface should be inspected for small scratches to see where it is binding. Usually, failure to seat is caused by small positive defects not seen on the first inspection. Attempts at forcing the casting into place cause irreparable damage to the die and difficulties when trial-seating the casting in the mouth.

After the accuracy of the casting is found to be satisfactory, the casting is separated from the sprue, as close to the inlay as possible, using a carborundum separating disk. The cut should be made twice as wide as the thickness of the disk to prevent binding and should not cut completely through the sprue (a small uncut portion should be left) (see Fig. 17-54, B). If the cut is made completely through, control of the disk is sometimes lost, often resulting in damage to the casting or to the operator's fingers. The uncut portion should be so small that bending with the fingers breaks it with very little effort (see Fig. 17-54, C).

Having seated the casting on the die, the technician hand burnishes the marginal metal using a ball or beaver-tail bur-nisher (see Fig. 17-54, D). An area approximately 1 mm in width is burnished, using strokes that increasingly approach the marginal metal and are directed parallel to the margin. Burnishing improves marginal adaptation and begins the smoothing process, almost imparting a polish to this rubbed surface. While burnishing, the adaptation of the casting along the margin is continually assessed by using magnification, as needed, to see any marginal opening 0.05 mm in size. Moderate pressure during burnishing is indicated during closure of small marginal gaps. When the casting is well adapted, pressure is reduced to a gentle rubbing for continued smoothing of the metal surface. At this stage, marginal openings and irregularities should not be detectable even under ($\times 1.5$ or $\times 2$) magnification (see Fig. 17-54, E and F). Care must be taken not to over-burnish the metal because this can crush and destroy the underlying die surface. Over-burnished metal prevents complete seating of the casting on the prepared tooth. Proper burnishing usually improves the retention of the casting on the die so that the casting does not come loose during subsequent polishing steps. A casting must not be loose on the die if the inlay is to be polished properly.

The remaining sprue metal is carefully removed with a heatless stone or a carborundum disk (see Fig. 17-54, G and H). The grooves are accentuated by lightly applying a dull No. 1 round bur (see Fig. 17-54, I) or other appropriate rotary instrument. Next, a knife-edge rubber polishing wheel is used on accessible surfaces (see Fig. 17-54, J) (Flexie rubber disk, Dedico International Inc., Long Eddy, NY). The operator should guard against the polishing wheel touching the margins and the die because both can be unknowingly and quickly polished away, resulting in "short" margins on the tooth. Also, at this time, the proximal contacts are adjusted one at a time. If the distal surface of a mesio-occluso-distal casting on the first molar is being adjusted, only the first and second molar dies are on the cast. Proximal contacts are deemed correct when they are the correct size, correctly positioned, and passive. If a temporary restoration was made properly, these contact relationships would be the same in the mouth as on the cast. Chairtime can be reduced by carefully finishing the contacts on the cast.

The occlusion of the castings is checked by marking the occlusal contacts with articulating paper. Any premature contacts are corrected, and their locations are refined by selective grinding. Often, prematurities occur where the sprue was attached and insufficient sprue metal was removed. The operator applies a smaller, rubber, knife-edge wheel, which should reach some of the remaining areas not accessible to the larger disk (Fig. 17-55, A and B). The grooves, pits, and other most

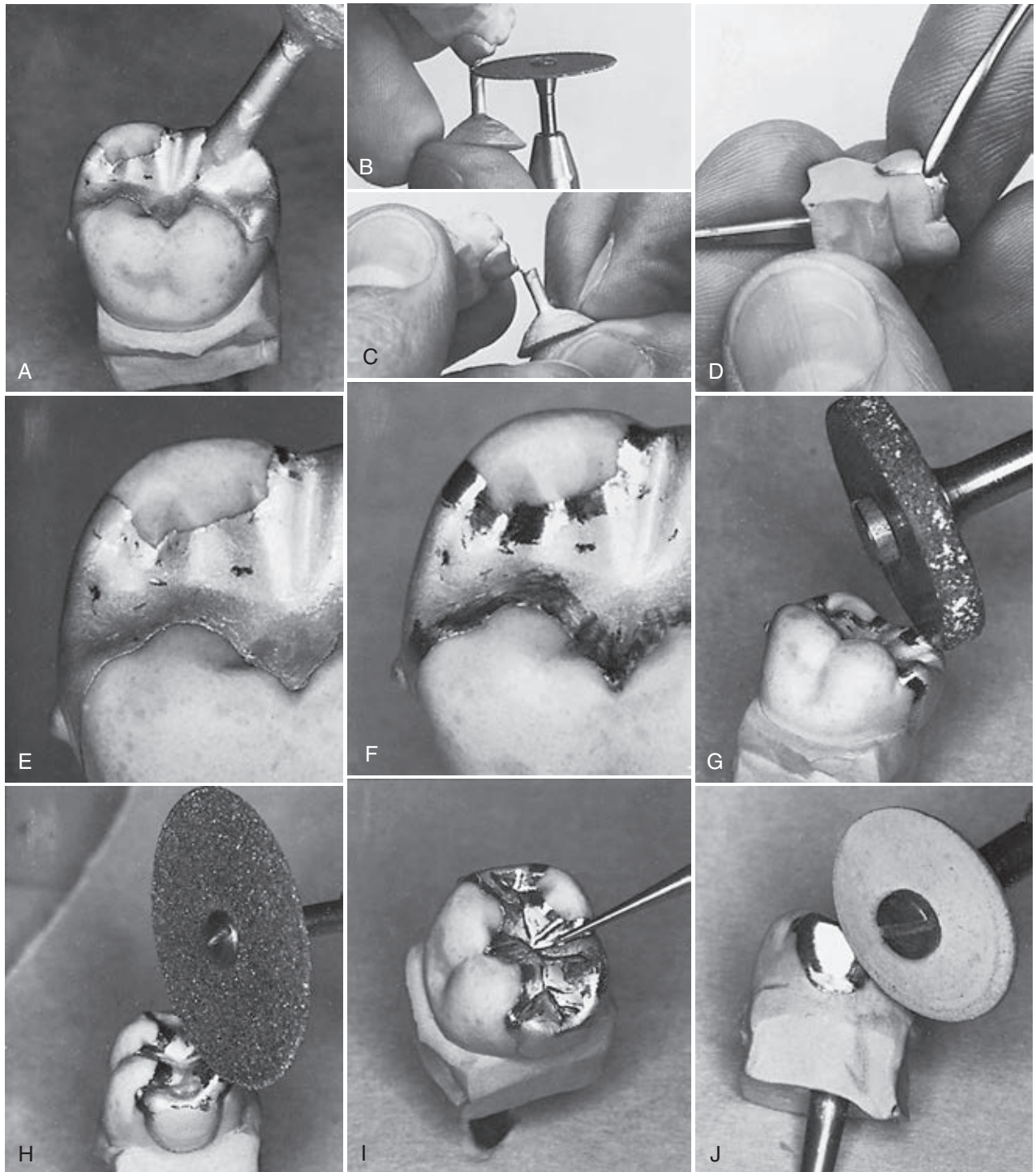


Fig. 17-54 **A**, Cleaned casting should be tried on the die to determine if it has a satisfactory fit. **B** and **C**, To remove sprue, a cut that is not quite complete and twice the width of the disk is first made (**B**), and then the slim, uncut portion is bent and broken (**C**). **D**, The inlay is burnished with a No. 2 burnisher along a 1-mm path that is parallel with and adjacent to the margin. **E**, Magnified view of the casting before burnishing. **F**, Magnified view of the same marginal region shown in **E** after burnishing. **G** and **H**, Removing the remaining sprue metal with heatless stone (**G**) or with a carborundum disk (**H**). **I**, Accentuating the grooves with a dull No. 1 round bur. **J**, Smoothing the surfaces accessible to the rubber polishing wheel.

inaccessible regions are smoothed by rubber, abrasive points (Browne and Greenie rubber points; Shofu Dental Corp., San Marcos, CA) (see Fig. 17-55, **C**). Care should be exercised when using the rubber disks and points so that the die surface is not touched and anatomic contours are not destroyed by

over-polishing. When finished with the rubber abrasives, the surface of the casting should have a smooth, satin finish. It should be ensured that the contact relationships with the adjacent and opposing teeth have the correct size, position, and intensity.

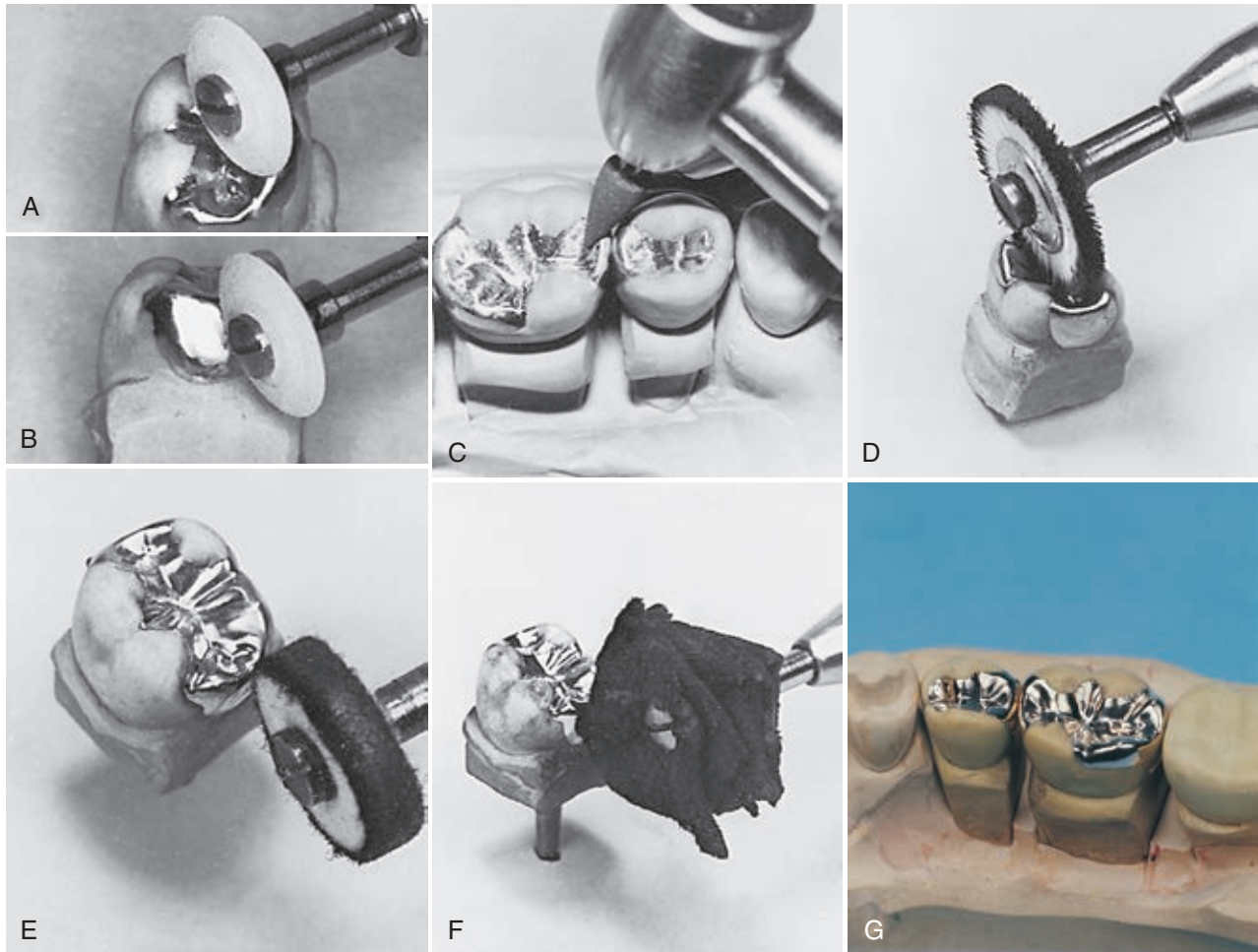


Fig. 17-55 **A** and **B**, Using a small knife-edge rubber disk on the areas of the occlusal surface that are accessible to this wheel (**A**) and on proximal surfaces (**B**). **C**, Polishing the grooves and other relatively inaccessible areas with a rubber point. **D**, Applying tripoli/BBC to the occlusal surface using a bristle disk. **E**, Applying tripoli/BBC to the proximal surfaces using a felt wheel. **F**, Imparting luster by using a chamois wheel and rouge. **G**, Polished castings.

The technician brushes the occlusal surface of the casting with a soft bristle disk and tripoli (or buffing bar compound [BBC]) (Buffing Bar Compound; Heraeus Kulzer Inc., Armonk, NY) polishing compound, running the disk parallel with the grooves (see Fig. 17-55, **D**). A small felt wheel with polishing compound should be used on the proximal and other accessible surfaces (see Fig. 17-55, **E**). The metal should be so smooth before this application of polishing compound that a beautiful luster should develop in a few seconds. A high sheen may be imparted, if desired, with a felt or chamois wheel and rouge (see Fig. 17-55, **F** and **G**). As in the application of tripoli/BBC, only a few seconds of rouge application should be required. If more time were expended in the application of these polishing compounds, over-polishing (polishing away) of the margins and die would result. Also, such overuse of polishing compounds is often an unsuccessful attempt to mask the fact that the preliminary stages of polishing were not thoroughly completed.

The technician cleans the polished casting of polishing compounds by immersing the die with its inlay in a suitable solvent for 1 or 2 minutes or by scrubbing with a soft brush and soap and water. The technician rinses and removes the

casting from the die. No polishing compounds should be found on the preparation side of the casting or on the preparation walls of the die. The presence of such materials on these surfaces indicates that marginal adaptation on the die is not as good as it should be.

Trying-in the Casting Preparing the Mouth

Local anesthesia of the tooth may be necessary before removal of the temporary restoration and the try-in of the casting on the tooth. Anesthesia blocks stimuli from inducing pain and salivation, neither of which is conducive to the best results, particularly in cementation. When teeth are not particularly sensitive, however, an option is to delay or eliminate administering the anesthetic because the patient can tell better if the proximal contacts are tight or if the occlusion is high. The temporary restoration is removed, ensuring that all the temporary cement has been dislodged from the preparation walls and cleared away. To improve visualization, the region is isolated with cotton rolls. Saliva is removed from the tooth operated on and from the adjacent teeth with the air syringe.

Seating the Casting and Adjusting the Proximal Contacts

The operator confirms the fit of the casting on the tooth. A 3 × 3 inch (7.5 × 7.5 cm) gauge sponge should be placed as a “throat screen” to catch the casting if it is accidentally dropped (see Fig. 17-60, A). The dentist tries the casting on the tooth, using light pressure. *Do not force the casting on the tooth.* If the casting does not seat completely, the most likely cause is an over-contoured proximal surface. Using the mouth mirror, where needed, one views into the embrasures from the facial, lingual, and occlusal aspects. The dentist judges where the proximal contour needs adjustment to allow final seating of the casting, producing at the same time the correct position and form to the contact. Passing dental floss through the contact indicates tightness and position, helping the trained operator identify the degree of excess contact and its location. The dentist applies the floss at an angle and with secure finger-bracing to pass it gently through the contact and not with a snap that is likely to injure interproximal soft tissue. If the floss cannot enter or if it tears on entering, the contact is excessive. *Caution:* When adjusting a mesio-occluso-distal restoration, only one excess contact should be adjusted at a time (the stronger one) before trying again on the tooth and evaluating, unless both contacts feel equally strong. This is done because one excessively strong contact can cause the other to feel strong, when in actuality, the latter contact may be correct or even found to be weak (short of contact) after the excessively strong contact is adjusted properly.

A rubber wheel abrasive is used to adjust the proximal contour and to correct the contact relationship; this often requires several trials on the tooth, but it is best not to remove

too much at a time. After each trial and removal, the position of contact is visible in the form of a bright spot on the satiny surface left on the casting from previous surfacing by the rubber wheel. By noting the position of this bright spot in conjunction with observation in the mouth of the contact relationship, the contact position and form can be judged, and the operator can determine whether additional adjustment should be made to alter this position and form. (For removing the casting after each trial on the tooth, see the section on removing the casting.)

Often, the patient is able to indicate whether the contact is strong, particularly when an anesthetic has not been given. The patient should not be aware of any pressure between teeth after the final adjustment of contacts.

Proper proximal contact occurs when a visual inspection confirms that the adjacent proximal surfaces are touching and that the position and form of the contact relationship are correct. The correct “tightness” of the contacts is best judged with dental floss. This contact should be passive because any pressure between teeth would resolve soon and disappear in unwanted tooth movement.

If the contact is open (short of touching the adjacent tooth), a new contact area must be soldered to the casting. An open contact is best detected by visual inspection with the aid of the mouth mirror. The region must be isolated with cotton rolls and dried with the air syringe. Selection of the proper horizontal viewing angle usually discloses the spaces between teeth. Such an open contact permits the passage of food, which affects and irritates the interproximal gingiva.

When satisfied that the proximal contacts are correct when hand pressure first positions the casting to within 0.2 mm of seating (Fig. 17-56, A), the dentist removes the 3 × 3 inch

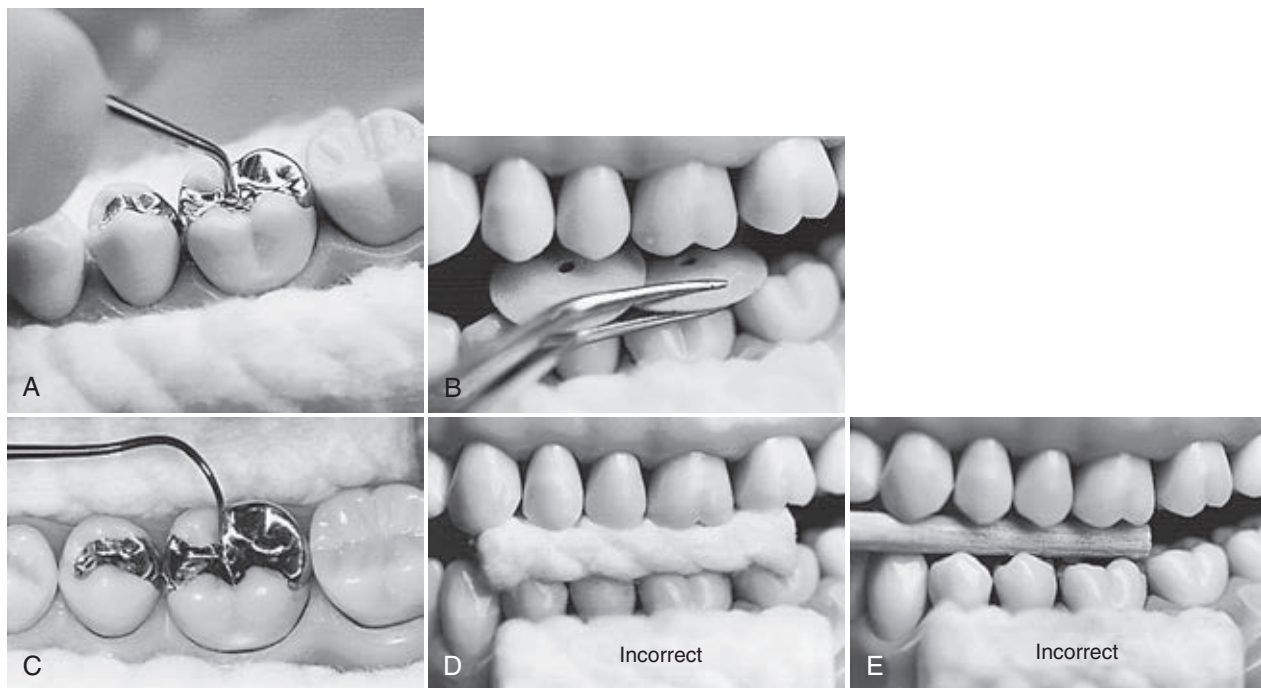


Fig. 17-56 **A**, Hand pressure is used initially to seat the casting on the tooth by applying a ball burnisher in the pit anatomy. **B**, If the casting fits to within 0.2 mm of the seating, complete seating is ensured by using masticatory pressure when the patient closes on the rubber polishing wheel interposed between the casting and the opposing tooth. **C**, The marginal fit of the tried-in inlay is inspected. **D** and **E**, A cotton roll (**D**) or piece of wood (**E**) should not be used in lieu of the rubber polishing wheel method (**B**).



Fig. 17-57 A–C, Castings tried on teeth. These photographs were taken immediately after the restorations were first seated on teeth before any dressing down or burnishing of margins. Neither occlusal adjustment nor contact adjustment was required. Extension of the mesiofacial margin of the second premolar was necessary because of extension of a previous amalgam restoration; extension of the distofacial margins of premolars is caused by skirting (or bracing), which provides maximal resistance form to these weak teeth. Note the area on the mesiofacial margin of the first molar that is to have a composite insert placed after cementation.

(7.5 × 7.5 cm) gauze sponge and ensures that the casting completely seats on the tooth by the application of masticatory pressure. This use of masticatory pressure should be a routine procedure. It is accomplished by positioning a small rubber polishing disk (unmounted) on the occlusal of the restoration and requesting the patient to bite firmly; the patient also is asked to move the jaw slightly from side to side while maintaining this firm pressure (see Fig. 17-56, B). At this time, the operator must judge whether the restoration is satisfactory or should be rejected and another casting made. When evaluating the fit (seating) of the casting, the operator should view particularly the margins that are horizontally directed (i.e., margins that are perpendicular to the line of draw). Along at least half the marginal outline, the tip of the explorer tine should move from tooth onto the metal, and vice versa, with barely a catch or a bump (see Figs. 17-56, C, and 17-57). Some operators recommend the use of a cotton roll or a piece of wood for the patient to bite on for seating pressure (see Fig. 17-56, D and E). The cotton roll may be too large and too soft to be effective for seating inlays, however, and the piece of wood may not distribute the pressure properly, resulting in less effective seating or tooth fracture. Figure 17-57 shows the castings tried on the teeth that were first shown in Figure 17-41, H.

Occluding the Casting

When the proximal contacts have been adjusted, and the casting is satisfactorily seated on the tooth, the patient is asked to close into maximum intercuspation, and the dentist inspects the unprepared adjacent teeth to see if any space exists between the opposing wear facets. Usually, the patient can indicate correctly if the casting needs occlusal adjustment; however, the dentist should verify the occlusal relationship objectively. After drying the teeth of saliva, the dentist inserts a strip of articulating paper and requests the patient to close and tap the teeth together (in maximum intercuspation) several times. The dentist removes the paper and examines it by holding it up toward the light for evidence of any areas of penetration caused by the restoration. Any holes can be matched with heavy markings on the casting, and shiny, metal-colored spots may be present in the center of the marks (Fig. 17-58, A). Such heavy contacts should be reduced with suitable abrasive

stones, while carefully observing the following fundamental concepts for equilibration of occlusion. The space observed between the opposing wear facets of the adjacent unprepared teeth (when the teeth are “closed”) is an indication of the maximal amount of vertical reduction of the casting required. Often, the “high” occlusal contacts are very broad and extend onto the cusp or ridge slopes. When this occurs, the dentist should grind away the most incorrect portion of the incline contact (a deflective contact), leaving the most correct portion intact (see Fig. 17-58, B). Occlusal contacts in maximum intercuspation should be composed of supporting cusp tips placed against flat or smoothly concave surfaces (or into fossae) for stability. The force vector of occlusal contacts should be one that parallels the long axis of the tooth (see Fig. 17-58, C). Contacts on inclines tend to deflect the tooth and are less stable (see Fig. 17-58, D). The use of articulating paper and the stone is continued until (1) the heavy markings are no longer produced, (2) the contacts on the restoration have optimal position and form, and (3) an even distribution of contacts exists on the casting and the adjacent teeth. Visual inspection should verify that the adjacent unprepared teeth are absolutely touching.

Care must be exercised not to over-reduce the occlusal contacts. In the final phase of equilibration, the strength of the occlusal contacts can be tested by using thin plastic shim stock (0.0005 inch [0.013 mm] thick; Artus Corp., Englewood, NJ) as a “feeler gauge.” The dentist tests the intensity of the occlusal contacts of the casting and the adjacent unprepared teeth to see if they hold the shim stock equally (see Fig. 17-58, E). It may be helpful to test the occlusal contacts of the adjacent unprepared teeth with the casting out of the mouth for comparison.

When the occlusal contacts have been adjusted in maximum intercuspation, the casting is checked for contacts that occur during lateral mandibular movements. Lateral working (functional) contacts on the casting are marked by (1) inserting a strip of articulator paper over the quadrant with the casting, (2) having the patient close into maximum intercuspation, and (3) “sliding” the teeth toward the side of the mouth where the casting is located. Contacts between the lingual inclines of the maxillary lingual cusps and facial inclines of the mandibular lingual cusps are considered unusually stressful and should be eliminated (see Fig. 17-58, F). Contacts between

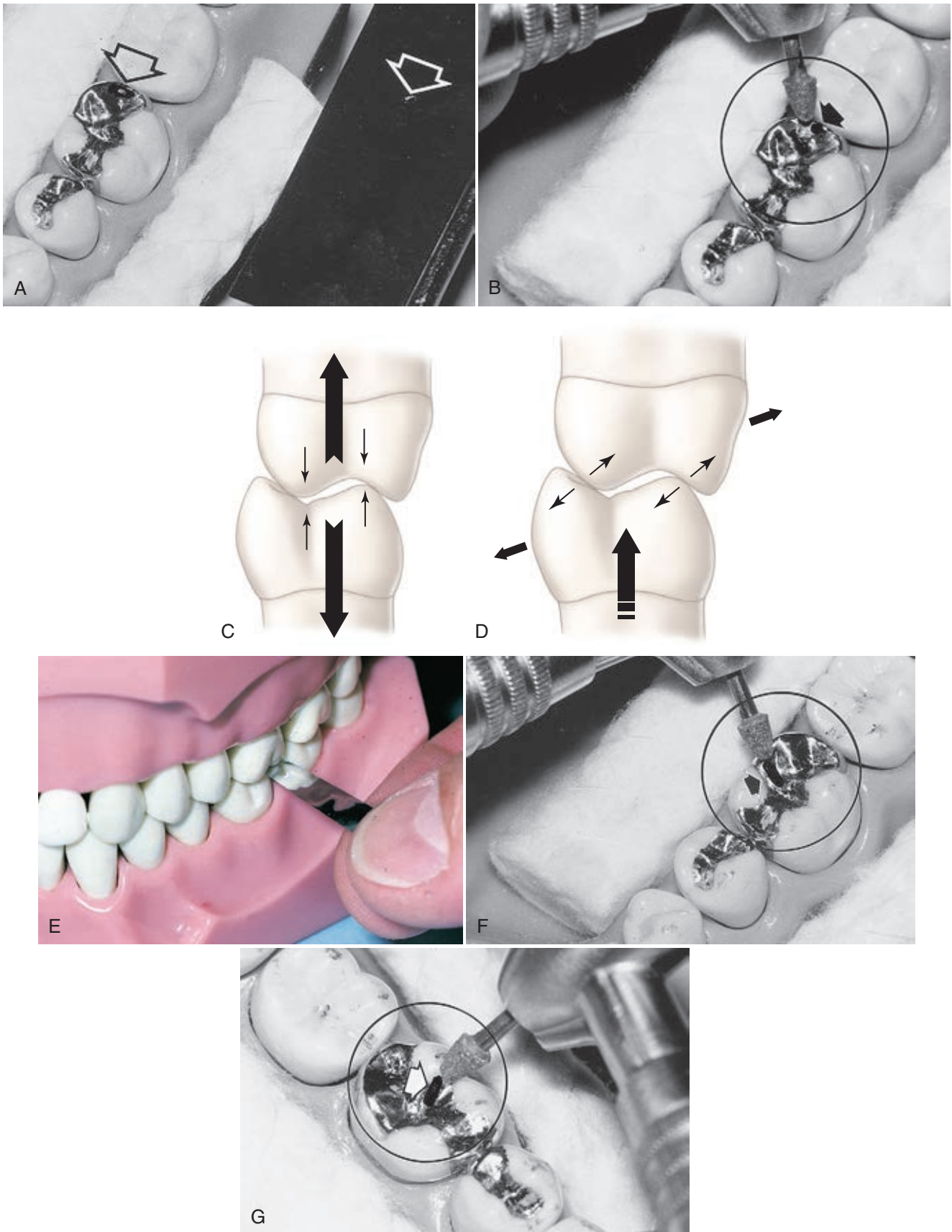


Fig. 17-58 Occluding the casting. **A**, The initial occlusal contact is high and produces a heavy mark with a metal-colored center. Note the corresponding perforation in the articulating paper. **B**, When adjusting occlusal contacts, the most incorrect portion of the contact is removed, leaving the most correct portion intact. **C**, The proper occlusal contacts in maximum intercuspation are composed of cusp tips placed against flat or smoothly concave surfaces (or fossae) for stability. **D**, Incline contacts are less stable and tend to deflect the tooth. Occluding the casting. **E**, Testing the intensity of the occlusal contacts with a thin (0.0005 inch [0.013 mm] thick) shim stock used as a feeler gauge. **F**, Removing the undesirable contact (lingual range) that may occur on the working side during lateral mandibular movement. **G**, Removing the undesirable contact that may occur on the nonworking side during lateral mandibular movement.

the lingual inclines of the maxillary facial cusps and the facial inclines of the mandibular facial cusps should remain only if they are passive and a group function pattern of occlusion is desired.

The dentist inserts a strip of articulating paper over the teeth with the castings and has the patient close into maximum intercuspation and slide the teeth laterally toward the opposite side. This action marks any lateral nonworking (nonfunctional) contacts on the restoration. In a normal arrangement of teeth, contacts that might occur during the nonworking pathway are positioned on the facial inclines of the maxillary lingual cusps and the lingual inclines of the mandibular facial cusps. These nonworking contacts must be removed with a suitable stone (see Fig. 17-58, G). Complete elimination of nonworking contacts can be verified by using the plastic shim stock. A strip of shim stock is inserted over the casting, and the patient bites together firmly. As soon as the patient begins sliding the mandible toward the opposite side, the shim stock should slip out from between teeth. The dentist examines the casting for interferences in protrusive mandibular movements using the shim stock and articulating paper. The areas that may have to be adjusted to prevent contact are the distal inclines of maxillary teeth and the mesial inclines of mandibular teeth.

Finally, interferences that occur on the casting between centric occlusion and maximum intercuspation are identified and removed. Most patients have a small discrepancy between centric occlusion and maximum intercuspation. Such a “skid” is considered normal for most patients, but the operator should ensure that the casting does not have premature contact at any point between centric occlusion and maximum intercuspation. The preferred technique for manipulating the mandible into centric relation and making teeth touch in centric occlusion is credited to Dawson.¹³ When teeth have been marked in centric occlusion, the dentist observes them to ensure that the casting does not have premature contacts in centric occlusion and that it does not exacerbate any centric occlusion–maximum intercuspation skid. If it does, the mesial inclines of maxillary restorations and the distal inclines of mandibular restorations are the areas that may need adjustment.

Improving Marginal Adaptation

The next step is to “dress down” the margins, that is, to adapt the metal as closely as possible to the margins of the tooth. Regardless of how accurately a casting may seat in the preparation, the fit usually can be improved by using the following procedures. With a ball or beaver-tail burnisher, the operator improves marginal adaptation by burnishing the marginal metal with strokes that parallel the margin except for the gingival margin (Fig. 17-59, A). If the margin is inaccessible to the ball or beaver-tail burnisher (as sometimes occurs at the termination of the casting in groove regions where possibly more enameloplasty or extension could have been employed), the edge of the discoid-type hand instrument serves well as a burnisher. The discoid instrument is held perpendicular to the margin and is moved parallel with the margin (see Fig. 17-59, B). The sharp edges of the instrument also trim away any slight excess of metal at the margin. The operator continues on other portions of accessible margins

where a slight excess of metal is present. When burnishing the casting on the tooth, the dentist should ensure that the casting is fully seated. Otherwise, burnishing may bend the marginal metal, keep the casting from seating, and result in the rejection of the casting.

If necessary, the marginal adaptation and continuity can be improved further by the application of a pointed, fine-grit carborundum stone, especially where the marginal enamel is slightly “high” and should be reduced or where more than just a slight amount of excess metal should be removed (see Fig. 17-59, C). This stone should be used at low speed with light pressure and should rotate either parallel with the margin or from metal to tooth across the margin (never from tooth to metal). After this procedure, the margins are burnished again to enhance marginal adaptation and to smooth the marginal metal.

Another instrument that can be used to improve marginal fit in accessible areas (e.g., the occlusal two thirds of the proximal margins) is a fine-grit paper disk. Wherever possible, the disk should be revolved in a direction from the metal toward the tooth (see Fig. 17-59, D). Sometimes, these margins are inaccessible to the disk, and a gingival margin trimmer, a gold file, or a cleoid instrument may be helpful to remove a slight excess of metal (see Fig. 17-59, E). It is moved in a scraping motion parallel to the margin and burnishes and trims the metal.

The experienced operator, with proper use of the elastic impression material, can produce restoration margins that require little or no burnishing or dressing down. One of the significant advantages of the indirect procedure, when correctly applied, is the high degree of accuracy of the gingival margin adaptation.

The margins should now be such that the explorer tip can pass across the margins smoothly without jumping or catching. The operator should use rubber polishing points of increasing fineness at low speed to smooth and polish the accessible areas of roughness left from adjusting procedures (see Fig. 17-59, F and G). An attempt should be made to preserve the anatomic contour and detail. The operator should take care to use light, intermittent pressure when using rubber points to avoid overheating the tooth. The casting surface should be cleaned and dried to verify that it is smooth and free of scratches.

Removing the Casting

When preparing to remove a casting from a tooth, the dentist first places a 3 × 3 inch (7.5 × 7.5 cm) gauze sponge throat screen to prevent the patient from swallowing or aspirating the casting in the event that it is accidentally mishandled (Fig. 17-60, A). If the casting is highly retentive, the dentist first initiates removal with the aid of a sharp Black spoon (15-8-14). The tip of the spoon is inserted as deep as possible in the occlusal embrasure with the back of the spoon resting against the marginal ridge of the adjacent tooth (see Fig. 17-60, B). With the tip of the spoon firmly seated against the metal casting, the spoon is pivoted using the adjacent tooth as a fulcrum (see Fig. 17-60, C). This procedure is repeated on the other occlusal embrasure if the casting is a mesio-occluso-distal restoration. This should initiate the displacement of the casting, making complete removal thereafter easy.

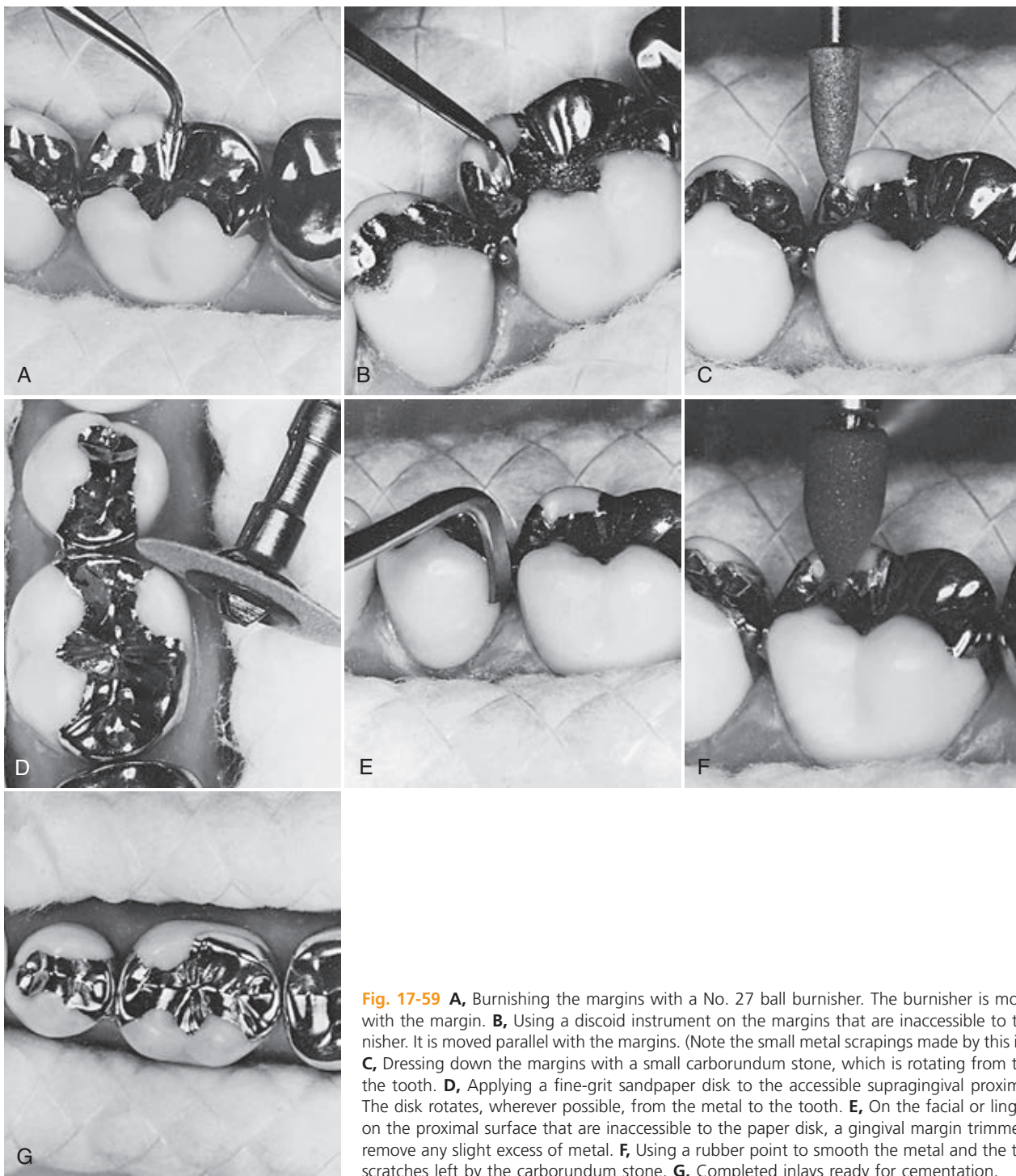


Fig. 17-59 **A**, Burnishing the margins with a No. 27 ball burnisher. The burnisher is moved parallel with the margin. **B**, Using a discoloid instrument on the margins that are inaccessible to the ball burnisher. It is moved parallel with the margins. (Note the small metal scrapings made by this instrument.) **C**, Dressing down the margins with a small carborundum stone, which is rotating from the metal to the tooth. **D**, Applying a fine-grit sandpaper disk to the accessible supragingival proximal margins. The disk rotates, wherever possible, from the metal to the tooth. **E**, On the facial or lingual margins on the proximal surface that are inaccessible to the paper disk, a gingival margin trimmer is used to remove any slight excess of metal. **F**, Using a rubber point to smooth the metal and the tooth of any scratches left by the carborundum stone. **G**, Completed inlays ready for cementation.



Fig. 17-60 Initiating the removal of the inlay before cementation. **A**, Place 3 × 3 inch (7.5 × 7.5 cm) gauze throat screen to prevent swallowing or aspiration of casting should it be accidentally mishandled. **B**, The tip of a sharp Black spoon (15-8-14) is inserted first as deep as possible in the occlusal embrasure with the back of the spoon against the adjacent marginal ridge. **C**, The spoon is pivoted in the direction of the curved arrow by using the adjacent tooth as a fulcrum. The casting has lifted from its seating. After only slight unseating, a similar procedure is applied to the distal aspect.

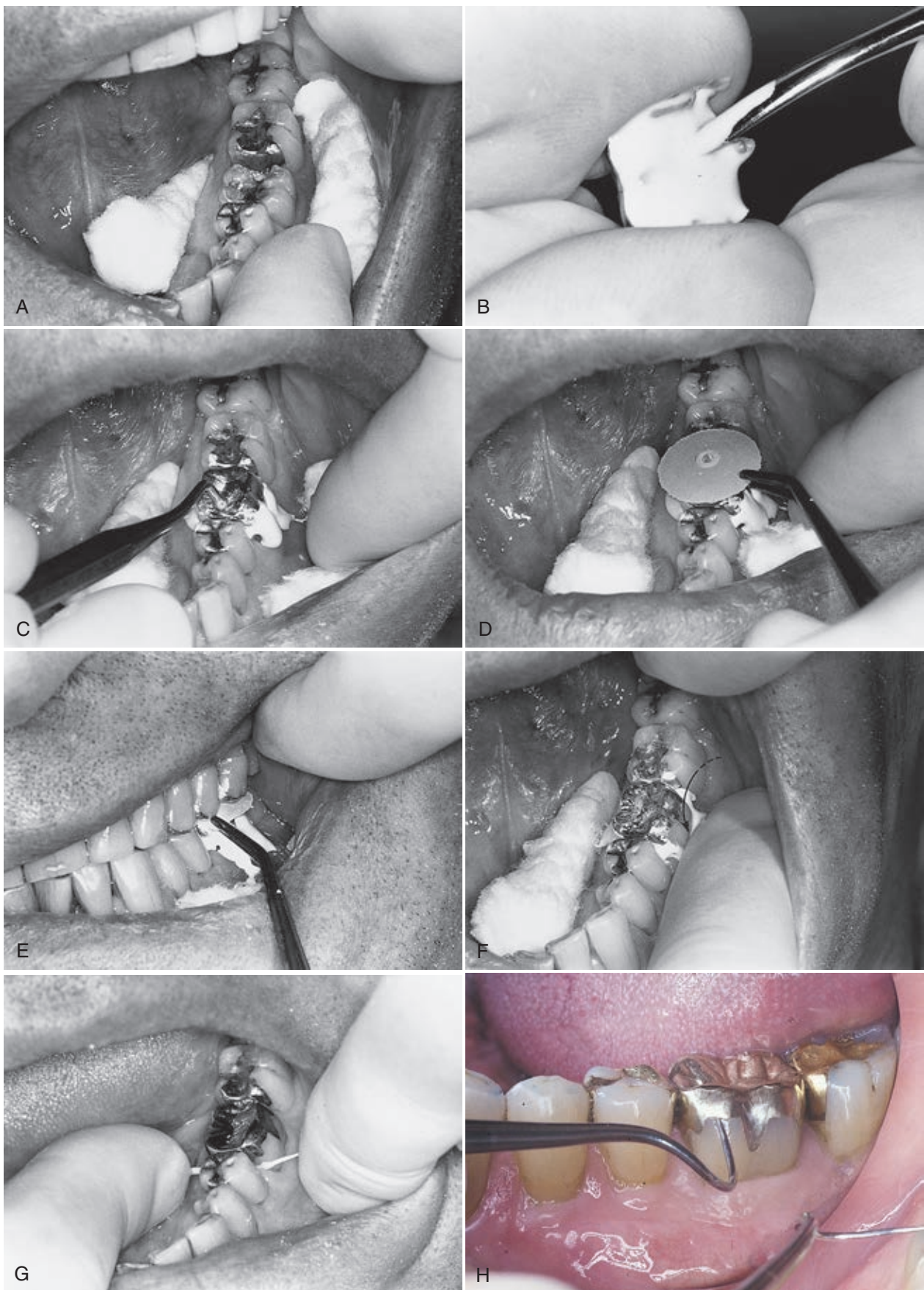


Fig. 17-61 Cementing the cast metal onlay on the preparation initially shown in [Figure 17-39, B](#). **A**, Isolating the tooth from saliva with cotton rolls. **B**, Applying cement with No. 2 beaver-tail burnisher to preparation side of onlay. **C**, Seating the onlay by using a ball burnisher and hand pressure. **D**, Placing a rubber polishing disk over the onlay and cementing the cast metal onlay on the preparation initially shown in [Figure 17-39, B](#). **E**, The patient is instructed to apply masticatory pressure while slightly moving the jaw from side to side. **F**, When the disk is lifted from the casting, much of the occlusal aspect is free of cement. With a sweeping, rolling motion of the forefinger, any accessible facial surface margin is cleaned of excess cement to permit visual inspection for verification of proper seating of the onlay. Similarly, any accessible lingual margin is cleaned of excess cement. Full seating also should be verified tactilely with the explorer tine. **G**, Excess set cement is removed by using the explorer and air-water spray. Dental tape with a small knot is used to dislodge small pieces of interproximal cement. **H**, Onlay after cementation.

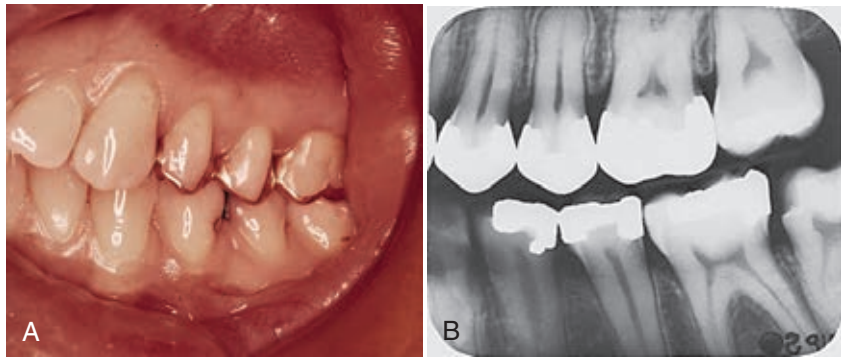


Fig. 17-62 **A**, Cemented castings on teeth first shown in Figure 17-41, **E**. This photo was taken immediately after cementation and insertion of the composite insert on the molar. **B**, Bitewing radiograph of the restored quadrant shown in **A**. Note the fit of inlays at the gingival margins and the contour of the proximal surfaces.

Cementation

Cement Selection

The selection of cement for permanent cementation is crucial to the success of the final restoration. The advantages and disadvantages of each cement are discussed in the chapter on dental materials. No cement is without shortcomings. Each product has specific requirements with regard to tooth surface conditioning, casting surface conditioning, and manipulation techniques. To obtain optimal performance from the cement, the dentist should carefully follow the manufacturer's instructions for dispensing, mixing, and application.

Cementation Technique

Before cementing the casting, the tooth is isolated from saliva with the aid of cotton rolls (and saliva ejector, if necessary) (Fig. 17-61, **A**). With the air syringe, the dentist dries the preparation walls but does not desiccate them. This air should eliminate visible moisture from the walls except possibly on the gingival bevel. The cement is mixed according to the manufacturer's instructions. With the cement mix applied generously to the preparation side of the casting (see Fig. 17-61, **B**), the dentist starts to place the casting with the fingers or with operative pliers. Next, the dentist places the ball burnisher in the pit areas (first one and then another), exerting firm pressure to seat the casting (see Fig. 17-61, **C**). The dentist places a small flexible rubber polishing disk over the casting, removes the saliva ejector, and requests the patient to close and exert biting force (see Fig. 17-61, **D** and **E**). The patient also is asked to move the mandible slightly from side to side, while continuing to exert pressure. A few seconds of this pressure is sufficient. When the disk is removed, much of the occlusal area should be clean of the cement mix and easier to inspect and to verify complete seating of the casting. When the cusps are capped, complete seating of the casting is verified by inspection of the facial and lingual margins after wiping the excess cement away (see Fig. 17-61, **F**). While the cement is still soft, all accessible margins are burnished. The saliva ejector is replaced in the mouth and the region kept dry during the setting of the cement. Excess moisture during this setting reaction can weaken many types of cement.

After the cement has hardened, any excess is cleaned off with an explorer and air-water spray. Dental floss should be passed through the contact, carried into the interproximal gingival embrasures and sulci, and pulled facially and lingually

to help in the removal of cement in this region (see Fig. 17-61, **G**). Tying a small knot in the floss helps dislodge small bits of interproximal cement. Finally, directing a stream of air into the gingival sulcus opens it and reveals any remaining small pieces of cement, which should be removed. When cementing has been properly accomplished, a cement line should not be visible at the margins (see Fig. 17-61, **H**). A quadrant of inlays after cementation is illustrated in Figure 17-62.

Repair

The weak link of most cast metal inlays and onlays is the cement seal. At times, the operator may find discrepancies at margins that require replacement or repair. If the restoration is intact and retentive and if the defective margin area is small and accessible, small repairs can be attempted with amalgam or composite. If cement loss is found in one area of the restoration, however, other areas are usually suspect. When defects are found, the most common procedure is to remove the defective restoration and replace it.

Summary

Cast metal inlays and onlays offer excellent restorations that may be under-used in dentistry. The technique requires multiple patient visits and excellent laboratory support, but the resulting restorations are durable and long lasting. High noble alloys are desirable for patients concerned with allergy or sensitivity to other restorative materials. Cast metal onlays, in particular, can be designed to strengthen the restored tooth while conserving more tooth structure than does a full crown. Disadvantages such as high cost and esthetics limit their use, but when indicated, cast metal inlays and onlays provide a restorative option that is less damaging to pulpal and periodontal tissues compared with a full crown.

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- Zinc phosphate cement, 288
- Zirconia, ceramic and, 135
- Zn. See Zinc
- ZOE. See Zinc oxide-eugenol

Biomaterials

Stephen C. Bayne, Jeffrey Y. Thompson

The science of biomaterials for restorative dentistry is derived from the science of materials. Biomaterials include synthetic and tissue-engineered biomaterials. Synthetic biomaterials can be organized in terms of four categories of materials, with four categories of structural considerations that govern their properties and four categories of general properties. For each of these categories, a rich basis of materials science definitions exists. This information is presented in greater depth in biomaterials textbooks, but it is reviewed here for reference during discussions in other parts of this book.¹⁻²⁴

Tissue-engineered biomaterials have existed approximately 40 years as simple biomimetic structures. Since the publication of the human genome and the explosion of post-genomic efforts, however, tissue engineering has gained substantial momentum. Replacement of human tissue with new tissue can be accomplished by generating replacements outside of the body or in situ in the body. In each case, the key elements are described as the tissue engineering triad of scaffolds, cells, and signals (Online Fig. 18-1).^{25,26} Scaffolds can be produced synthetically or derived naturally. Typical synthetic scaffolds include polylactic acid–polyglycolic acid (PLA-PGA) co-polymers, which have the advantage of being biodegradable and biologically resorbable, and naturally derived scaffolds include reconstituted collagen from a variety of non-human sources. At present, mature differentiated mammalian cells (e.g., osteoblasts) are placed, or seeded, on scaffolds.²⁷⁻²⁹ The use of undifferentiated stem cells in tissue-engineered constructs also offers great promise.³⁰ Signals such as bone morphogenetic proteins are crucial in orchestrating the development of the normal biologic architecture of a tissue. These signals can be collected from other environments and added or generated by growing and developing cells. The entire process can be staged outside of the body and implanted, conducted in a biologic setting and replanted to the final location, or managed in situ. Ex vivo work has been facilitated by using inkjet deposition techniques to build three-dimensional structures.³¹⁻³³

Despite optimism about this process and its ultimate potential, myriad problems need to be managed and barriers are yet to be overcome. Although the process may sound simple, reliable control of these systems is daunting. Many other new technologies may become part of this science. Nano-engineering, in combination with evolving knowledge about

self-assembling systems, offers the possibility of using molecular scale processes to create building blocks for in situ engineering of scaffolds and chemical triggers for controlling the signaling of cells. Normal biologic processes involve self-assembly of tissues but are high-energy events. Low-energy self-assembly is a new science and offers help for many of the tissue engineering steps.^{29,30}

This transformation in the way we manage diseased, damaged, or lost soft and hard tissues raises immense hope for medicine and dentistry; however, this will take considerable time. The field of biomaterials will be in a transition period for at least the next generation (≥ 20 or more years), in which tissue engineering (biologic biomaterials) slowly will begin to offer alternatives to traditional synthetic biomaterials. New teeth, bone, or other material is not expected to be available widely to replace or repair existing tissues in the near future. When these processes become available, cost and practicality will be issues that will need to be considered. To use these strategies, significant acceleration or alternative processing will be required. Even though this is an exciting time, we will, in the meanwhile, focus on the current science of synthetic biomaterials.

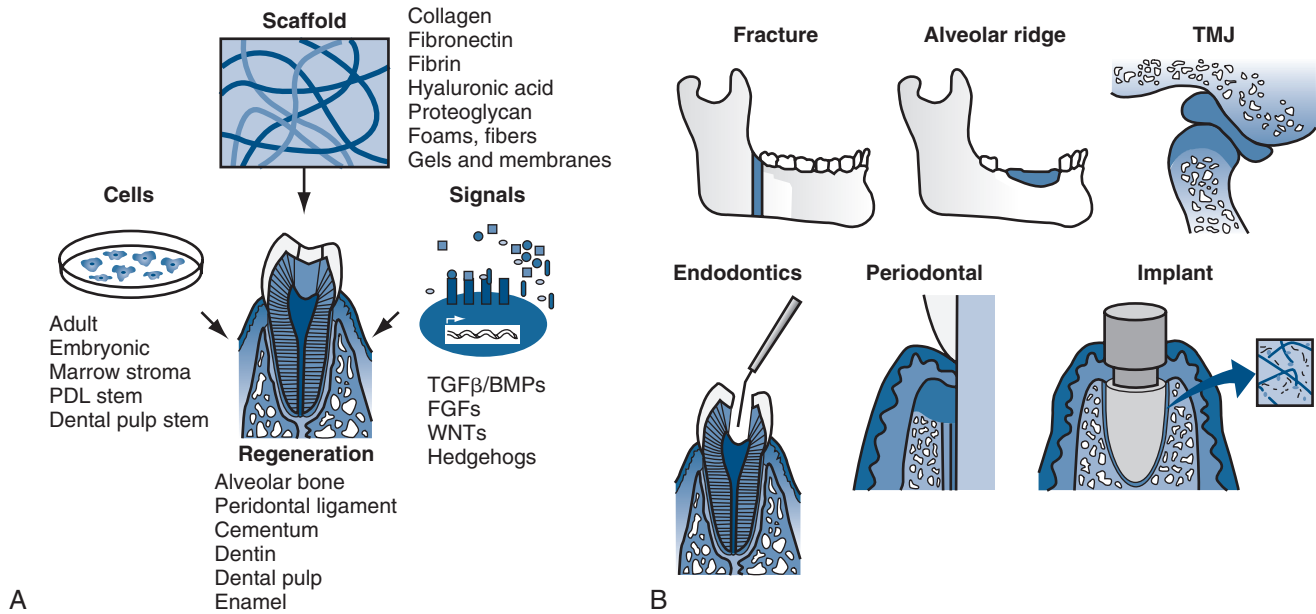
Review of Materials Science Definitions

Material Categories

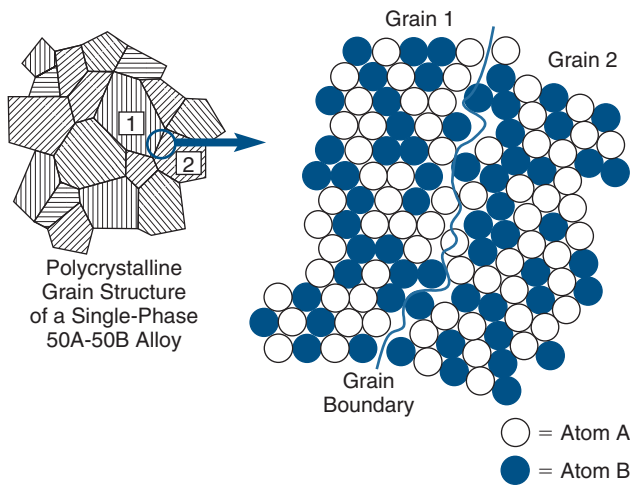
The four categories of materials are metals, ceramics, polymers, and composites. Each one of these has characteristic microstructures and resulting properties. It is paramount in every situation in restorative dentistry that the structures and properties involved are known. Formal engineering definitions of each category are not practically useful. The following definitions are most often substituted instead.

Metals

A metal is an element that diffusely shares valence electrons among all of the atoms in the solid, instead of forming local ionic or covalent bonds. A metal alloy is an intentional mixture of metallic elements that occurs in a chemically intimate



Online Fig. 18-1 Summary of the opportunities for tissue engineering to develop scaffolds, cells, and signals to create substitute or replacement dental tissues in the future. Some potential applications include fracture replacement, alveolar ridge augmentation, temporomandibular joint reconstruction, dentin replacement, periodontal ligament replacement, and pre-osseointegration of dental implants. (From Nakashima M, Reddi AH: *The application of bone morphogenic proteins to dental tissue engineering*, Nat Biotech 21:1025–1032, 2003.)



Online Fig. 18-2 Schematic example of the microstructure of a crystalline two-phase metal alloy involving gold (clear) and copper (solid) atoms. The grain boundaries are shown as discontinuities between the individual crystals (grains).

manner. As a result of mixing, the elements may be completely soluble (e.g., gold–copper [Au–Cu]) or may be only partially soluble (e.g., silver–tin [Ag–Sn]), producing more than one phase. Metallic systems are almost exclusively crystalline, and most exist as polycrystalline solids. The individual crystals, or grains, are generally microscopic. Grains may be all the same composition (single-phase) or several different phases (multiple-phase). Different phases represent locally different chemical compositions. In metal alloys, no phase (or crystal or grain) ever represents a pure metallic element (Online Fig. 18-2). The distribution of phases is influenced by the thermal and mechanical histories of the solid, allowing a wide range

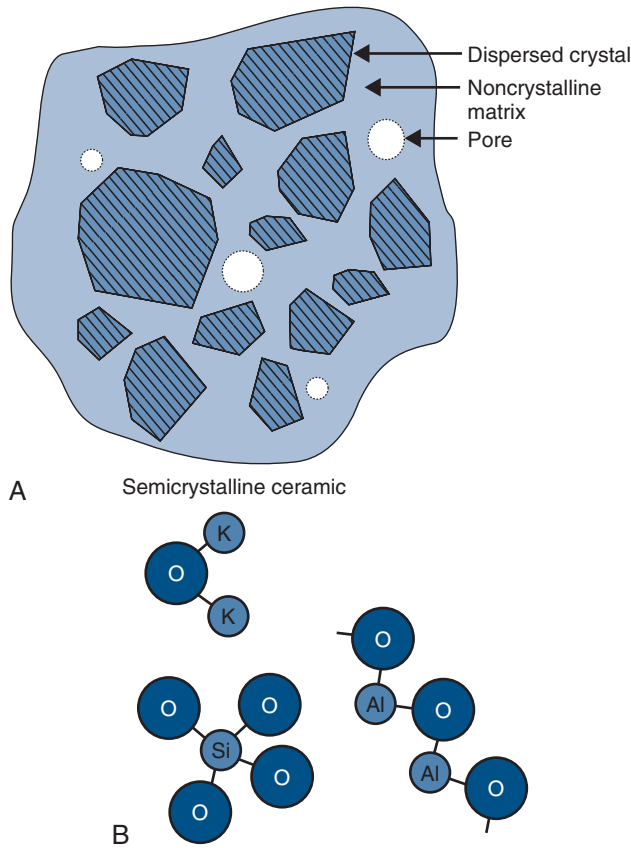
of properties to be developed from a single overall composition. The periodic table consists mostly of metallic elements. A wide range of potential metallurgical systems exists.

Metals and metal alloys generally are prone to chemical and electrochemical corrosion. Chemical corrosion occurs by direct chemical reaction on the surfaces of metallic objects of metal atoms with oxygen or other chemicals. Electrochemical corrosion occurs when two metallic electrodes of differing composition, structure, or local environment, while connected by a circuit and an electrolyte, produce metallic ions at the anode and an electron flow toward the cathode, resulting in anodic and cathodic reactions. Most chemical reactions can proceed by chemical and electrochemical mechanisms. In a moist environment such as the mouth, electrochemical reactions are extremely likely.

Ceramics

Ceramics are chemically intimate mixtures of metallic and non-metallic elements, which allow ionic (potassium oxide [K₂O]) bonding, covalent (silicon dioxide [SiO₂]) bonding, or both to occur. In the periodic table, only a few elements such as carbon, oxygen, nitrogen, hydrogen, and chlorine, are non-metallic. The most common ceramics in dentistry are semi-crystalline (Online Fig. 18-3, A) and are chemical mixtures of three main metallic oxides (SiO₂, aluminum oxide [Al₂O₃], K₂O) (see Online Fig. 18-3, B). Ceramics also may result from corrosion of metals (iron oxide [Fe₂O₃], tin oxide [SnO], silver sulfide [Ag₂S]).

The corrosion behavior of metallic elements is classified as *active*, *passive*, or *immune* with respect to chemical or electrochemical reactions with other elements in their environments. Active metals corrode to form solid ceramic products or soluble products. Iron reacts with oxygen to form iron oxide. Passive metals corrode to form thin films of ceramic products



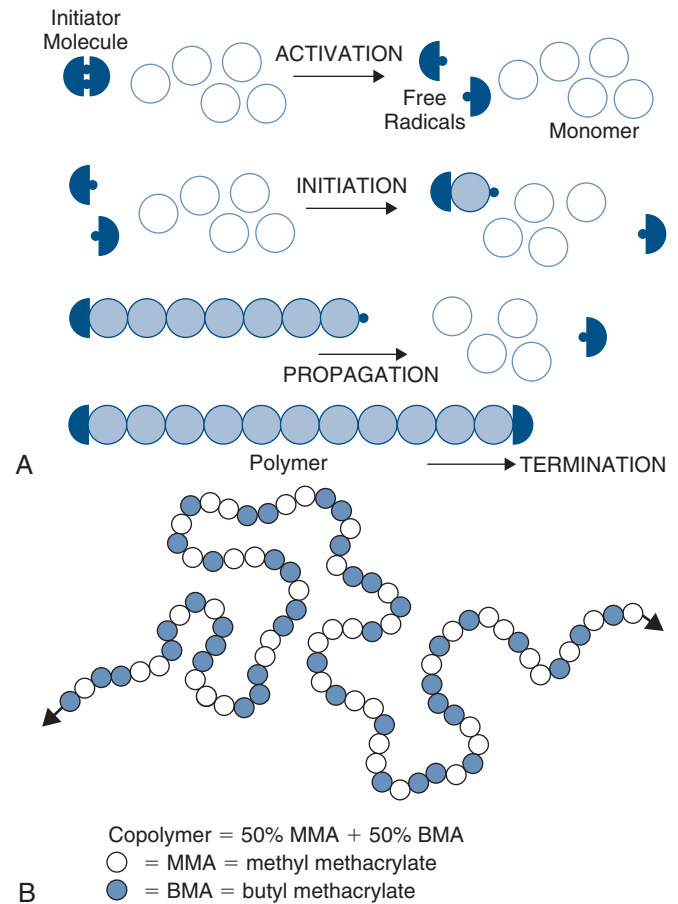
Online Fig. 18-3 Schematic example of the microstructure of a multi-phase semi-crystalline ceramic. **A**, This microstructure is typical for laboratory-processed feldspathic porcelains. Generally, the crystalline phase appears as islands within the noncrystalline phase. Pores are included as typical defects in these structures. **B**, Examples of the major chemical components involved in the formation of dental ceramics, particularly dental porcelain.

that remain adherent to their surfaces and prevent further corrosion (passivation). Titanium reacts with oxygen to form a titanium dioxide (TiO₂) coating that prevents further reaction and protects the surface. Immune metals such as gold are not reactive under normal environmental conditions. Most metals are active, and ceramics are much more common than metals in the world. Most of the key ceramics used for dentistry are oxides.

Ceramics may be classified on the basis of (1) being crystalline, non-crystalline, or both; (2) being predominantly based on silica (SiO₂) and called silicates; (3) being predominantly formed by metal reactions with oxygen and called oxides; or (4) involving relatively simple parent structures (main structures) or highly substituted ones (derivative structures). Most ceramics are semi-crystalline, silicates, oxides, and derivative structures (see [Online Fig. 18-3, B](#)). Simple ceramic structures are more often ionically bonded. More complicated structures generally involve combinations of ionic and covalent bonding.

Polymers

Polymers are long molecules composed principally of non-metallic elements (e.g., carbon [C], oxygen [O], nitrogen [N], hydrogen [H]) that are chemically bonded by covalent bonds.



Online Fig. 18-4 Schematic summary of polymerization. **A**, Schematic representation of the four stages of chain reaction polymerization (activation, initiation, propagation, and termination) typical of free radical-initiated acrylic systems. Each stage has different reaction kinetics. Accelerators speed up free radical formation. Retarders and inhibitors forestall initiation. **B**, Schematic picture of a co-polymer molecule formed from two different types (*clear and solid*) of monomer units.

Their principal distinction from other common organic materials is their large size and molecular weight. The process of forming a polymer from identifiable subunits, monomers, is called *polymerization* ([Online Fig. 18-4](#)). Monomer means “one unit”; polymer means “many units.”

A common commercial and dental example is the polymerization of methyl methacrylate monomer (100 grams per molecule [g/mol]) into methyl methacrylate polymer (typically 300,000 g/mol). Most polymers are named by adding “poly-” as a prefix to the word for the major monomer in the polymer chain (e.g., polymethyl methacrylate [PMMA]) or by adding “poly-” to the description of the chemical links formed between monomer units (e.g., polyamide, polysaccharide, polyester, polyether, polyurethane). In other cases, the original commercial brand name has become the common name (e.g., Nylon, Teflon, Dacron, Plexiglas).

The large size and complexity of most polymers prohibits molecular scale organization that would produce crystallization. Almost all polymers under normal circumstances are noncrystalline. Polymers may be classified in terms of the kinetics of their polymerization reaction. Chain-reaction polymerization involves rapid monomer addition to growing

chains. Stepwise-reaction polymerization occurs slowly by random addition of monomers to any growing chain ends.

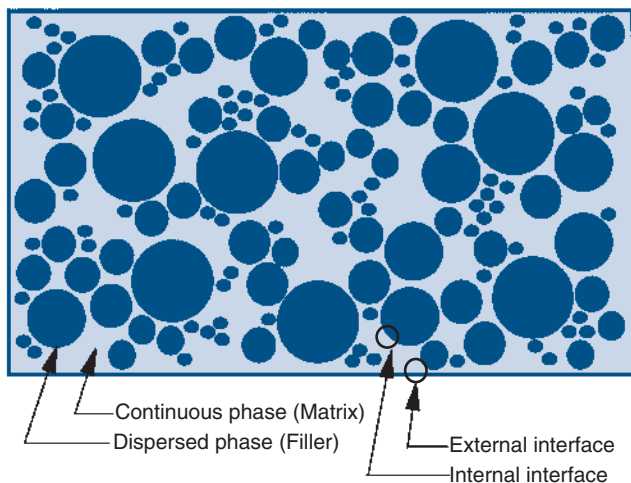
Acrylic monomers are used widely in dentistry and undergo chain-reaction polymerization. The stages of chain-reaction polymerization (see Online Fig. 18-4, A) include (1) activation (production of free radicals), (2) initiation (free radical combination with a monomer unit to create the beginning of a growing chain), (3) propagation (continued addition of monomer units), and (4) termination (cancellation of the growing chain end by any one of several possible events). The reaction kinetics of any step may be complex and may be influenced by many variables such as temperature, extent of reaction, or method of initiation. Accelerators (chemical, light, or heat) may be used to increase the rate of activation. Inhibitors or retarders (chemical) may be added to consume newly formed free radicals and prevent or postpone initiation. When chain-reaction polymerization has started, the process may proceed at extremely high speeds, producing extensive release of heat. Methyl methacrylate monomers combine to form polymer at a rate of one million units per second.

Composites

Composites are physical mixtures (or blends) of metals, ceramics, or polymers. The goal is to blend the properties of the parts to obtain intermediate properties and to take advantage of the best properties of each phase. The classic mixture for dental restorations involves ceramic particles mixed with a polymer matrix. This is commonly called *dental composite* or *composite*.

Properties of composites can be explained readily in terms of the volume fraction of the phases being physically mixed. This principle is called *the rule-of-mixtures* and has wide application for all materials. By knowing the phases present in the structure of any material and the interfacial interactions, it is possible to predict the overall properties fairly well.

Composites can be described as a dispersed (filler) phase mixed into a continuous (matrix) phase (Online Fig. 18-5). The matrix phase is generally the phase that is transiently fluid during the manipulation or placement of materials. It also is



Online Fig. 18-5 Key components of composites. Schematic view of generalized composite showing continuous phase, dispersed phase, internal interface, and external interface.

the phase that tends to have the least desirable properties in the mixture. As a general rule, minimizing the matrix of any system produces materials with more desirable clinical properties. For a composite to distribute energy within the system to all of the phases, it is important that the dispersed phase be bonded effectively to the continuous phase.

Material Structure

A material traditionally is defined in terms of its composition. The composition of a material represents only one of four important categories, however, describing its structure and properties. The four structural categories are atomic arrangement, bonding, composition, and defects. Atomic arrangement may be crystalline (ordered) or non-crystalline (disordered, glassy, amorphous). Primary bonding may include metallic, ionic, or covalent chemical bonds. Secondary bonding is much weaker and may include van der Waals or hydrogen bonds. Composition includes the elemental components and the resulting phases that form. The defects encompass imperfections ranging from those on the atomic scale to voids or pores. The thermal and mechanical histories strongly influence these structural categories, producing a wide range of possible properties for the same overall chemical composition. Gold alloys have different mechanical properties if their defect concentrations are changed. Silicon dioxide (SiO_2) can be produced as a noncrystalline solid or as any of three equilibrium crystalline solids (cristobalite, tridymite, or quartz).

Material Properties

Properties are descriptions of a material's interactions with the energy in its environment. The four common material property categories are physical, mechanical, chemical, and biologic properties. Physical properties include mass properties, thermal properties, electrical properties, optical properties, and surface properties. Mechanical properties include descriptions of stresses and strains within a material as a result of an external force. Chemical properties include chemical and electrochemical interactions. Biologic properties include characterization of toxicity or sensitivity reactions during clinical use.

Physical Properties

Physical properties involve reversible interactions of a material with its environment. A few common physical properties are reviewed here with respect to important dental situations. Metals, ceramics, polymers, and composites have different types and numbers of bonds. During temperature changes, these materials respond differently. During temperature increases, more frequent atomic motions stretch the bonds and produce net expansion. During temperature decreases, solids undergo contraction. The relative rate of change is called *the coefficient of thermal expansion* (or contraction). If it is referenced to a single dimension, it is called *the linear coefficient of thermal expansion* (LCTE), symbolized by the Greek letter alpha (α). The LCTE is expressed in units of "inch/inch/ $^{\circ}\text{F}$," "cm/cm/ $^{\circ}\text{C}$," or "ppm/ $^{\circ}\text{C}$." Because the rate of change is small, the actual value is typically a multiple of 10^{-6} cm/cm/ $^{\circ}\text{C}$ and is reduced to ppm/ $^{\circ}\text{C}$. Ceramics typically have an LCTE of 1 to 15 ppm/ $^{\circ}\text{C}$. Metals typically have values of 10 to

30 ppm/°C. Polymers typically have values of 30 to 600 ppm/°C. The LCTE of tooth structure is approximately 9 to 11 ppm/°C. It is important that the LCTE of a restorative material be as near that of tooth structure as possible. Online Table 18-1 presents examples of values for biomaterials.

One of the consequences of thermal expansion and contraction differences between a restorative material and adjacent tooth structure is percolation. This process is typified by an intracoronal amalgam restoration. During cooling, amalgam contracts faster than the tooth structure and recedes from the preparation wall, allowing the ingress of oral fluids.

Online Table 18-1 Linear Coefficients of Thermal Expansion	
Biomaterials/Structures	LCTE (ppm/°C)
Aluminous dental porcelain	4
Alumina	6.5–8
In-Ceram	8–10
CP-titanium	8–9
Traditional dental cements	8–10
Tooth structure	9–11
Stainless steel	11
PFM ceramics	14
PFM alloys	14
Gold foil	14–15
Gold casting alloys	16–18
Co-Cr alloys	18–20
Hybrid glass ionomers	20–25
Dental amalgam	25
Packable composites	28–35
Anterior and flowable composites	35–50
Composite cements	40
PMMA direct-filling resins	72–83
Dental wax	260–600

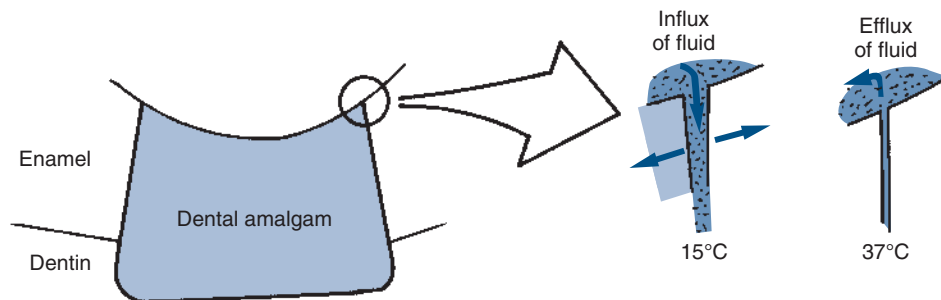
Co-Cr, cobalt–chromium; CP, commercially pure; PFM, porcelain-fused-to-metal; PMMA, polymethyl methacrylate; ppm, parts per million.
 From Bayne SC, Thompson JY: *Biomaterials science*, ed 7, Chapel Hill, NC, 2000, Brightstar.

During subsequent expansion, the fluid is expressed. Cyclic ingress and egress of fluids at the restoration margin is called *percolation* (schematically presented in Online Fig. 18-6).

Other important physical properties involve heat flow through materials. Enamel and dentin are composed primarily of finely packed ceramic crystals (i.e., hydroxyapatite, $\text{Ca}_{10}[\text{PO}_4]_6[\text{OH}]_2$) that make those structures act as thermal insulators. If the tooth structure is replaced by a metallic restoration, which tends to be a thermal conductor, it may be important to provide thermal insulation to protect the dental pulp from rapid increases or decreases in temperature in the mouth. Generally, dental cements that may be used as bases under metallic restorations act as insulators. An advantage of a composite is low thermal conductivity. Composites do not need liners and bases to provide thermal insulation. Heat flow through a material is measured in terms of either the relative rate of heat conduction (thermal conductivity) or the amount of heat conduction per unit time (thermal diffusivity). Thermal diffusivity is the more important property because it determines the amount of heat flow per unit time toward the pulp through a restoration. The dental pulp can withstand small temperature changes (37–42°C) for relatively short periods (30–60 seconds) without any permanent damage.^{5,34,35} Under most circumstances, the microcirculation of the pulp transports the heat entering the pulp away to other parts of the body, where it is dissipated easily. Extreme temperature changes or extended times of exposure to high temperatures cause pulpal changes, however.

Electrical conductivity is a measure of the relative rate of electron transport through a material. This concept is important for metallic restorations that easily conduct electricity. If a galvanic cell (electrochemical cell) is present, electrical current may flow, and that process would stimulate nerves in the pulp. This may occur accidentally, such as when a tinfoil wrapper of chewing gum contacts a cast gold restoration and produces a minor electrical shock.

Mass properties of materials involve density or specific gravity. Density is a material's weight (or mass) per unit volume. Most metallic materials have relatively high densities (6–19 gram per cubic centimeter [g/cm^3]). Ceramic densities are typically 2 to 6 g/cm^3 . Polymer densities generally range from 0.8 to 1.2 g/cm^3 . Density is an important consideration for certain dental processing methods such as casting. Dense metal alloys are much easier to cast by centrifugal casting methods. Density is important in estimating the properties of mixtures of different materials (composites) because the final



Online Fig. 18-6 Percolation along the margins of an amalgam restoration owing to its difference in linear coefficient of thermal expansion from tooth structure during intraoral temperature changes. Fluid influx occurs during cooling (contraction). Fluid efflux occurs during heating (expansion).

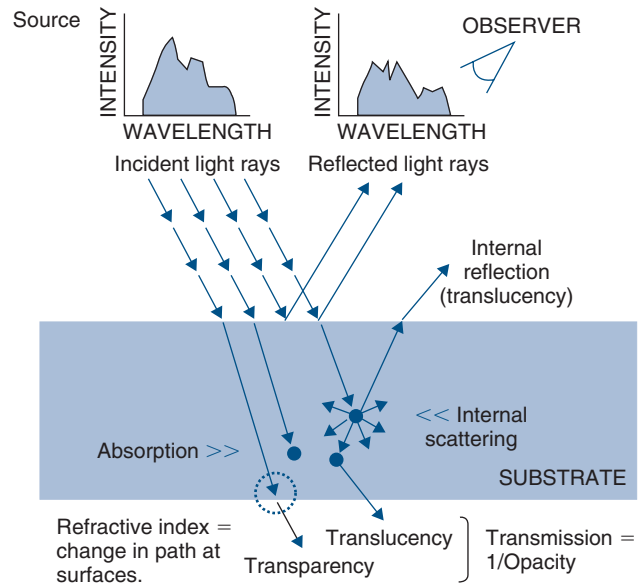
properties of the mixture are proportional to the volume of mixed materials (and not the weight). Occasionally, the relative density (or specific gravity) may be reported. Relative density is the density of the material of interest compared with the density of water under a standard set of conditions. At 25°C at 1 atmosphere of pressure, the density of water is 1 g/cm³. A specific gravity of 1.2 translates into a density of 1.2 g/cm³ under the same conditions.

Optical properties of bulk materials include interactions with electromagnetic radiation (e.g., visible light) that involve reflection, refraction, absorption (and fluorescence), or transmission (Online Fig. 18-7). The radiation typically involves different intensities for different wavelengths (or energies) over the range of interest (spectrum). Any of these interactive events can be measured using a relative scale or an absolute scale. When the electromagnetic radiation is visible light, the amount of reflection can be measured in relative terms as gloss or in absolute terms as percent reflection. Visible light absorption can be measured in absolute terms as percent absorption (or transmission) for every wavelength (in the visible spectrum). Color is a perception by an observer of the distribution of wavelengths. The same color sensation may be produced by different absorption spectra (metamerism). An individual's eye is capable of sensing dominant wavelength, luminous reflectance (intensity), and excitation purity. Variations among individuals' abilities to sense these characteristics give rise to varying perceptions of color.

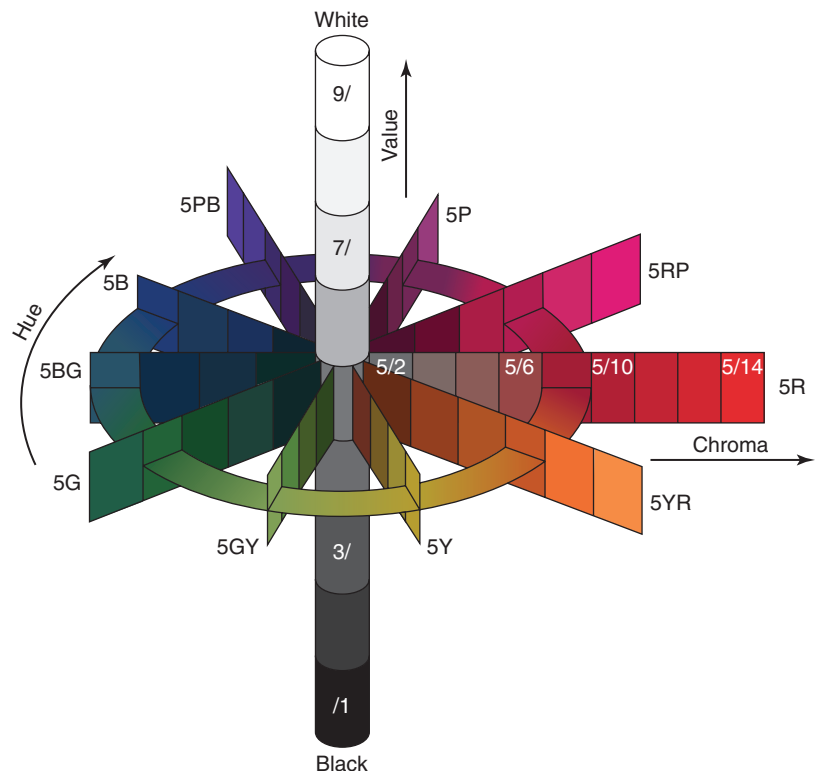
Color measurement techniques do not measure these quantities directly. Color traditionally has been measured using the Munsell color system in terms of *hue*, *value*, and *chroma*. These terms correspond approximately to *wavelength*, *intensity*, and *purity*. The relationships of these quantities are represented schematically in Online Figure 18-8. Shade guides for matching restorative biomaterials to the tooth structure are

based on this system of describing color. The quality of color also is measured by the Commission Internationale de l'Éclairage system as tristimulus values and reported as color differences (ΔL^* , Δa^* , and Δb^*) compared with standard conditions.

Color is more than a property of a material. It is coupled with the electromagnetic spectrum involved (and the relative



Online Fig. 18-7 Schematic summary of interactions of electromagnetic radiation with materials. The color perceived by the observer is the result of several interactions between substrate and incoming radiation producing reflection, internal scattering, absorption, fluorescence, and transmission.



Online Fig. 18-8 Munsell scale of hues, values, and chromas in color space. (From Sakaguchi RL, Powers JM: Craig's restorative dental materials, ed 13, Mosby, St. Louis, 2012.)

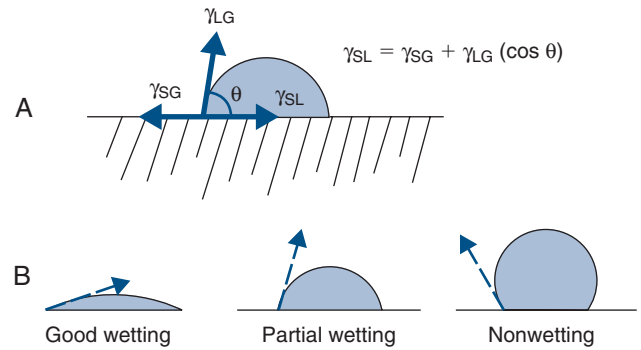
intensity of every wavelength in the spectrum) and the perceptive abilities of the observer. A practical example of the importance of the spectrum and the observer would be the appearance of anterior dental porcelain crowns in a nightclub in which the lighting involves low-level fluorescent lamps. The crowns fluoresce differently in that light and appear different from the adjacent natural teeth compared with a natural appearance in full-spectrum visible daylight.

Radiation of another wavelength may be preferentially absorbed (e.g., x-rays). Composites that contain lithium, barium, strontium, or other good x-ray absorbers may appear radiopaque (radiodense) in dental radiographs. Materials that are good absorbers (for whatever form of radiation) are described as *opaque*.

The appearance of a dental restoration is a combination of events of surface reflection, absorption, and internal scattering. The scattering simply may deflect the path of the radiation during transmission (refraction), or it may reflect the radiation internally from varying depths back out of a solid to the observer (translucency). Enamel naturally displays a high degree of translucency; *translucency* is a desirable characteristic for restorative materials attempting to mimic enamel.

A wet tooth that is isolated from the wetting by saliva soon has a transient whiter appearance. Most of this shade change is the effect of loosely bound water lost from subsurface enamel (by dehydration) between hydroxyapatite crystals. This increases the internal scattering of light, with much of it reflected back to the observer (see internal reflection in [Online Fig. 18-7](#)). This probably explains why it takes 15 to 20 minutes for the isolated tooth to develop the whiter appearance and 30 minutes or more for it to regain its original appearance after isolation is terminated. Larmas et al showed that 0.8% to 1% by weight of pulverized moist enamel is exchangeable water and that it can be removed at 4% relative humidity and 20°C.³⁶ Loosely bound water also provides channels for diffusion through enamel of ions and molecules. The direction of radiation may be perturbed as it crosses an interface from a medium of one type of optical character to another. Refractive index is the angle of changed path for a standard wavelength of light energy under standard conditions.

Another group of physical properties comprises surface properties. Surfaces are important because all restorative biomaterials meet and interact with the tooth structure at a surface. Also, all dental surfaces interact with intraoral constituents such as saliva and bacteria. Changing a material's surface properties can mitigate the extent of that interaction. The type of interaction between two materials at an interface is defined as the energy of interaction, and this is conveniently measured for a liquid interacting with a solid under a standard set of conditions as the contact angle (θ). The contact angle is the angle a drop of liquid makes with the surface on which it rests ([Online Fig. 18-9, A](#)). This angle is the result of an equilibrium between the surface tensions of the liquid–gas interface (γ_{LG}), solid–gas interface (γ_{SG}), and solid–liquid interface (γ_{SL}). These relationships can be expressed as an equation (see [Online Fig. 18-9, A](#)). If the energy difference of the two materials in contact is large, they have a large contact angle. If the energy difference is very small, the contact angle is low, and the liquid appears to wet the solid by spreading. Wetting is a qualitative description of the contact angle. Good wetting, or spreading, represents a low contact angle. Partial (poor) wetting describes a contact angle approaching 90 degrees.



Online Fig. 18-9 Interfacial interactions of materials. **A**, Interaction quantified as contact angle (see formula). **B**, Interaction described in terms of good wetting (spreading), partial (poor) wetting, or nonwetting.

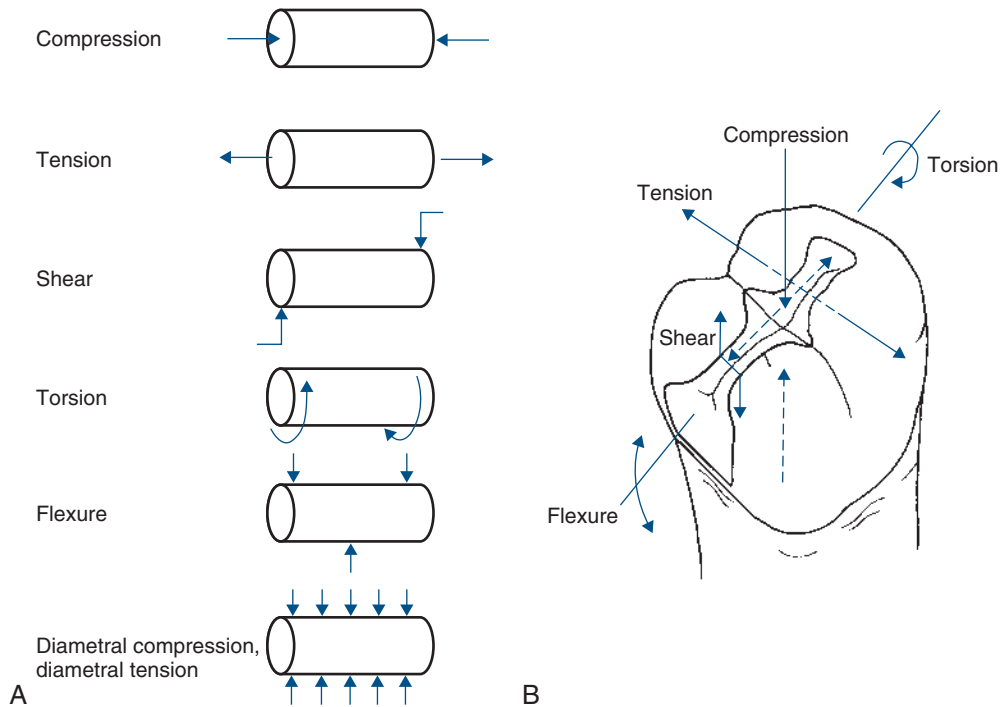
Nonwetting is a contact angle approaching 180 degrees (see [Online Fig. 18-4, B](#)).

It is important that film formers such as varnishes, liners, cements, and bonding agents (all of which are discussed later in this chapter) have good wetting on tooth preparation surfaces or other restorative materials on which they may be placed so that they adapt to the microscopic interstices of the surfaces. In other instances, poor wetting may be an advantage. Experimental posterior composites have been formulated to have high contact angles to retard water or bacterial interactions or both. In most cases, wetting can be anticipated on the basis of the hydrophilicity (water-loving) or hydrophobicity (water-hating) of materials. Hydrophilic surfaces are not moistened well by hydrophobic liquids.

Mechanical Properties

The mechanical properties of a material describe its response to loading. Although most clinical situations involve complicated three-dimensional loading situations, it is common simply to describe the external load in terms of a single dimension (direction) as *compression*, *tension*, or *shear*. Combinations of these can produce *torsion* (twisting) or *flexion* (transverse bending). These modes of loading are represented schematically in [Online Figure 18-10](#), with respect to a simple cylinder and a mesio-occlusal amalgam restoration. For testing purposes, it is often impossible to grip and pull a specimen in tension without introducing other, more complicated stresses at the same time. To circumvent problems for tensile testing of cylinders, it is possible to compress the sides of a cylinder and introduce stresses equivalent to tension. This variation of tension is called *diametral tension* (or *diametral compression*).

When a load is applied, the structure undergoes deformation as its bonds are compressed, stretched, or sheared. The load–deformation characteristics are useful only if the absolute size and geometry of the structure involved are known. It is typical to normalize load and deformation (in one dimension) as stress and strain. *Stress* (abbreviated σ) is load per unit of cross-sectional area (within the material). It is expressed in units of load per area ($\text{lb/in}^2 = \text{psi}$, or $\text{N/mm}^2 = \text{MPa}$). *Strain* (abbreviated ϵ) is deformation (ΔL) per unit of length (L). It is expressed in units of length per length (inch/inch, or cm/cm), which is a dimensionless parameter. A schematic summary is



Online Fig. 18-10 Examples of directions of loading. **A**, Uniaxial loading of cylinder. **B**, Uniaxial loading of a mesio-occlusal amalgam restoration.

presented in [Online Figure 18-11](#). During loading, bonds generally are not compressed as easily as they are stretched. Materials resist compression more readily and are said to be stronger in compression than in tension. Materials have different properties under different directions of loading. It is important to determine what the clinical direction of loading is before assessing the mechanical property of interest.

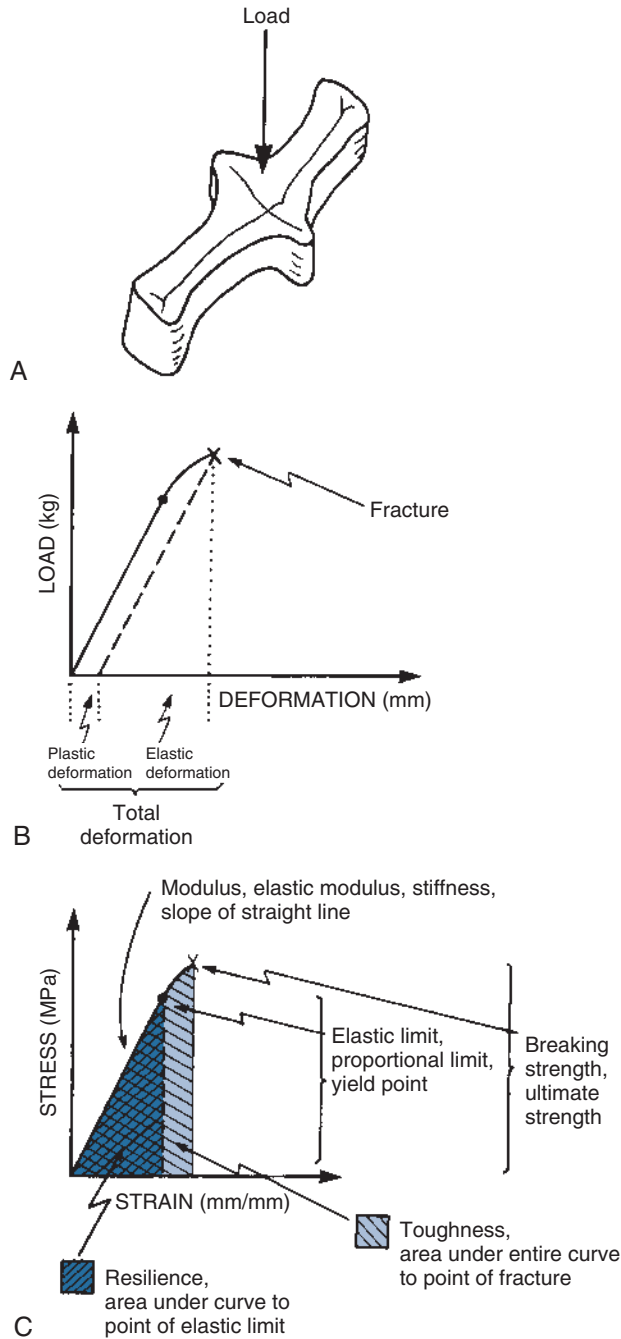
As loading continues, the structure becomes deformed. At first, this deformation (or strain) is completely reversible (elastic strain). Increased loading finally produces some irreversible strain as well (plastic strain), however, which causes permanent deformation. The point of onset of plastic strain is called *the elastic limit* (*proportional limit*, *yield point*). This point is indicated on the stress–strain diagram (see [Online Fig. 18-11](#)) as the point at which the straight line starts to become curved. Continuing plastic strain ultimately leads to failure by fracture. The highest stress before fracture is the ultimate strength (see [Online Fig. 18-11, C](#)). The total plastic tensile strain at fracture is called *elongation*; this also may be expressed as the percent elongation. Materials that undergo extensive plastic deformation before fracture are called *ductile* (in tension) or *malleable* (in compression). Materials that undergo very little plastic deformation are called *brittle*.

The slope of the linear portion (constant slope) of the stress–strain curve (from no stress up to the elastic limit) is called *modulus*, *modulus of elasticity*, *Young's modulus*, or *stiffness of the material* and is abbreviated as E . It represents the amount of strain produced in response to each amount of stress. Ceramics typically have much higher modulus values (high stiffness) than polymeric materials (low stiffness). Because the slope of the line is calculated as the stress divided by the strain ($E = \sigma/\epsilon$), modulus values have the same units as stress (i.e., pounds per square inch [psi] or megapascals [MPa]).

Two of the most useful mechanical properties are the modulus of elasticity and the elastic limit. A restorative material generally should be extremely stiff so that under load, its elastic deformation is extremely small. An exception is a Class V composite, which should be less stiff to accommodate tooth flexure. If possible, a material should be selected for an application so that the stress level during function usually does not exceed the elastic limit. If the stress exceeds the elastic limit by a small amount, the associated plastic deformation tends to be very small. If the stress is well beyond the elastic limit, the resulting deformation is primarily plastic strain, which at some point results in failure.

It is often convenient to determine the elastic limit in a relative manner by comparing the onset of plastic deformation of different materials using scratch or indentation tests, called *hardness tests*. The Mohs hardness scale ranks scratch resistance of a material compared with a range of standard materials ([Online Table 18-2](#)). Rockwell, Brinell, and Knoop hardness tests employ indenters instead. The energy that a material can absorb before the onset of any plastic deformation is called its *resilience* (see [Online Fig. 18-11, C](#)) and is described as the area under the stress–strain curve up to the elastic limit. The total energy absorbed to the point of fracture is called *toughness* and is related to the entire area under the stress–strain curve (see [Online Fig. 18-11, C](#)).

Mechanical events are temperature dependent and time dependent. These conditions must be described carefully for any reported mechanical property. Generally, as the temperature increases, the mechanical property values decrease. The stress–strain curve appears to move to the right and downward. The opposite occurs during cooling. As the rate of loading decreases, the mechanical properties decrease. This is described as *strain rate sensitivity* and has important clinical implications: To make a material's behavior momentarily



Online Fig. 18-11 Schematic summary of mechanical properties with respect to amalgam restoration in function. **A**, Occlusal loading of Class I amalgam restoration. **B**, Load or deformation curve describing the behavior of amalgam. **C**, Normalization of load or deformation curve to stress-strain curve with the important characteristics of curve indicated. (Mechanical responses depend on temperature and strain rate involved.)

stiffer or more elastic, the material should be strained quickly. For recording undercut areas in an elastic intraoral impression, the material should be removed rapidly so that it is more elastic and more accurately records the absolute dimensions of the structures. This is an excellent example of applied materials science.

Other time-dependent responses to stress or strain also occur. Deformation over time in response to a constant stress

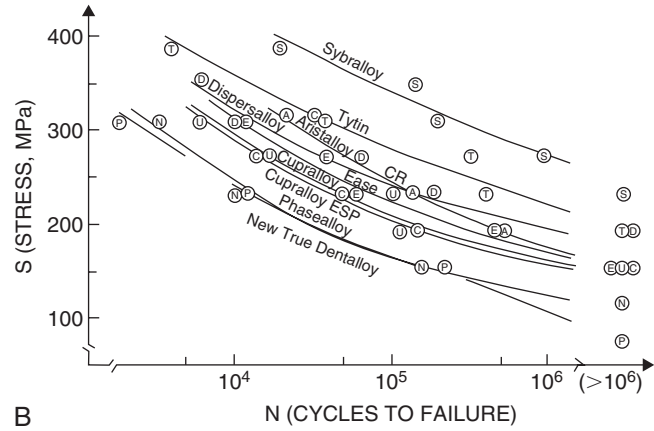
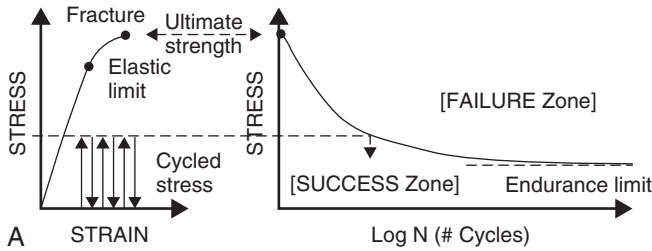
Online Table 18-2 Mohs Hardness Scale

Mohs Hardness/Reference Material	Mohs Hardness/Materials Examples
10/Diamond (C)	9–10/Silicon carbide (SiC) 9.5/Tungsten carbide (WC)
9/Corundum (Al ₂ O ₃)	8–9/Chrysoberyl (FeAl ₂ O ₄) 8/Zirconia (ZrO ₂)
8/Topaz (Al ₂ SiO ₄ (FOH) ₂)	7–8/Tool steels
7/Quartz (SiO ₂)	6–7/Garnet 6.5–7.5/Feldspathic 6–7/Porcelain 6/Pumice
6/Orthoclase (KAlSi ₃ O ₈)	5–6/Dental enamel [(Ca ₆ (PO ₄) ₁₀ (OH) ₂)] 5–5.5/Dental composite
5/Apatite (Ca ₅ (PO ₄) ₃ (OH))	4–5/Low-carbon steels 4–4.5/Platinum 4–5/Amalgam
4/Fluorite (CaF ₂)	3–4/Dentin 3.5/Copper penny 3–4/Plastic
3/Calcite (CaCO ₃)	2–3/Copper (Cu), silver (Ag), gold (Au)
2/Gypsum (CaSO ₄ ·2H ₂ O)	1–2/Ice
1/Talc (Mg ₃ Si ₄ O ₁₀ (OH) ₂)	

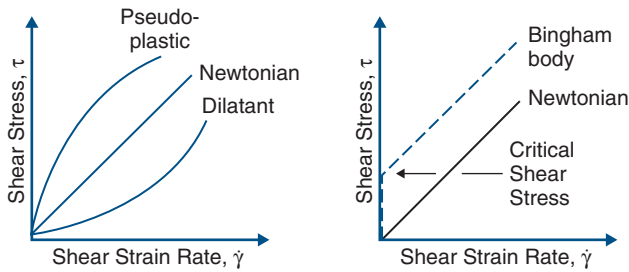
is called *creep* (or *strain relaxation*). Materials that are relatively weak or close to their melting temperature are more susceptible to creep. Dental wax deforms (creeps) under its own weight over short periods. Traditional amalgam restorations are involved in intraoral creep. Deformation over time in response to a constant strain is called *stress relaxation*.

During loading, for all practical purposes, the strain below the elastic limit is all elastic strain. The amount of plastic strain is infinitesimal—so small that it is ignored. During multiple cycles, these very small amounts of plastic strain begin to accrue. After millions of cycles, the total plastic strain accumulated at low stress levels may be sufficient to represent the strain required to produce fracture. This process of multiple cycling at low stresses is called *fatigue* (Online Fig. 18-12, A). A standard engineering design limit for dental restorative materials is approximately 10 million cycles (or approximately 10 years of intraoral service). A rule of thumb is that materials on working surfaces of teeth are mechanically cycled approximately one million times per year on average. The curve correlating cyclic stress levels (S) to the number of cycles to failure (N) is called *fatigue curve* (*S-N curve*). These curves have been determined only for a few biomaterials because conducting the tests requires such a long time.³⁷ The compressive fatigue curves for Tytin and Dispersalloy amalgams are shown as part of Online Figure 18-12, B.

Mechanical properties can be used to describe the behavior of liquids and solids. As the temperature of a solid is increased, its stress-strain curve shifts downward and to the right. At the melting point, the stress-strain curve is a horizontal line lying at zero stress along the strain axis. Rather than examining the stress-strain behavior of liquids, it is more meaningful to examine the shear stress (τ) versus shear strain rate ($\dot{\gamma}$).



Online Fig. 18-12 Fatigue curves. **A**, Relationship between single-cycle stress–strain and fatigue curves. A typical fatigue curve separates characteristic regions (survival, fracture) and asymptotically levels off at an endurance limit. **B**, Fatigue curves from compression testing for several commercial amalgams. A, Aristalloy; C, Cupralloy; D, Dispersalloy; E, Ease; N, New True Dentalloy; P, Phasealloy; S, Sybralloy; T, Tytin; U, Cupralloy ESP. (**B**, From Zardiackas LD, Bayne SC: *Fatigue characterization of nine dental amalgams*, *Biomaterials* 6:49–54, 1985.)

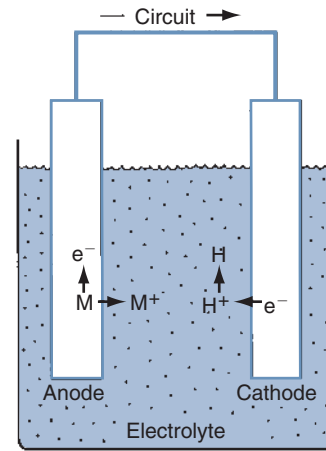


Online Fig. 18-13 Schematic summary of mechanical property behaviors of liquids. The curves represent typical flow behaviors described as Newtonian, pseudoplastic, dilatant, and Bingham body. (From Bayne SC, et al: *Biomaterials science*, ed 6, Chapel Hill, NC, 1992, Brightstar.)

Well-behaved liquids (newtonian behavior) form a straight line (Online Fig. 18-13). Departures may occur that produce lines curving down (pseudoplastic behavior) or curving up (dilatant behavior). In some cases, the starting point of the line is shifted up along the shear stress axis, representing a material that does not start to flow until a critical shear stress has been reached (*Bingham body behavior*). Pseudoplastic and Bingham body behaviors are typical for biomaterials. The lines on these diagrams are described by a relatively simple equation, $\eta^p = \tau/\dot{\gamma}$, which is similar to the equation for elastic modulus, $E = \sigma/\epsilon$. The term η , or *viscosity*, is the resistance to flow or stiffness of the liquid. As the temperature is increased above the melting point, the viscosity behavior tips down and toward the right. A 37% phosphoric acid solution gel used for etching displays pseudoplastic Bingham body behavior. It does not flow until a critical shear stress is exceeded, and as the shear stress is linearly increased, the shear strain rate increases even more rapidly, producing more flow.

Chemical Properties

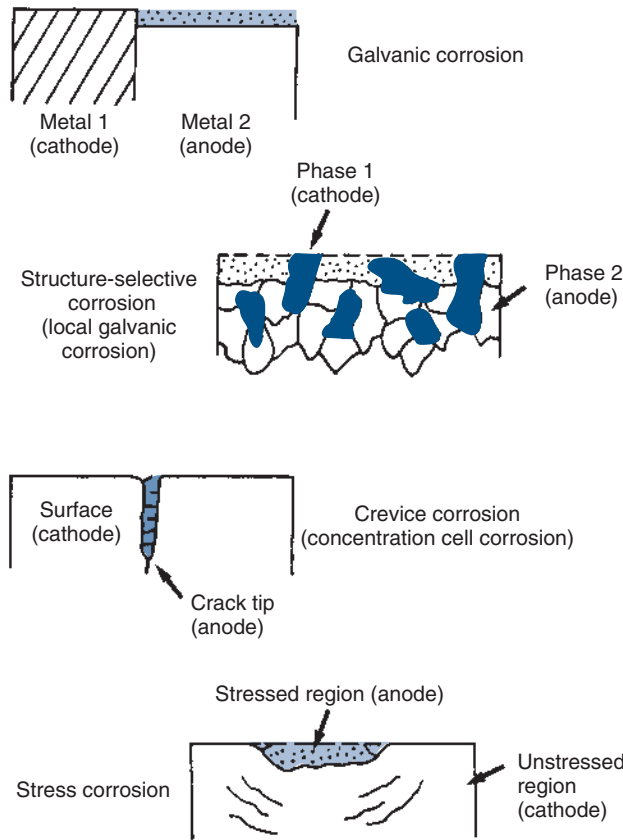
Chemical properties of a material are properties that involve changes in primary or secondary bonding. Primary bonding changes occur during chemical reactions and electrochemical



Online Fig. 18-14 Schematic representation of electrochemical cell. (From Bayne SC, et al: *Biomaterials science*, ed 6, Chapel Hill, NC, 1992, Brightstar.)

reactions. Secondary bonding changes occur during processes such as adsorption and absorption. For metallic materials in the oral environment, the principal changes in primary bonding occur as a result of chemical corrosion (tarnish) or electrochemical corrosion. Chemical corrosion involves direct reaction of species by contact in solution or at an interface. An example of this process is the sulfide tarnishing of silver in amalgams to produce a black surface film. Another example is the oxidation of casting alloys containing very high copper to produce a green patina.

For any material, many electrochemical corrosion processes also may occur. Electrochemical corrosion involves two coupled chemical reactions (half cells) at separate sites, connected by two paths. One path (a circuit) is capable of transporting electrons, whereas the other path (an electrolyte) is capable of transferring metallic ions.³⁸ The basic components required for any electrochemical cell are (1) an anode (site of corrosion), (2) a cathode, (3) a circuit, and (4) an electrolyte (Online Fig. 18-14).



Online Fig. 18-15 Types of electrochemical cells. Dotted regions indicate anodic material being lost during corrosion. (From Tomashov ND: Theory of corrosion and protection of metals, ed 1, New York, 1966, Macmillan.)

Electrochemical corrosion occurs intraorally when these four components are present. The conditions define which of the metallic sites acts as an anode. Many types of electrochemical cells are possible. Examples are shown schematically in Online Figure 18-15. Many of these electrochemical cells are possible in a single restorative dentistry situation. When an amalgam is in contact with a gold alloy restoration, galvanic, local galvanic, crevice, and stress corrosion are possible. Galvanic corrosion is associated with the presence of macroscopically different electrode sites (amalgam and gold alloy). Local galvanic corrosion (structure-selective corrosion) is caused by the electrochemical differences of different phases in a single material (e.g., amalgam). Electrochemical cells may arise whenever a portion of the amalgam is covered by plaque or soft tissue. The covered area has a locally lowered oxygen or increased hydrogen ion concentration, making it behave more like an anode and corrode (concentration cell corrosion). Cracks and crevices produce similar conditions and encourage concentration cell corrosion. Both corrosion processes are commonly termed *crevice corrosion*. When the restoration is under stress, the distribution of mechanical energy is not uniform, and this produces different corrosion potentials. This process is called *stress corrosion*.

Ceramics and polymers do not undergo chemical or electrochemical corrosion in the same sense. Most of their changes are related to chemical dissolution, absorption, or adsorption. Chemical dissolution normally occurs as a result of the solubilization created by hydrogen bonding effects of water and

locally high acidity. The tooth structure is dissolved by high concentrations of lactic acid under plaque. Dental ceramics may be dissolved by extremely acidic fluoride solutions (acidulated phosphate fluoride) used for protecting outer layers of enamel against caries.

Adsorption involves the addition of molecules to a surface by secondary bonding, and *absorption* involves the penetration of molecules into a solid by diffusion. Protein adsorption alters the behavior and reactivity of dental material surfaces. Water absorption into dental polymers affects their mechanical properties.

Biologic Properties

Biologic properties of biomaterials are concerned with toxicity and sensitivity reactions that occur locally, within the associated tissue, and systemically. Most biomaterials interface locally with a variety of tissues (enamel, dentin, pulp, periodontium, cheek, tongue). Local reactions may vary. It is possible to evaluate local toxic effects on cells by clinical pulp studies or by tissue culture tests. Unset materials may release cytotoxic components. In clinical situations, however, this problem is rarely evident. Two important clinical factors determining toxicity are the exposure time and the concentration of the potentially toxic substance. Generally, restorative materials harden quickly or are not readily soluble in tissue fluids (or both). Potentially toxic products do not have time to diffuse into tissues. Even more importantly, the concentration makes the poison. Some authorities believe that if the amount of material involved is small, the pulp or other tissues can transport and excrete it without significant biochemical damage. Others believe that no threshold exists. A threshold level for toxicity is one below which no effect can be detected.

Systemic changes resulting from biomaterial interactions have been difficult, if not impossible, to monitor. Most evidence of biocompatibility has come from long-term usage and indirect monitoring. This is an area of increasing concern for understanding potential risks of new or alternative restorative biomaterials.

Finally, toxicology is undergoing rapid evolution. In the 1970s, most toxicologic screening involved the use of the Ames test for determining mutagenicity. The inventor of that test has now withdrawn support for the conclusions derived from that screening procedure.^{39,40} Results from earlier screening tests of biomaterials may need to be reconsidered.

Biomechanics for Restorative Dentistry

Teeth are subjected to many forces during normal use. The interactions among the applied forces, the shape and structure of teeth, the supporting structures, and the mechanical properties of tooth components and restorative materials all are included in biomechanics, which is the study of loads (or stresses) and deformations (or strains) occurring in biologic systems.

The biomechanical behavior of restored teeth can be studied at any level from gross to microscopic. Examples of situations of interest include the calculation of stress transfer to the margin of an amalgam restoration, from the amalgam to tooth structure, from tooth structure to the periodontal ligament,

from several teeth to bone, and throughout bone. The most common analysis focuses on stress transfer at the interface between a restoration and tooth structure.

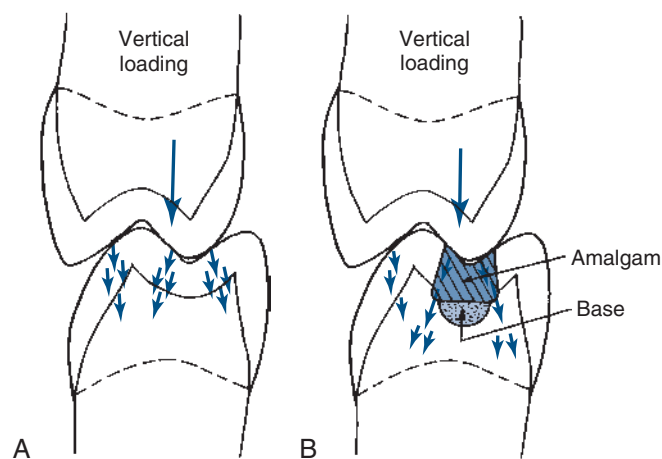
Biomechanical Unit

The standard biomechanical unit involves (1) the restorative material, (2) the tooth structure, and (3) the interface (interfacial zone) between the restoration and the tooth. Different restorative procedures can involve different interfaces. Composite–enamel interfaces are micromechanically bonded. Amalgam–enamel interfaces are weak and discontinuous unless a bonding system is used. Cemented crown–enamel interfaces are weak but are continuous. The importance of considering three structures in the biomechanical unit is to detect stresses that may cause unwanted fractures or debonding. The restorative material may be strong enough to resist fracture, but the interface or the tooth structure may not be.

Stress Transfer

The normal tooth structure transfers external biting loads through enamel into dentin as compression (Online Fig. 18-16, A). The concentrated external loads are distributed over a large internal volume of the tooth structure, and local stresses are low. During this process, a small amount of dentin deformation may occur, resulting in tooth flexure. These deformations are discussed in more detail in the following section.

A restored tooth tends to transfer stress differently from how an intact tooth does. Any force on the restoration produces compression, tension, or shear along the tooth–restoration interface.^{41,42} When enamel is no longer continuous, its resistance is much lower. Most restorations are designed to distribute stresses onto sound dentin, rather than onto enamel (see Online Fig. 18-16, B).⁴³ When in dentin, the



Online Fig. 18-16 Schematic view of occlusal loading of amalgam restorations. **A**, Stress transfer into an unrestored tooth occurs through dental enamel into dentin. **B**, Stress transfer into a tooth restored with dental amalgam is conducted through enamel and the restoration to be distributed within dentin (and not enamel). The facial and lingual seats at initial cavity preparation at the pulpal wall level (before removal of remaining infected dentin and placement of base) help transfer stresses laterally.

stresses are resolved in a manner similar to that in a normal tooth. The process of stress transfer to dentin becomes more complicated when the amount of remaining dentin is thin and the restoration must bridge a significant distance to seat onto thicker dentin (see the section on liners and bases).

For an amalgam restoration in a pulpally deep tooth preparation, 1 to 2 mm of underlying dentin or other insulating material is preferred pulpal of the amalgam to provide adequate thermal and mechanical protection of the pulp.²⁰ If the thickness of dentin is still inadequate, the insertion of an insulating liner or base is recommended. Sometimes it may be necessary, however, to ensure that the amalgam restoration is “seated” on sound dentin at three or more widely separated areas at the level of the initial tooth preparation pulpal wall. This seating provides optimal stress transfer. For a nonmetallic restoration, which has better insulating properties than does a metallic one, 0.5 to 1 mm of dentin or liner or base is sufficient for thermal and mechanical protection.

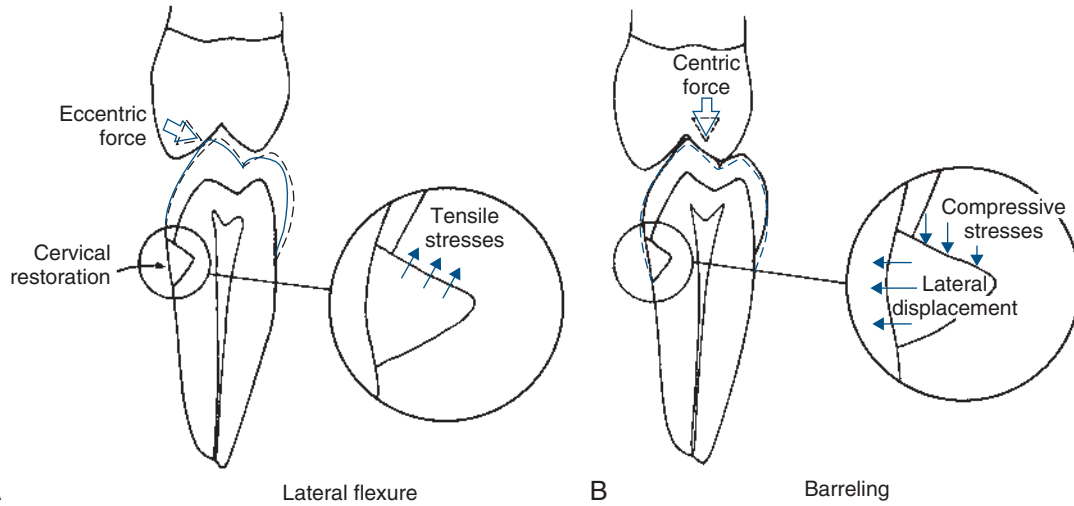
Strain within Tooth Structure (Tooth Flexure)

Teeth are not rigid structures. They undergo deformation (strain) during normal loading.⁴⁴ Intraoral loads (forces) vary widely and have been reported to range from 10 N to 431 N (1 N = 0.225 lb of force), with a functional load of 70 N considered clinically normal.⁴⁵ The number of teeth, type of occlusion, and occlusal habits of patients (e.g., bruxism) affect the load per tooth. The amount of strain is roughly proportional to the amount of stress. Because the tooth structure is heterogeneous and asymmetric, however, and its properties change with time, a simple description of the state of stress or amount of strain does not exist. To date, increasing evidence indicates that the amount of strain and its effect on tooth structure may play a crucial role in fatigue.

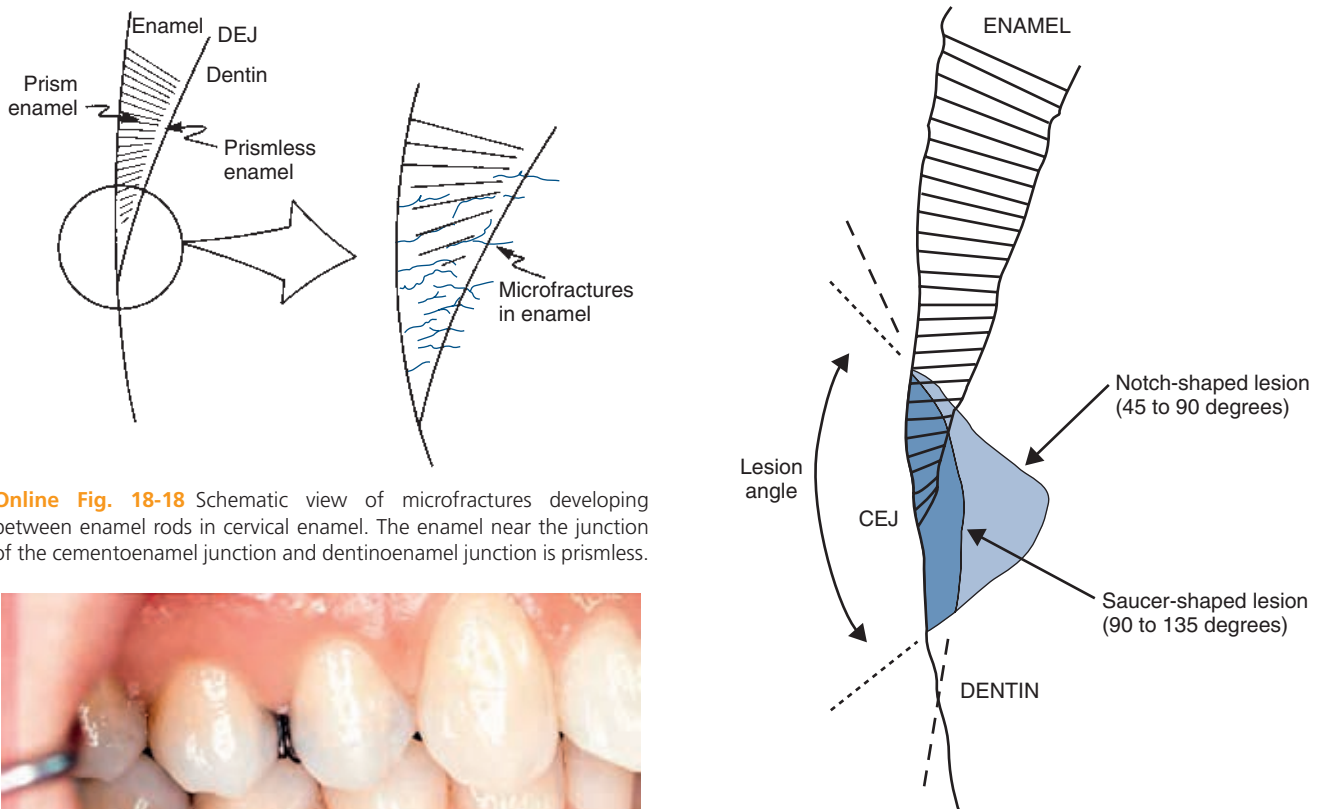
Tooth flexure has been described as either a lateral bending or an axial bending of a tooth during occlusal loading.⁴⁶ This flexure produces the maximal strain in the cervical region, and the strain seems to be resolved in tension or compression within local regions, sometimes causing the loss of bonded Class V restorations in preparations with no retention grooves (Online Fig. 18-17). One current hypothesis is that tensile or compressive strains gradually produce microfractures (called *abfractions* by some authors) in the thinnest region of enamel at the cemento-enamel junction (CEJ) (Online Fig. 18-18).⁴⁷⁻⁵⁰ Such fractures predispose enamel to loss when subjected to toothbrush abrasion and chemical erosion. This process may be key in the formation of some Class V defects (Online Figs. 18-19 and 18-20). Additionally, in unbonded or leaking restorations, this flexure of dentin may produce changes in fluid flow and microleakage, leading to sensitivity and pulpal inflammation. Careful documentation of these events is just beginning.

Effects of Aging

As a tooth becomes older, it undergoes changes in structural mass and in the character of the remaining tissue. Older teeth have lost most prismless enamel along the outer surface and may have encountered numerous microfractures in the cervical portions, as just discussed earlier. In response to disease assaults such as caries or other external stimuli, odontoblastic



Online Fig. 18-17 Schematic diagram of tooth flexure creating cervical stresses. **A**, Lateral flexure results from eccentric forces that produce tensile stresses at the marginal interface with cervical restoration placed in the facial cemento-enamel junction region. **B**, Barreling results from heavy centric forces that produce compressive stresses along the marginal interface with cervical restoration in the entire cemento-enamel junction region, resulting in lateral displacement (loss) of the restoration. (From Heymann HO, et al: *Tooth flexure effects on cervical restorations: A two-year study*, J Am Dent Assoc 122:41–47, 1991.)



Online Fig. 18-18 Schematic view of microfractures developing between enamel rods in cervical enamel. The enamel near the junction of the cemento-enamel junction and dentino-enamel junction is prismless.



Online Fig. 18-19 Class V lesions on two premolars suspected of being abfractions arising from tooth flexure. (From Grippo JO, et al: *Attrition, abrasion, corrosion, and abfraction revisited: a new perspective on tooth surface lesions*, J Am Dent Assoc 135:1109–1118, 2004.)

Online Fig. 18-20 Schematic view of Class V cervical defects comparing a shallow saucer-shaped lesion with a deep notch-shaped lesion. Angulation is determined by the average slope of walls and not walls at the perimeter of the lesion. (From Bayne SC, et al: *Class V angulation, size, and depth effects on composite retention [abstract 1669]*, J Dent Res 71A:314, 1992.)

processes may have laid down more peritubular dentin occluding the outer zones of dentinal tubules.⁵¹ Peritubular dentin is mostly hydroxyapatite and tends to stiffen dentin. Secondary and reparative dentin also may have been produced, replacing some of the pulp chamber and canals. Other strong evidence suggests that with aging, all type I collagen in the human body becomes more cross-linked.⁵² It is strongly suspected that this process of cross-linking makes intertubular dentin more brittle. It is logical that the modulus of teeth is observed to increase with aging (50% increase from 20–29 years of age to 40–49 years of age), and that teeth behave in a more brittle fashion.⁵³ This alteration, coupled with microcracks that may have developed with fatigue, may produce large cracks or fractures in the tooth over time. Supporting bone also may undergo property changes with age.⁵⁴ These changes produce a substrate that may not transfer stress as readily and that no longer may be well matched to the properties of a restorative material that has survived for a long time. The complete implication of these changes is not yet fully understood.

Principles of Biomechanics

Stress transfer and the resulting deformations of structures are governed principally by (1) the elastic limit of the materials, (2) the ratio of the elastic moduli involved, and (3) the thickness of the structures. Materials with a high elastic modulus transfer stresses without much strain. Lower modulus materials undergo dangerous strains where stresses are concentrated, unless there is adequate thickness. The resistance to strain increases approximately as the third power of the thickness of the material involved. Doubling the thickness increases the resistance to elastic strain eightfold. If the local stress does exceed the material's elastic limit, the capacity for plastic deformation before fracture determines when fracture actually occurs.

These principles can be shown easily using the case of a mesio-occluso-distal restoration in a first molar. A low modulus material such as amalgam must have sufficient thickness to resist flexural deformation that would produce fracture in this brittle material. Increased amalgam thickness improves its resistance to flexure but compromises the resistance of the remaining dentin and base floor for the restoration. Properly prepared and condensed amalgam in a proper tooth preparation that provides the recommended occlusopulpal restoration thickness serves for many years, however, without fracture.

Direct Restorative Biomaterials

Loss of tooth structure to caries or other processes usually proceeds gradually. A patient's initial encounter with a dentist often involves the restoration of a small portion of tooth structure that is defective. This restoration can be accomplished relatively easily by designing a tooth preparation with retention features and restoring it with a pliable material that is capable of hardening in situ. While in a moldable stage, the material can be adapted to the tooth structure and shaped to recreate normal anatomic contours. This process is called *direct restorative dentistry* because it is accomplished directly in the intraoral environment. The development or selection of materials for direct application may require compromise of

mechanical properties or other desired characteristics. If extensive loss of tooth structure has occurred, the restorative materials must provide better stress distribution characteristics and be bonded more carefully to the remaining tooth structure. In most cases, this requires the use of materials that cannot be made fluid for direct use. These materials must be fabricated into a restoration outside of the mouth and cemented or bonded in place. The procedures involved with this approach are categorized as indirect restorative dentistry.

Amalgam Terminology

Amalgam technically means an alloy of mercury (Hg) with any other metal. Dental amalgam is an alloy made by mixing mercury with a silver–tin dental amalgam alloy (Ag–Sn). In dentistry, it is common to use the term *amalgam* to mean dental amalgam.

Amalgam alloy is a silver–tin alloy to which varying amounts of copper (Cu) and small amounts of zinc (Zn) have been added. Low-copper amalgam alloys contain 2% to 5% copper. The earliest successful amalgams were made by combining filings of such alloys with mercury. A typical modern low-copper amalgam alloy may contain 69.4% silver, 26.2% tin, 3.6% copper, and 0.8% zinc ([Online Table 18-3](#)). Amalgams made from such low-copper alloy filings are often referred to as *conventional amalgams*. High-copper amalgam alloys contain 12% to 30% copper, and because of their higher copper content, these alloys display significantly better corrosion resistance than do low-copper amalgams. A typical high-copper amalgam alloy may contain 60% silver, 27% tin, 13% copper, and 0% zinc (see [Online Table 18-3](#)). The particles of these alloys that are mixed with mercury may be filings, but they are often small spheres. Amalgam is mixed for use by combining amalgam alloy particles with mercury, vigorously mixing the components (trituration) for a few seconds during the initial reaction, placing the plastic mass into a tooth preparation, compressing the mixture (condensation) to remove the excess mercury-rich phase, and finally carving and finishing the hardening mass.

Because of concerns about the possible toxicity of mercury in amalgams, numerous materials have been developed as amalgam alternatives. Amalgam alternatives constitute any materials (e.g., composite, glass ionomer, cast gold alloys) that can be used to restore a tooth instead of using amalgam.⁵⁵ Amalgam substitutes (e.g., cast gold alloys) are materials generally considered to have equal or better properties compared with the amalgam restoration they replace. A few are compositions that contain some components of amalgam (e.g., Ag–Sn alloy particles), but do not contain mercury. Gallium alloys are an example of such a substitute made with silver–tin particles in gallium–indium (Ga–In).^{56–58} Gallium melts at 28°C and can be used to produce liquid alloys at room temperature by the addition of small amounts of other elements such as indium. In this case, gallium–indium has been substituted for mercury in amalgam. Other systems that use gold mixed with other noble metals to form the restoration matrix are being explored.⁵⁹

The American Dental Association (ADA), in association with the National Institute on Standards and Technology (NIST), patented a mercury-free direct-filling alloy based on

Online Table 18-3 Composition and Classification of Dental Amalgam Alloy Powders*

Amalgam Alloys	Classification	Particle Type	Ag	Sn	Cu	Zn	Hg	Other
New True Dentalloy	Low Copper	Lathe-Cut	70.8	25.8	2.4	1	0	—
Micro II	Low copper	Lathe-cut	70.1	21	8.6	0.3	0	—
Dispersalloy	High copper	Mixed	69.5	17.7	11.9	0.9	0	—
Tytin	High copper	Spherical	59.2	27.8	13	0	0	—
Sybralloy	High copper	Spherical	41.5	30.2	28.3	0	0	—
Cupralloy	High copper	Mixed	62.2	15.1	22.7	0	0	—
Aristalloy CR	High copper	Spherical	58.7	28.4	12.9	0	0	—
Indiloy	High copper	Lathe-cut	60.5	24	12.1	0	0	3.4 In (indium)
Valiant	High copper	Lathe-cut	49.5	30	20	0	0	0.5 Pd (palladium)
Valiant PhD	High copper	Mixed	52.7	29.7	17.4	0	0	0.5 Pd

*Elements in the composition are reported in weight percent.

Data from Osborne JW, et al: Clinical performance and physical properties of twelve amalgam alloys, *J Dent Res* 57:983–988, 1978; and Vrijhoef MMA, et al: *Dental amalgam*, Chicago, 1980, Quintessence.

mercury-coated silver–tin particles that can be self-welded by compaction (hand-consolidated) to create a restoration. This approach was proposed as an alternative to amalgam but has not made much progress toward commercialization. Other transitional approaches include redesigning amalgam to have much less initial mercury. If alloy particle sizes are judiciously chosen to pack together well, it is possible to minimize the mercury required for mixing to the 15% to 25% range. The actual clinical properties of these low-mercury amalgams are unknown.

Classification

The major approaches to the classification of amalgams are based in terms of (1) amalgam alloy particle geometry and size, (2) copper content, and (3) zinc content. Each of these is discussed subsequently in a historical context.

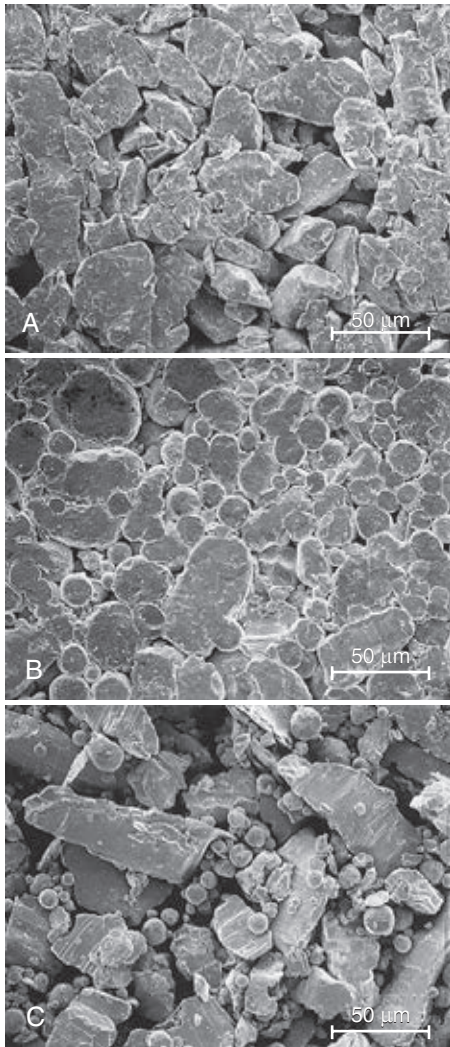
In the 1830s, an amalgam alloy was obtained by filing or grinding silver coins into coarse particles to mix with mercury. The compositions were inconsistent at best, and the reaction conditions were quite variable. This process could not reliably produce a final amalgam with uniform properties. During the 1860s and 1870s, Townsend, Flagg, and others made significant contributions to the investigation of composition versus properties. True amalgam science began, however, with investigations by Black during the 1890s. Traditional (or conventional) amalgam alloys were produced by early dental manufacturers such as S.S. White and predominated from 1900 until 1970. The basic composition was 65% silver, 30% tin, 5% copper, and less than 1% zinc.

Traditional amalgam was mixed initially by proportioning alloy and mercury components into a mortar and then grinding the mixture with a pestle. The process of manual mixing is known as *trituration*. The alloy was manufactured in bricks that were ground with a file into filings and mixed with mercury. A more efficient process involved grinding up the ingot of the alloy, typically on a lathe. For that reason, those particles became known as *lathe-cut particles* (Online Fig. 18-21). The filings were irregular in shape and gradually were produced in progressively finer sizes by manufacturers to

control the reaction, produce smoother mixtures, and enhance final properties. Lathe-cut particles could be purchased in regular-cut, fine-cut, and microfine-cut versions. Conventional amalgam alloys, thus, were commonly classified on the basis of particle size.

Irregular powder particles pack together relatively poorly (see Online Fig. 18-21, A) and require a relatively large amount of mercury (50%–60% by weight in the mixture) to fill in the spaces. After transfer of the mixture to the tooth preparation, it is possible to compact the mass and extrude some of the mercury-rich matrix. By eliminating the mercury-rich matrix as much as possible, the amount of reaction product matrix that forms is limited, improving the overall properties of the set amalgam. Mercury-rich mixtures, after trituration but before placement into the preparation, historically could be partially condensed by wringing the mass in a squeeze cloth. In the 1960s, Eames was the first to promote a low mercury-to-alloy mixing ratio (*Eames technique* or *no-squeeze-cloth technique*).⁶⁰ Later, it was shown that by spheroidizing the alloy particles, the particles could be packed more efficiently (see Online Fig. 18-21, B) and required much less mercury to make a practical mixture.⁶¹ Spherical particles also increased the fluidity of the mixture by presenting less resistance to particle sliding. Using some or all spherical alloy particles, it is possible to reduce the mercury portion of the mixture to less than 50% by weight. The distinction between irregular (lathe-cut) and spherical particle geometries became the next major basis for the classification of amalgam alloys. Most modern precapsulated amalgams are formulated with only 42% to 45% mercury by weight.

During the early part of the twentieth century, alloy powder and mercury were proportioned crudely and mixed manually (Online Fig. 18-22, A). To proportion and mix amalgam more carefully, manufacturers later recommended the use of alloy pellets, mercury dispensers, reusable mixing capsules and pestles, and amalgamators (see Online Fig. 18-22, B). A typical reusable capsule (Online Fig. 18-23, A) was a hollow tube with rounded ends constructed as two pieces that could be friction-fit or screwed together. Amalgam alloy was dispensed into the capsule as a pellet of pressed powder of standard weight.

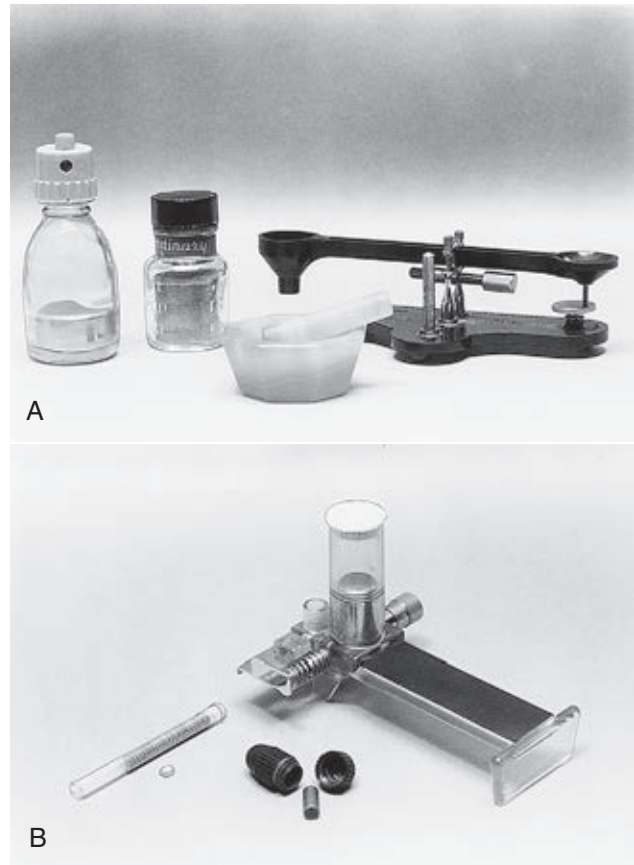


Online Fig. 18-21 Examples of amalgam alloy powder particles. **A**, Filings (New True Dentalloy). **B**, Spheres (Cupralloy). **C**, Mixed geometries (Dispersalloy). (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)

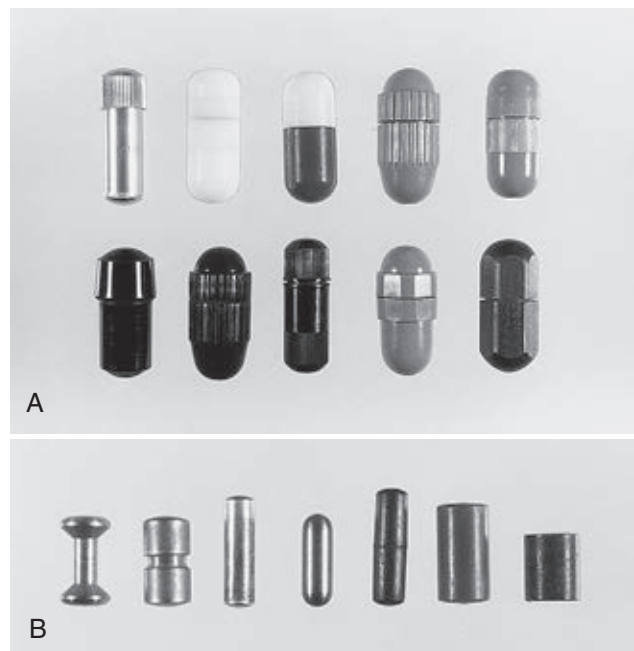
Mercury was dispensed into the capsule as a standard-sized droplet from an automatic dropper bottle. A small metal or plastic pestle (see [Online Fig. 18-23, B](#)) was added to the capsule, and it was closed. The capsule and its contents were automatically mixed using an amalgamator. The typical amalgamator has been designed to grasp the ends of the capsule in a claw that is oscillated in a figure-of-eight pattern. This design accelerates the mixture toward each end of the capsule during each throw and impacts the mixture with the pestle.

To guarantee that the amalgam alloy and mercury are mixed efficiently and consistently, it is important to calibrate amalgamators periodically. After several years of use, the bearings become worn, and the mixes no longer are sufficiently triturated. On standard electrical amalgamators, the trituration speed and trituration time are manually set on the front of the equipment. Settings vary for different products. Electronic amalgamators ([Online Fig. 18-24](#)) have digital controls and permit programming of settings.

Modern amalgams are produced from precapsulated alloy and mercury. The components are separated in the capsule by



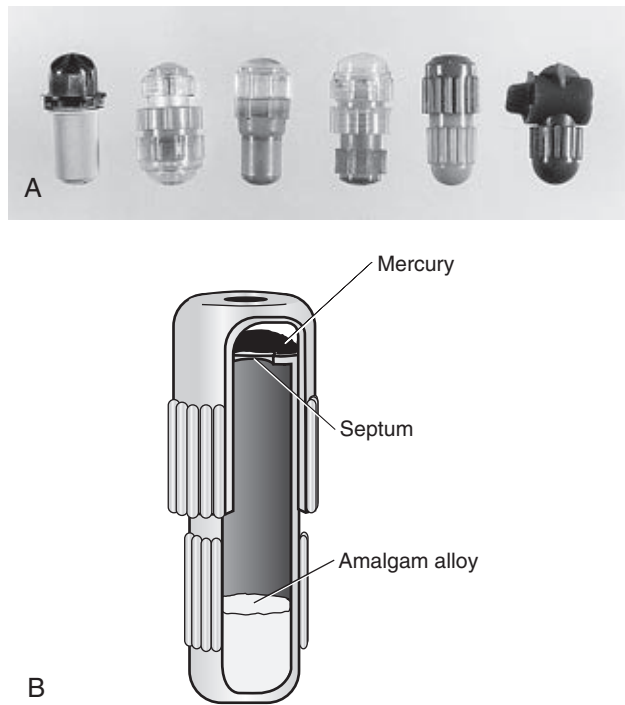
Online Fig. 18-22 Earlier methods of dental trituration. **A**, Equipment for hand mixing of alloy powder and mercury in mortar and pestle using excess mercury (circa 1900–1940). **B**, Equipment for mixing of alloy pellets and controlled mercury in reusable capsules with mechanical mixing in amalgamator (circa 1940–1970).



Online Fig. 18-23 Capsules and pestles for automatically mixing amalgam constituents using an amalgamator. **A**, Reusable capsules. **B**, Magnified view of pestles.



Online Fig. 18-24 Examples of dental amalgamator for automatically mixing amalgam in capsules. (Courtesy of Dentsply International, York, PA.)



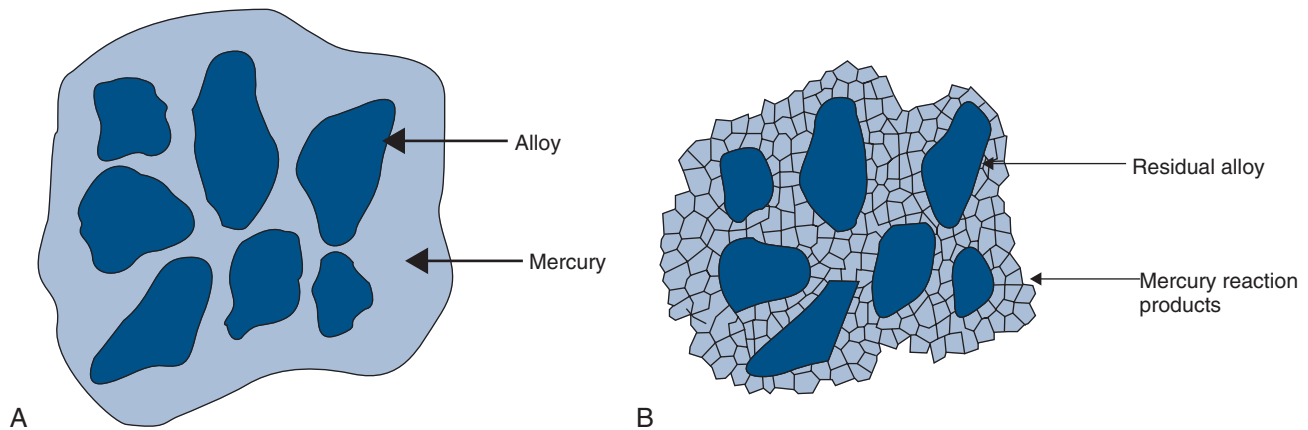
Online Fig. 18-25 Pre-proportioned alloy and mercury in prepackaged capsules (“precapsulated”) for mixing amalgam constituents using an amalgamator. **A**, Examples of pre-proportioned capsule designs. **B**, Schematic of pre-proportioned capsule showing mercury and powder separated by the septum that must be perforated before mixing. (**A**, From Rinne VW: Aluminum foil pouch packaging in pre-measured amalgam capsules, *J Dent Res* 62:116–117, 1983. **B**, From Daniel SJ, Harfst SA, Wilder RS: *Mosby’s dental hygiene: Concepts, cases, and competencies*, ed 2, St. Louis, Mosby, 2008.)

a special diaphragm that is broken when the capsule is “activated” just before mixing (Online Fig. 18-25). Precapsulated (pre-proportioned) amalgam (see Online Fig. 18-25, A) provides convenience and some degree of assurance that the materials will not be contaminated before use or spilled before mixing. Mercury hygiene is an important consideration for safe amalgam management and is discussed later in this section.

During the 1960s, major research emphasis was placed on the benefits of increased copper contents in amalgams. It was

confirmed that increasing the copper content greater than 12% by weight in the amalgam alloy effectively suppressed formation of the phase (Sn-Hg), which was prone to intraoral corrosion. A dramatic improvement in corrosion resistance led to a doubling or tripling of clinical longevity of these amalgams. Flagg originally explored the effect of copper in the 1860s, but the copper was not effectively prealloyed with silver, tin, or both. The effect was not shown. In the 1930s, Gayler investigated the effect of copper and found that in the coarse filing alloys of that time, copper contents greater than 6% produced excessive expansion, and the corrosion-reducing effect at higher copper contents was not realized. Also in the 1930s, early pioneers were admixing copper amalgams with amalgams to produce corrosion-resistant compositions. The setting times of the mixtures were slow, however, and the compositions varied. It was not until Innes and Youdelis added silver–copper spheres to the conventional amalgam alloy, with the intent of producing dispersion-hardened amalgams, that the advantageous effect of copper on corrosion resistance was clearly observed.⁶² Classification of amalgams based on copper content is the main system in use today (see Online Table 18-3). High-copper amalgams can be produced from amalgam alloy particles that are irregular or spherical.

Another important additive to amalgam alloy is zinc. Originally, zinc was added to conventional amalgams as a processing aid to suppress oxidation of the key elements in the alloy. Zinc tends to oxidize preferentially, forming a zinc oxide film that covers the surface of liquid alloy during manufacture and suppresses oxidation of other elements. Generally, 1% or more is added to accomplish this end. Some (0.2%–1%) is, however, left in the amalgam alloy at the end. A detrimental side effect of this residual zinc was that moisture contamination before setting converted the zinc to zinc oxide and produced hydrogen gas that could expand the amalgam excessively, causing pain to the patient. When the mechanism of delayed expansion was understood, care exercised during amalgam manipulation prevented this problem. Some manufacturers also produced non-zinc amalgams as an alternative. These alloys often were favored in cases in which isolation was difficult. It now seems as though zinc may have some beneficial effect on amalgam longevity. Clinical research evidence supports that zinc-containing, low-copper and high-copper amalgams may last 20% to 50% longer than do zinc-free amalgams.⁶³⁻⁶⁵ On the basis of this new evidence, amalgams continue to be



Online Fig. 18-26 Schematic summary of setting reaction of amalgam and its associated microstructure. **A**, Before reaction, alloy particles are dispersed in mercury. **B**, After reaction, residual alloy particles are embedded in a matrix of crystalline reaction products. Only a small percentage of individual powder particles is required to react completely with mercury. (Modified from Bayne SC, Barton RE: *Dental materials for direct restorations*. In Richardson RE, Barton RE, editors: *The dental assistant*, ed 6, Philadelphia, 1988, Lea & Febiger.)

produced and designated as zinc (zinc-containing) or non-zinc (zinc-free), although improved manufacturing techniques have largely eliminated the original need for zinc as a manufacturing aid.

Composition, Structure, and Properties

Examples of compositions and structure of amalgams of all types are summarized in [Online Table 18-3](#). The principal considerations for any amalgam are the amount of mercury in the final restoration and the types of reaction products formed. Conventional amalgam sets by the reaction of silver–tin from silver–tin particles with mercury to produce two reaction product phases: (1) the silver–tin phase and (2) the tin–mercury phase. These form solids and cause the mass to harden. The metallurgic reaction is complicated and is influenced by several variables. Schematically, the reaction is summarized in a simple way in [Online Figure 18-26](#). Because the original mixture contains a large excess of silver–tin alloy particles, only a minor portion of the outside of the particles is consumed during the reaction with mercury. The unreacted portion of the original amalgam alloy particles remains as residual alloy particles, reinforcing the final structure. Reaction products form a matrix surrounding the residual alloy particles. Because the residual alloy particles have physical, chemical, and mechanical properties that are significantly better than those of the reaction products, it is important to minimize the amount of matrix that forms during the reaction. Depending on the geometry and packing of the amalgam alloy particles, different amounts of mercury are required initially to create a condensable mixture. After the reaction begins and the amalgam has been placed into the tooth preparation, it is important to compress (condense) the mixture to reduce voids in the material, adapt it closely to the tooth preparation walls, and express excess mercury-rich matrix. The mercury-rich matrix is removed from the surfaces of condensed material in increments. This process ensures that the final structure is composed predominantly of reinforcing residual alloy within a minimum of reaction product matrix; this is illustrated in [Online Figure 18-27](#). The matrix phase of a well-condensed spherical dental amalgam is seen as a

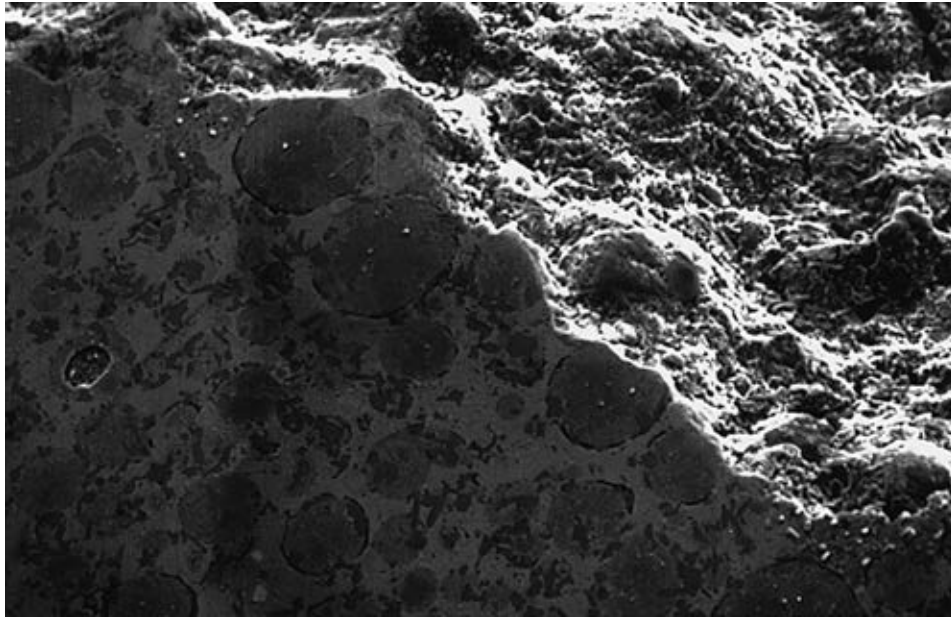
polished cross-section. The fractured surface can be seen only propagating through the matrix phase while following a tortuous path around the strong residual spherical alloy particles.

The major reaction product phases of silver–mercury and tin–mercury (approximately Ag_2Hg_3 and Sn_{7-8}Hg) are non-stoichiometric. In metallurgic terminology, the original alloy is designated as *gamma phase* (γ), and the reaction product phases are called *gamma-one* (γ_1) and *gamma-two* (γ_2).

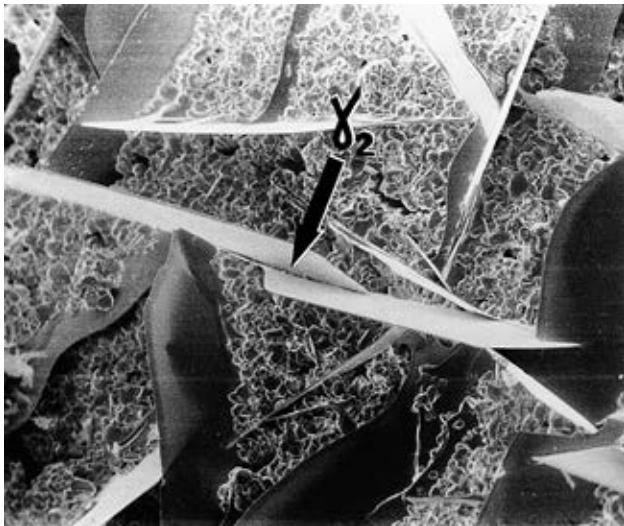
The silver–mercury (γ_1) crystals are generally small and equiaxed. Most of the matrix is silver–mercury. That phase has intermediate corrosion resistance. Tin–mercury (γ_2) reaction product crystals are long and blade-like, penetrating throughout the matrix. Although they constitute less than 10% of the final composition, they form a penetrating matrix because of intercrystalline contacts between the blades. That image is reinforced by the scanning electron microscopy picture of tin–mercury crystals in [Online Figure 18-28](#). This phase is prone to corrosion in clinical restorations, a process that proceeds from the outside of the amalgam, along the crystals, connecting to new crystals at intercrystalline contacts. This process produces penetrating corrosion that generates a porous and spongy amalgam with minimal mechanical resistance. Two key features of this degradation process are (1) the corrosion-prone character of the tin–mercury phase and (2) the connecting path formed by the blade-like geometry of the crystals. Both these are eliminated by the use of more copper in the initial composition.

High-copper amalgams set in a manner similar to low-copper amalgams except that tin–mercury reactions are suppressed by the preferential formation of copper–tin phases instead. Copper–tin phases that are part of the set amalgam matrix are much less corrosion-prone than are the tin–mercury phases they replace. The copper–tin phases are still the most corrosion-prone ones in amalgam. When they corrode, however, penetrating corrosion does not occur because individual crystals generally are not connected.

Low-copper and high-copper amalgams undergo two kinds of corrosion—chemical corrosion and electrochemical corrosion ([Online Fig. 18-29](#) and [Online Table 18-4](#)). Chemical corrosion occurs most notably on the occlusal surface and produces a black film of silver–sulfur (Ag-S) tarnish ([Online](#)



Online Fig. 18-27 Picture of Tytin restoration fracture surface and polished cross-section shows that fatigue failure crack proceeds through the matrix phase and around the stronger residual alloy particle phase. Greater condensation during placement reduces the amount of matrix, making the path for fatigue crack propagation more tortuous during clinical service and prolonging the service life of the restoration. (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)



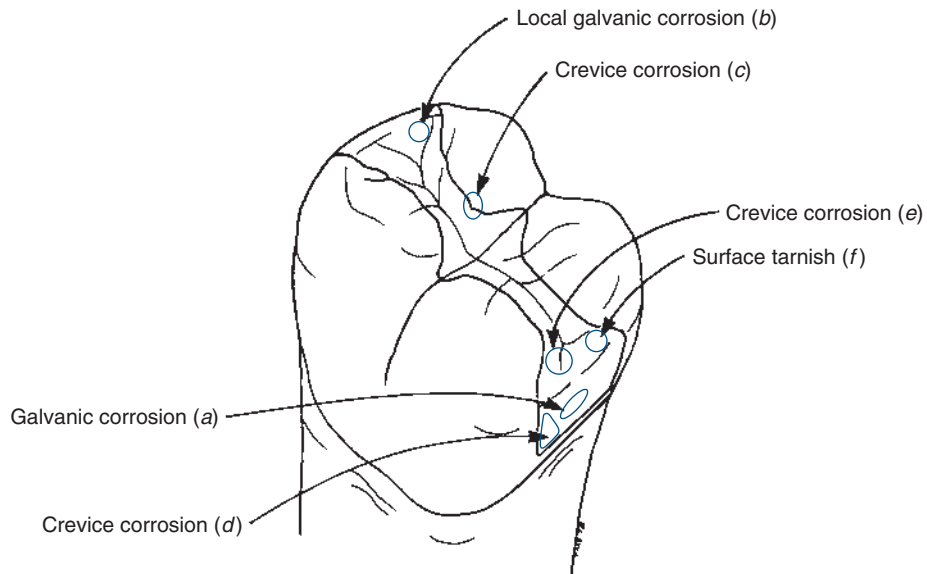
Online Fig. 18-28 Scanning electron microscopy view of tin-mercury (Sn-Hg) (g₂) crystals that occur in a matrix of set low-copper amalgams. Note the blade-like crystals that penetrate amalgam and touch each other to create a continuous matrix (arrow). (Courtesy of D.F. Taylor, School of Dentistry, University of North Carolina, Chapel Hill, NC.)

Fig. 18-30). This reaction is limited to the surface and does not compromise any properties except for esthetics. Amalgams with very high levels of copper also are capable of producing a copper oxide patina, but that is uncommon. Electrochemical corrosion is an important mechanism of amalgam corrosion and has the potential to occur virtually anywhere on or within a set amalgam. Electrochemical corrosion occurs whenever chemically different sites act as anode and cathode (see the

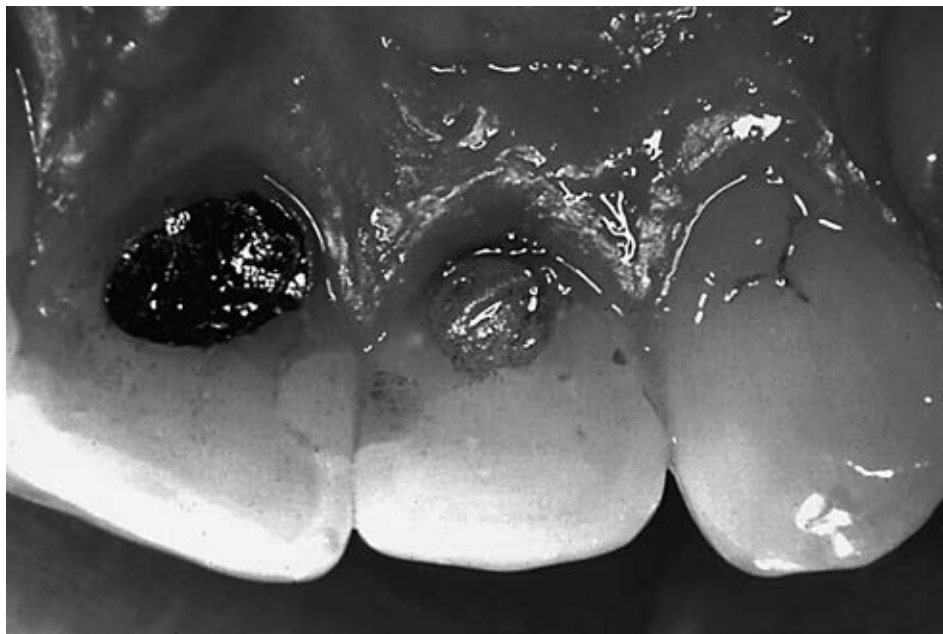
Online Table 18-4 Examples of Intraoral Situations for Which Electrochemical and Chemical Corrosion Would Occur

HIGH RISK	
Class I dental amalgam	Local galvanic corrosion between amalgam phases along all surfaces of amalgam Stress corrosion during occlusion with opposing tooth surfaces Concentration cell corrosion within margins with tooth structure Concentration cell corrosion below plaque on amalgam (causing pitting)
Class II dental amalgam	Same as for class I amalgam Corrosion at interproximal contacts with adjacent metal crowns
Class III dental amalgams	Same as for class I amalgam
LOWER RISK	
Noble metal casting alloys for inlays, onlays, crowns, bridges, and PFM alloys	Local galvanic corrosion between phases on multi-phase alloys Stress corrosion during occlusion with opposing tooth surfaces Concentration cell corrosion at margins with dental cement or tooth structure Concentration cell corrosion below plaque formed on surfaces
Non-noble PFM alloys and dental implants	Fretting corrosion where abrasion or rubbing continually removes protective passivating oxide film

PFM, porcelain-fused-to-metal.



Online Fig. 18-29 Examples of sites susceptible to electrochemical and chemical corrosion on amalgams: galvanic corrosion (a) at interproximal contact with metallic restoration, such as gold casting alloy; local galvanic corrosion (b) on occlusal surface at grain boundaries between different metallic phases; crevice corrosion (c) at margin owing to lower pH and oxygen concentration of saliva; crevice corrosion (d) under retained interproximal plaque owing to lower local pH; crevice corrosion (e) within unpolished scratches or detailed secondary anatomy; chemical corrosion of occlusal surface with sulfide ions in saliva, producing surface tarnish (f).



Online Fig. 18-30 Clinical example of tarnished occlusal surface of amalgam restoration. (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)

section on chemical properties). This corrosion requires that the sites be connected by an electrical circuit in the presence of an electrolyte, typically saliva. The anode corrodes, producing soluble and insoluble reaction products.

If an amalgam is in direct contact with an adjacent metallic restoration such as a gold crown, the amalgam is the anode in the circuit. This type of electrochemical corrosion is called *galvanic corrosion* and is associated with the presence of

macroscopically different electrode sites. The same process may occur microscopically (local galvanic corrosion or structure-selective corrosion) because of the electrochemical differences of different phases. Residual amalgam alloy particles act as the strongest cathodes. Tin–mercury or copper–tin reaction product phases are the strongest anodes in low-copper and high-copper amalgams. Local electrochemical cells also may arise whenever a portion of the amalgam is

covered by plaque or soft tissue. The covered area has a locally lowered oxygen or higher hydrogen ion concentration, making it behave more anodically and corrode. Cracks and crevices produce similar conditions and preferentially corrode (concentration cell corrosion or crevice corrosion). Regions within an amalgam that are under stress also display a greater propensity for corrosion (stress corrosion).

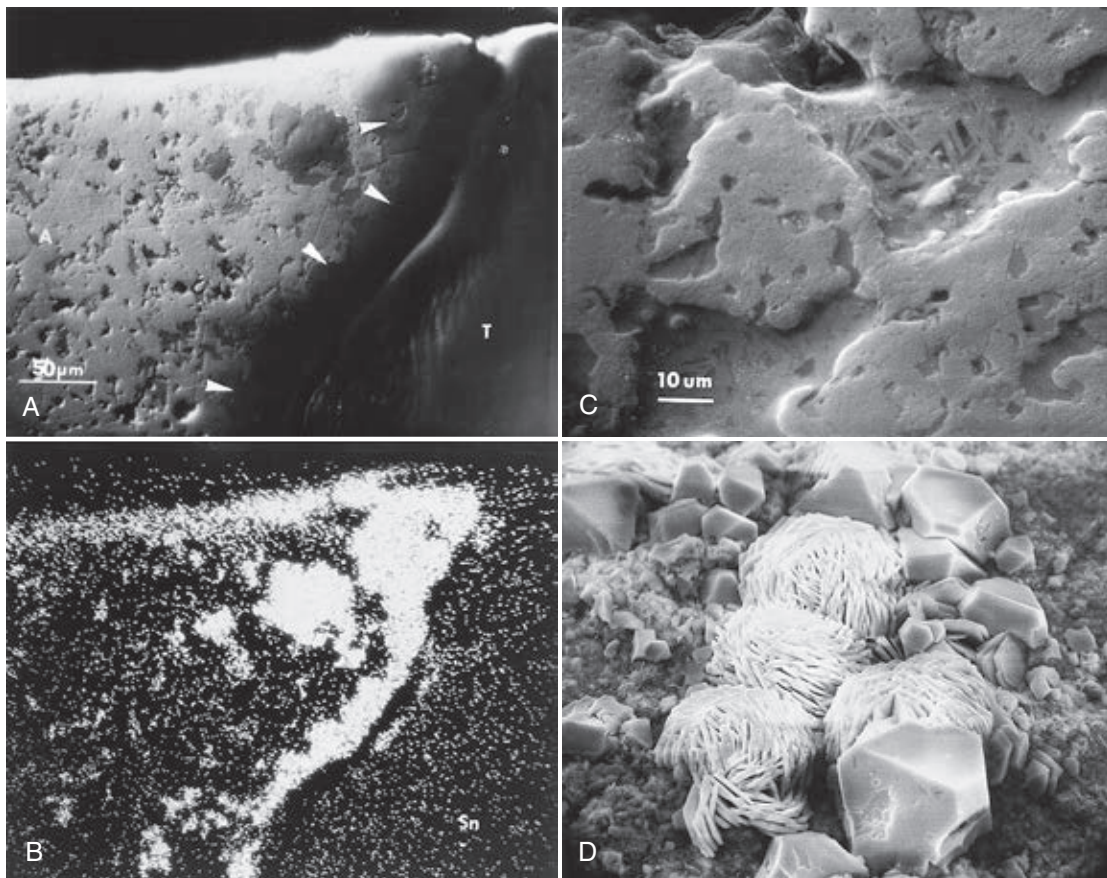
For an occlusal amalgam, the greatest combination of corrosion and mechanical stresses occurs along the margins. Most visible changes are associated with the margins. These are discussed below in detail.

During electrochemical corrosion of low-copper amalgams, the tin–mercury phase is oxidized into tin–oxygen (Sn–O), Sn–O–Cl (tin–oxygen–chlorine), or both.^{63,64} The oxychloride species is soluble. The oxide precipitates as crystals and tends to fill up the spaces occupied by the original tin–mercury phase. Along the margins of the amalgam, tin–oxygen helps seal the space against microleakage (Online Fig. 18-31). Amalgam has a linear coefficient of thermal expansion that is 2.5 times greater than the tooth structure, and it does not bond to the tooth structure (unless an amalgam bonding agent is used). During expansion and contraction, percolation could otherwise occur along the external walls (see Online Fig.

18-6) if corrosion products did not impede fluid ingress and egress along the margins.

Electrochemical corrosion of tin–mercury does not seem to release free mercury into the oral environment. Rather, mercury immediately reacts with locally available silver and tin from residual amalgam alloy particles and is reconsumed to form more reaction products. Electrochemical corrosion of copper–tin in high-copper amalgams produces copper and tin oxides and oxychlorides, but no mercury is involved in the process. Electrochemical corrosion is not a mechanism of mercury liberation from set amalgam.

The principal mechanical properties of amalgam (Online Table 18-5) include values for compressive strength, tensile strength, and creep. The compressive strengths of high-copper amalgams are greater than the strengths of low-copper amalgams because of the presence of the copper phases. High-copper amalgams have compressive strengths that range from 380 to 550 MPa (55,000–80,000 psi) and are similar to those of enamel and dentin. Dental manufacturers do not place much emphasis on increasing these values. Tensile strength is important for fracture resistance. Low-copper and high-copper amalgams have low tensile strengths, but high-copper amalgam is lower overall. This information is important



Online Fig. 18-31 Marginal sealing by corrosion products. **A**, Scanning electron microscopy cross-sectional view of tin–oxide (Sn–O) corrosion products sealing the amalgam (A) margin along the enamel wall (T). **B**, Elemental map of tin showing high concentration of tin (see large white areas) within amalgam near the interface with the tooth. **C**, Densely packed tin–chlorine (Sn–Cl) crystals within pores of retrieved conventional amalgam restoration. **D**, Sn–O polyhedra and Sn–O–Cl brush-heap crystals on amalgam surface after corrosion. (**A** and **B**, From Port RM, Marshall GW: Characteristics of amalgam restorations with variable clinical appearance, *J Am Dent Assoc* 110:491–495, 1985; **C**, From Marshall SJ, Marshall GW, Jr.: Sn4(OH)6Cl2 and SnO corrosion products on amalgams, *J Dent Res* 59:820–823, 1980; **D**, From Marshall GW, et al: Detection of oxygen in corrosion products of dental amalgam, *J Dent Res* 54:904, 1975.)

Online Table 18-5 Mechanical Properties Typical of Set Dental Amalgams

Amalgam Alloys	Classification	Particle Type	Compressive Strength (megapascal; MPa)			Tensile Strength (MPa)			Creep (%)
			15 min	1 hr	24 hr	15 min	1 hr	24 hr	24 hr
Velvalloy	Low copper	Lathe-cut	37	120	388	4	13	62	1.1
Spheraloy	Low copper	Spherical	40	126	392	3	11	61	1.5
Optalloy II	Low copper	Mixed	62	164	386	7	16	50	1.6
Dispersalloy	High copper	Mixed	43	154	413	4	12	48	0.25
Indiloy	High copper	Spherical	32	181	445	3	17	45	0.22
Sybralloy	High copper	Spherical	164	345	501	15	32	46	0.05
Tytin	High copper	Spherical	70	281	545	7	26	64	0.1

From Osborne JW, et al: Clinical performance and physical properties of twelve amalgam alloys, *J Dent Res* 57:983–988, 1978.

because it is likely that most intraoral loading conditions produce tensile stresses along the occlusal surface and at the margins. During direct contact with the opposing teeth, cusps and amalgam restorations are stretched laterally, producing tension and perhaps flexion (see Online Fig. 18-10). Amalgams that are corroded or have inadequate bulk to distribute stresses may fracture. At margins, where amalgams are thinner, extrusion may have occurred, and corrosion may have compromised the integrity of amalgam, fracture is even more likely.

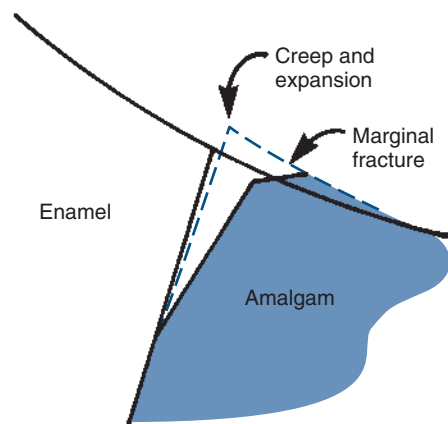
Amalgam generally is considered a brittle material. It is not capable of much plastic deformation before fracture when subjected to stress at moderate-to-high strain rates, such as during vigorous chewing. Traumatic stresses during chewing can produce fracture in an amalgam without sufficient bulk. In contrast, at slow strain rates, such as expansion caused by phase changes or corrosion, amalgam (particularly low-copper amalgam) is capable of clinically significant plastic deformation (creep), even though the stresses are well below the elastic limit.

Amalgam creep is plastic deformation principally resulting from slow metallurgical phase transformations that involve diffusion-controlled reactions and produce volume increases. The associated expansion makes amalgam protrude from the tooth preparation. Such secondary expansion can occur throughout the clinical life of a restoration. On nonocclusal surfaces, the entire amalgam restoration may appear extruded (Online Fig. 18-32), and this can produce esthetics-related problems or overhangs in some areas. On occlusal surfaces, abrasion and attrition tend to limit the overall extrusion. Occlusal margins become fracture-susceptible ledges elevated above the natural contours of the adjacent enamel (Online Fig. 18-33). Extrusion at margins is promoted by electrochemical corrosion, during which mercury from tin–mercury re-reacts with silver–tin particles and produces further expansion during the new reaction. This mechanism, called *mercuroscopic expansion*, originally was proposed by Jorgensen as an explanation for the prevalence of marginal fracture associated with occlusal amalgams.⁶⁶ The most common evidence of degradation of low-copper amalgams is marginal fracture.

Combinations of brittleness, low tensile strength, and electrochemical corrosion make occlusal amalgam susceptible to marginal fracture. Then, at some point, occlusal stress during contact with the opposing teeth causes local fractures that produce a ditch along the margin. Progression of the events



Online Fig. 18-32 Clinical photograph of Class V amalgam restoration being extruded by mercuroscopic expansion.



Online Fig. 18-33 Schematic view of Class I amalgam restoration that was extruded by mercuroscopic expansion, underwent marginal fracture, and now contains marginal ditch. (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)

to deeper or more extensive ditching has been used as visible clinical evidence of conventional amalgam deterioration (Online Fig. 18-34) and was the basis of the Mahler scale (Online Fig. 18-35).^{67,68} Mahler ratings were established from No. 1 to No. 11 by comparing the image of the clinical

restoration of interest to a series of five photographs (scale values of No. 2, No. 4, No. 6, No. 8, and No. 10) representing increasingly worse marginal breakdown. The rest of the rating scale deals with the severity of marginal ditching that is less than (No. 1), intermediate with (No. 3, No. 5, No. 7, and No. 9), or greater than (No. 11) the main scale images.

The impression of extensive (progressive) marginal fracture (to Mahler values of 4–11) for low-copper amalgams has been translated as a reason for clinical intervention and replacement with high-copper amalgams. High-copper amalgams also undergo marginal fracture. Despite early ditching, however, they do not progress to levels of extensive ditching that would place them at high risk for secondary caries. Instead, high-copper amalgams display only modest marginal fracture (Mahler values of 3–5) over long periods. Excellent clinical research evidence substantiates clinical half-lives for well-placed high-copper amalgam restorations of 24 to 25 years (which is addressed later in the section on clinical considerations).

High-copper amalgams that are left in place may fail eventually because of bulk fracture. It is hypothesized that such bulk fracture is the result of mechanical fatigue. A rule of thumb for clinical service is that occlusal restorations are stressed an average of one million times per year. A 25-year service life would correspond to 25 million cycles of

mechanical stress. Typically, materials fail in the 10- to 100-million-cycle range during laboratory testing. The events contributing to mechanical fatigue affect the restoration and the tooth structure. The stresses and strains in both must be considered together, particularly in the case of restorations bonded to the tooth structure.

Mercury Management

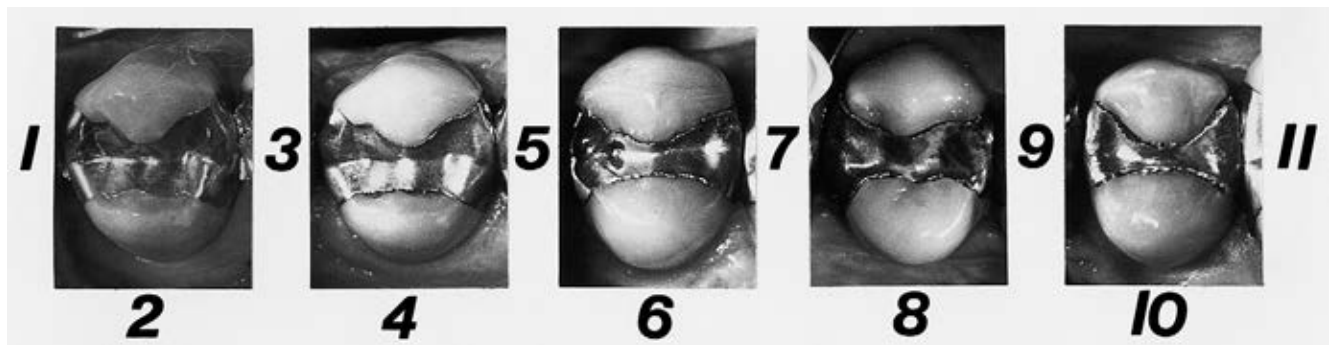
Similar to all other materials in the world, mercury has the potential to be hazardous if not managed properly. It is crucial that the alloying reaction of mercury with the silver–tin alloy go to completion to ensure that mercury does not diffuse into the oral environment. When the reaction is complete, only extremely minute levels of mercury can be released, and those are far below the current health standard. Mercury is ubiquitous in the environment and is taken into the body in one form or another via water, air, and food on a daily basis.

The contribution of mercury derived from amalgam to the overall body burden, which has been the source of much controversy, seems to be relatively low. The important perspective is that mercury enters the body every day, no matter what restorative filling materials are present in the mouth. Under normal circumstances, mercury is biochemically processed and excreted. As long as the levels are low, mercury toxicity is not a risk. Although poorly understood, mercury hypersensitivity at times has been claimed as a potential hazard. This is an immune system response to very low levels of mercury. The number of individuals identified as potentially hypersensitive is extremely low, however, and the sensitivity reaction is mild and not life threatening. Mackert et al and Mandel reviewed these issues in detail and scientifically refuted the hypothesized problems.⁶⁹⁻⁷¹

Early claims of mercury-related problems appeared as soon as amalgams were first used in the United States. The original amalgamation process was demonstrated by a chemist in France.⁷² In 1833, two English entrepreneurs, the Crawcour brothers, realized the practical importance of the process for dentistry, carried the idea to New York, and promoted the material as an inexpensive and convenient restoration.⁷³ No attention was given, however, to the proper mercury-to-alloy ratios or the type of alloy used. For the most part, the alloy mixed with the mercury was prepared by filing silver coins with considerably variable compositions. In many cases, the inconsistency in materials and techniques led to slow-setting



Online Fig. 18-34 Occlusal amalgam restoration with extensive marginal deterioration. (Courtesy of A.D. Wilder, School of Dentistry, University of North Carolina, Chapel Hill, NC.)



Online Fig. 18-35 Mahler scale showing visual levels of marginal deterioration (rating 1 = none, rating 11 = extensive). The numbers of the scale indicate ratings assigned to the restoration’s appearance based on comparison of an existing restoration to scale. (Courtesy of D.B. Mahler, School of Dentistry, Oregon Health Sciences Center, Portland, OR.)

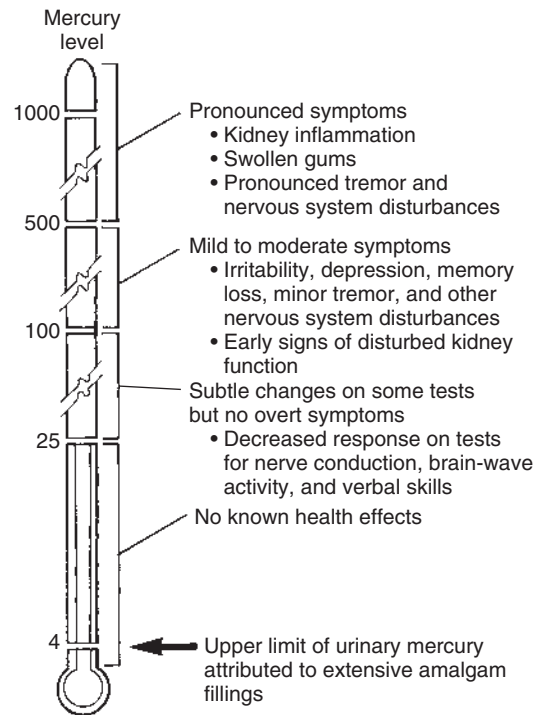
amalgams that released mercury from the unset mass into unprotected dentinal tubules. Although no cases of patient deaths have been reported, several cases of pulp death did occur.

A complex battle ensued (the so-called First Amalgam War) between dentists using traditional restorative techniques based on gold foil and those using techniques involving amalgam. The dispute was based on philosophical choices as to dental standards and differences in points of view about the safety of amalgam. Periodically, the elimination of amalgam use was called for because of potentially harmful mercury release. In the 1920s, another series of challenges to amalgam use occurred when it was inferred that mercury was not tightly bound in amalgams.⁷⁴ The next serious controversy arose in 1980, when Huggins publicly condemned amalgam. Huggins, a practicing dentist in Colorado, was convinced that mercury released from amalgam was responsible for a plethora of human diseases affecting the cardiovascular and nervous systems. Patients claimed recoveries from multiple sclerosis, Alzheimer's disease, and other afflictions as a result of removing their amalgam fillings. For almost a decade, a loyal following of patients and dentists sounded the call to ban amalgam. Research in the United States and other developed countries has since shown clearly that these claims do not have any solid grounds.

In 1991, the general American public was widely exposed to the controversy when it was reported by a major television program (*60 Minutes*). In response to numerous public questions, the dental profession, the National Institute for Dental and Craniofacial Research (NIDCR), the U.S. Food and Drug Administration (FDA), and several other groups held forums of world-famous scientists and clinicians to re-examine the issue.⁷⁵ Although these experts agreed that more research on amalgam was needed on an ongoing basis, they concluded that the claims that amalgam was a significant health hazard were not justified.⁷⁵ They strictly recommended that amalgams not be removed for that reason. The controversy, however, remains unresolved. Claims of hazards continue to be published in local papers, nonscientific journals, and occasionally even in scientific journals.^{23,76-79} All published research shows clearly, however, that no cause-and-effect relationship exists between amalgam restorations and other health problems.⁸⁰ This controversy probably will never be resolved because a certain percentage of patients will always seek a miracle cure for their problems. Fears of amalgam are not a basis for amalgam removal.⁸¹

Understanding the issues related to amalgam use has been a challenging problem for dental patients. The issues are complex, and dealing with them requires some knowledge of physical chemistry and biochemical processes. It is unrealistic to think that a general dentist has the time to communicate this information effectively to patients. In addition, most patients perceive dentists as having a vested interest in the decision to use amalgam. Clearly, the public wants to know. Clear, concise reviews of the controversy have been published by reputable consumer affairs groups (Online Fig. 18-36).^{82,83}

The health risk from amalgam use is clearly greater for members of the dental office team than for a patient. Historically, a major, although rare, source of mercury contamination in dental offices was the accidental spillage of quantities of liquid mercury. Mercury was commonly purchased in bottles containing approximately 1 lb. This mercury was transferred to dispensers and eventually to individual capsules for mixing,



Online Fig. 18-36 Mercury thermometer portraying different levels of mercury toxicity. Chronic exposure can be assessed by urinary mercury concentration (as micrograms of mercury per gram of creatinine). (From *The Mercury in Your Mouth*, © 1991, by Consumers Union of U.S., Inc, Yonkers, NY 10703-1057, a nonprofit organization. Reprinted with permission from the May 1991 issue of *Consumer Reports*, for educational purposes only. No commercial use or photocopying permitted. To subscribe, call 1-800-234-1645 or visit at www.consumerreports.org.)

Online Table 18-6 Absorption Efficiency of Mercury*

	Skin	Lungs	Gastrointestinal Tract
Elemental	—	80%	0.01%
Inorganic	—	80%	7%
Organic	—	—	95–98%

*Efficiency is reported in percentage per exposure. No information is reported for some routes (e.g., skin) because the values are suspected to be very low and are not yet well established.

Mishandling at any stage could result in mercury splashing on the bench or floor, causing it to be scattered widely as small droplets. The current use of precapsulated amalgam has mostly eliminated any chance of a major spill, but care must be exercised to avoid all hazards in the routine use of amalgam. Careful review of amalgam-handling procedures reveals that the critical times are when metallic mercury exists in liquid or vapor form, rather than bound in a set amalgam. As a vapor, metallic mercury can be inhaled and absorbed through the alveoli in the lungs at 80% efficiency. Inhalation is the major route of entry into the human body. Metallic mercury is poorly absorbed through the skin or via the gastrointestinal tract.⁸⁴ Online Table 18-6 presents a summary of the routes of absorption.

In addition to metallic mercury, inorganic and organic mercury compounds are potentially toxic. Mercury is normally mined as an inorganic sulfide (cinnabar) ore, which is heated in air to oxidize and drive off the sulfur.⁸⁵ Mercury is then collected as a liquid. Mercury can exist in a wide variety of inorganic compounds, in addition to sulfide. Many of them are water soluble and release mercury ions into solution. Some of these compounds have been used in the past as medications. Such materials are poorly absorbed through the lungs but are easily absorbed in the gastrointestinal tract.

Mercury also can form organic compounds such as methyl mercury. These mercury compounds are readily absorbed by many organisms and concentrated as they are passed up the food chain. The concentration of naturally derived mercury in food is aggravated at times by the use of fungicides and pesticides containing methyl mercury. For most people, organically bound mercury in food is the primary source of mercury exposure. Humans absorb methyl mercury from food readily but excrete it less effectively than they do other forms of mercury. After absorption, mercury has a tendency to concentrate in certain organs such as the liver, kidney, and brain. Methyl mercury is eventually excreted completely, but the rate depends on the body's ability to convert it to other forms. It has been suggested that metallic mercury can be changed into methyl mercury by microorganisms in either the mouth or the gastrointestinal tract. Careful examination of mercury concentrations in blood indicates, however, that no biotransformation seems to occur.⁸⁶

In the dental office, the sources of mercury exposure related to amalgam include (1) amalgam raw materials being stored for use (usually as precapsulated packages); (2) mixed but unhardened amalgam during trituration, insertion, and intraoral hardening; (3) amalgam scrap that has insufficient alloy to consume the mercury present completely; (4) amalgam undergoing finishing and polishing operations; and (5) amalgam restorations being removed. Each of these is considered in more detail in the following paragraphs. Specific recommendations by the ADA have been revised and are summarized in [Online Box 18-1](#).⁸⁷⁻⁸⁹ In addition, the ADA and local dental societies have developed best management practices for the management of all hazardous materials (e.g., amalgam, chemiclave wastes, silver wastes from x-ray developers) within the dental office.

It is difficult, if not impossible, to contain liquid or gaseous mercury totally because it is very mobile, has a high diffusion rate, and penetrates through extremely fine spaces. Even in packages that include plastic blister wrapping and layers of cardboard, mercury vapor leakage is possible. Mercury-containing products should not be stored in the open, but rather in closets or cabinets, to minimize local concentrations in the rest of the office. Storage locations should be near an exhaust vent that carries air out of the building.

During amalgam trituration, small amounts of material may escape from capsules. Reusable capsules and precapsulated designs experience some leakage. Small local spills or spatters of triturated materials are best dealt with by collection with a vacuum aspirator (not a vacuum cleaner). During trituration, the high frequency of agitation can force some mercury-rich material out of the capsule and create an aerosol of liquid droplets and a vapor that may extend 6 to 12 feet away from the triturator. To minimize this risk, small covers are mounted on mechanical triturators to contain the aerosol

to the region of the triturator; this does not eliminate the hazard. These materials persist as air contaminants or as particles that may drop onto the floor and contaminate carpeting or cracks between tiles. Air contamination is managed by ensuring that air flow is reasonably high and that fresh air is brought into the office in a path from the waiting room, through the outer office, and into the operatories, before being expelled to the outside of the building without contaminating other building areas.

When small droplets of mercury-rich material contaminate the floor coverings, the only practical approach to decontaminating the area is to replace the coverings. No effective treatment exists for removing liquid mercury from carpeting. Mercury reacts with sulfur to form a stable sulfide (cinnabar), but the reaction is slow and inefficient. Sprinkling sulfur powder onto sites of mercury spills would not adequately control the problem.

During insertion of amalgam into tooth preparations, the mixture is not yet fully reacted, and the high vapor pressure of mercury causes contamination of the air above the material. While the unhardened material sits in a Dappen dish for loading into an amalgam carrier, some vapor is released. This vapor should be cleared by the airflow system for the room. During the intraoral placement and condensation procedures, some mercury vapor is released. To control the vapor, a rubber dam can be used to protect the patient, and high-volume evacuation should be used to prevent intraoral vapor from diffusing. After initial setting, the material hardens to a solid, and the vapor pressure decreases by several orders of magnitude.

Scrap amalgam from condensation procedures should be collected and stored under water, glycerin, or spent x-ray fixer in a tightly capped jar. The jar should be almost completely filled with liquid to minimize the gas space where mercury vapor can accumulate. The unused amalgam sets, but the mercury-rich material in the scrap may not have sufficient alloy present to become completely reacted. Spent x-ray fixer has an advantage for controlling mercury because it is a source of silver and sulfide ions for reaction to a solid product. Periodically, this material should be recycled to minimize the amount of material being stored. No more than a small jar of material should be present in the office at any time. Recycling mercury, silver, and other elements is a professional job. The only known case of human death related to mercury management was that of a misinformed dental technician who tried to distill mercury out of amalgam scrap in the basement of his home.

When amalgam has solidified, the mercury is tightly bound. One of the reaction products, silver-mercury compound Ag_2Hg_3 , however, has a very low melting point (127°C). It can be easily liquefied during finishing or polishing procedures that generate heat. Then, as a liquid, it has a much higher mercury vapor pressure. This situation routinely arises when dentists or dental hygienists polish amalgams without using adequate cooling water and slow polishing. This process is very deceptive. The silver-mercury phase is melted, producing a mercury-rich liquid phase that is easily smeared over the amalgam surface making it look bright and shiny. The operator can misinterpret this appearance as a highly polished surface.

Melting of the silver-mercury phase also occurs during amalgam removal. It is common for surface temperatures to

Online Box 18-1 Dental Mercury Hygiene Recommendations

1. Educate all personnel involved in the handling of mercury or dental amalgam on the potential hazard of mercury vapor and the necessity for observing good mercury hygiene practices.
2. Make personnel aware of the potential sources of mercury vapor in the dental operator (e.g., spills; open storage of amalgam scrap; open storage of used capsules; trituration of amalgam; placement, polishing, or removal of amalgam; heating of amalgam-contaminated instruments; leaky capsules or bulk mercury dispensers). Personnel should be knowledgeable about the proper handling of amalgam waste and be aware of the environmental issues. Some state dental societies have published waste management recommendations applicable to their states.
3. Work in well-ventilated spaces with fresh air exchanges and outside exhaust. If the spaces are air-conditioned, air-conditioning filters should be replaced periodically.
4. Regularly check the dental operator atmosphere for mercury vapor. Monitoring should be considered in case of a mercury spill or suspected spill or when a reasonable concern about the concentration of mercury vapor in the operator exists. Dosimeters may be used for monitoring. Mercury vapor analyzers (i.e., hand-held monitors often used by industrial hygienists), which provide rapid readouts, also are appropriate, especially for rapid assessment after a spill or cleanup. The current limit for mercury vapor established by OSHA is 50 µg/m³ (time-weighted average) in any 8-hour work shift over a 40-hour work week.
5. Use proper work area design to facilitate spill contamination and cleanup. Floor coverings should be nonabsorbent, seamless, and easy to clean.
6. Use only precapsulated alloys; discontinue the use of bulk mercury and bulk alloy.
7. Use an amalgamator with a completely enclosed arm.
8. Use care in handling amalgam. Avoid skin contact with mercury or freshly mixed amalgam.
9. If possible, recap single-use capsules from precapsulated alloy after use. Properly dispose of them, according to applicable waste disposal laws.
10. Use high-volume evacuation when finishing or removing amalgam. Evacuation systems should have traps or filters. Check and clean or replace traps and filters periodically to remove waste amalgam (including contact amalgam) from the waste stream.
11. Salvage and store all scrap amalgam (i.e., noncontact amalgam remaining after a procedure) in a tightly closed container, either dry or under radiographic fixer solution. Amalgam scrap should not be stored in water. If the scrap is stored dry, mercury vapor can escape into room air when the container is opened. If the scrap is stored under radiographic fixer solution, special disposal of the fixer may be necessary. Some recyclers only accept scrap amalgam that is dry.
When feasible, recycle amalgam scrap and waste amalgam. Otherwise, dispose of amalgam scrap and waste amalgam in accordance with applicable laws. When choosing a recycling company, it is important to check that the company has obtained all required government permits and has not been the subject of a state or federal enforcement action. Because of the nature of environmental laws, the generator of waste (e.g., the dental office) may be held legally responsible if others handle the waste improperly further down the waste stream. Dentists should check with their state or local dental society about the laws that apply to recycling and request documentation from the recycling company that the scrap or waste has been handled properly.
12. Dispose of mercury-contaminated items in sealed bags according to applicable regulations.
13. Consult the state or local dental society about the regulations that apply in a given area. Do not dispose of mercury-contaminated items in regulated (medical) waste containers or bags or along with waste that will be incinerated.
14. Clean up spilled mercury properly using trap bottles, tape or freshly mixed amalgam to pick up droplets, and commercial cleanup kits. Do not use a household vacuum cleaner.
15. Remove professional clothing before leaving the workplace.

OSHA, Occupational Safety and Health Administration.

From the American Dental Association Council on Scientific Affairs: Dental mercury hygiene recommendations, *J Am Dent Assoc* 130:1125–1126, 1999.

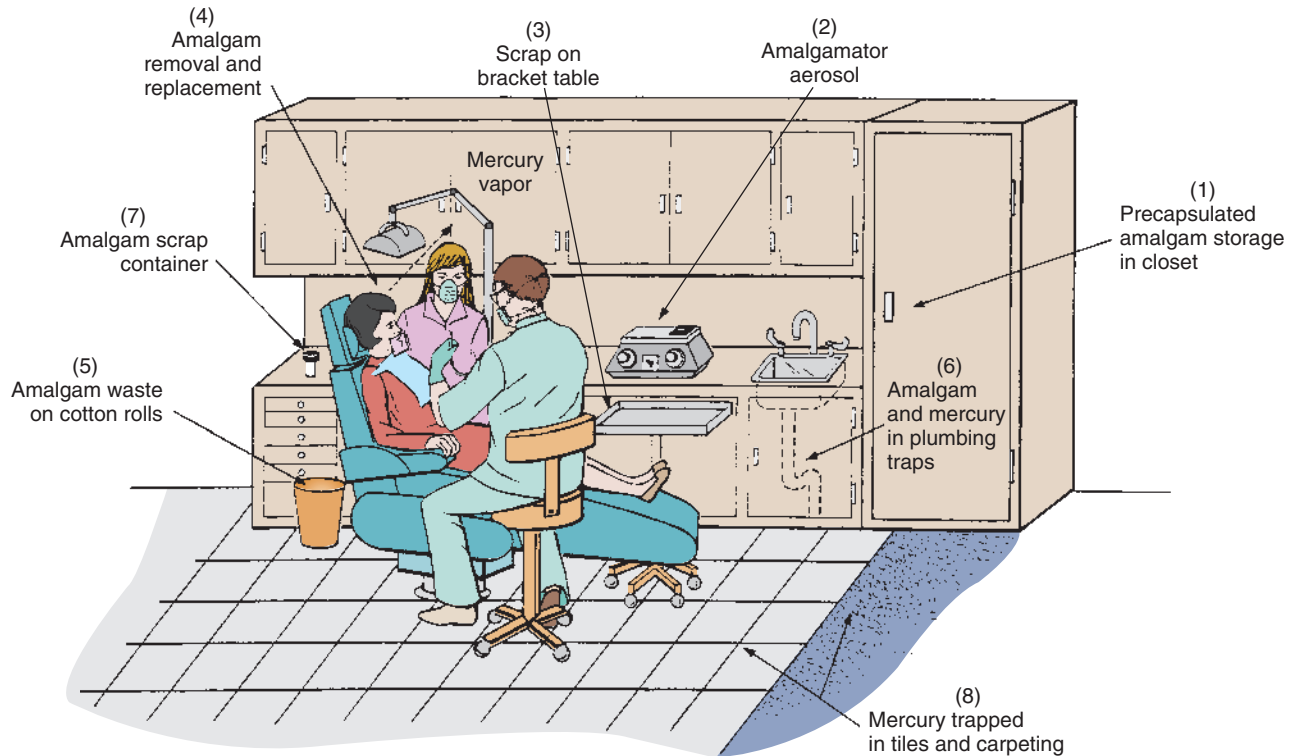
increase several hundred degrees where high-speed burs contact tooth structure.⁹⁰ This is well above the temperatures for melting the silver–mercury phase and vaporizing mercury. Rubber dam, high-volume evacuation, and water cooling can be used to control this situation.

Instruments used for inserting, finishing, polishing, or removing amalgam restorations contain some amalgam material on their surfaces. During instrument sterilization techniques, this material may be heated and can release mercury liquid or vapor.^{91,92} It is advisable to isolate or properly vent the air from sterilization areas.

Historically, capsules and other contaminated surfaces have not been managed well in the operator. Spent capsules and mercury-contaminated cotton rolls or paper napkins should not be thrown out with regular trash. They should be stored in a tightly capped plastic container or closed plastic bag for separate disposal. In most locations, these materials can be

placed into a sanitary landfill, but those regulations may change in the future.

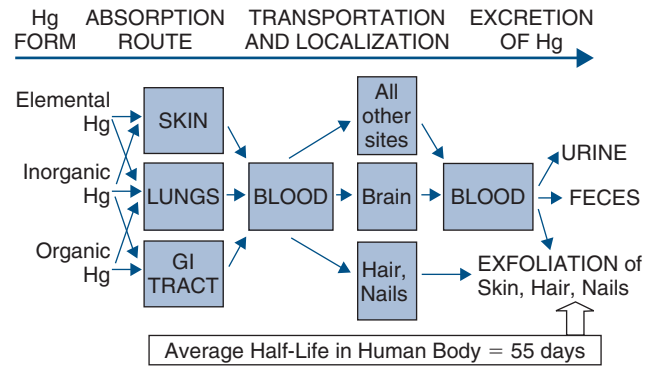
Online Figure 18-37 summarizes all of the potential mercury management problems. In addition to the storage and recycling of materials, routine precautions with regard to exposure must be followed. With the use of a rubber dam and high-volume evacuation, the patient is well protected from even minor, transient exposure to mercury vapor. These precautions are easy to follow and effectively protect the dentist, the assistant, and the hygienist from any vapor. Infection control masks do not provide sufficient protection from mercury vapor that may escape into the room air. Masks may catch particulate debris greater than 1 µm in size and catch droplets or sprays in the air, but they do not filter mercury vapor from the air. Routine exposures can be monitored with exposure badges (dosimeters) worn by individuals in the office or positioned within dental operatories near working areas.⁹³



Online Fig. 18-37 Sources of mercury hazards in the dental operator: (1) some mercury vapor released from stored materials; (2) small losses from capsules during trituration; (3) spillage during manipulation for tooth restorations; (4) some vapor exposures to the dentist, the assistant, and the patient during removal, placement, or finishing or polishing of amalgam; (5) contamination of cotton rolls; (6) collection of debris via vacuum suction into the plumbing system and the sewer system; (7) collection of remnants in a jar for recycling; and (8) mercury trapped in small cracks between floor tiles or in carpet fibers.

In the dental office, because of their long-term contact with mercury vapor, the dentist, the assistant, the hygienist, and other staff are at more risk of mercury toxicity than are patients. The ADA's monitoring of mercury levels in dentists has shown that these levels are within safe ranges, even though the levels are almost twice the national average for non-dentists. As a group, dentists actually show better than average survival rates. The inference is that if dentists are exposed and survive better than most individuals do, the perceived problem does not seem to have any grounds.

Much of the confusion about mercury effects is related to inadequate understanding of mercury processing by the human body. Mercury that is absorbed into the circulatory system may be deposited in any tissue. Higher than average accumulations occur in the brain, liver, and kidneys. Mercury ions (Hg^{2+}) circulate readily in blood but pass the membrane barriers of the brain and placenta only with difficulty. In contrast, nonionized mercury (Hg^0) is capable of crossing through lipid layers at these barriers and, if subsequently oxidized within these tissues, is removed only slowly. This fact has become the basis for many claims of neuromuscular problems in patients with amalgams. This mercury is not uniquely from amalgam, the levels are low, and removing amalgam restorations does not completely eliminate exposure to mercury. Mercury does not collect irreversibly in human tissues. The average half-life for transport through the body to the point of excretion is 55 days. Mercury that came into the body years ago is, therefore, no longer present in the body. **Online Figure**



Online Fig. 18-38 Summary of events occurring during mercury absorption, transportation, and excretion in the body.

18-38 summarizes the variety of events involved in mercury absorption and elimination.

Various events mitigate the conversion of mercury into ions and affect the conversion of the ions to other compounds. Ethyl alcohol is known to interrupt some of the biochemical steps required for blood–brain transport, facilitating mercury's rapid excretion. The placental barrier is less effective than the blood–brain barrier, and some mercury ions are capable of placental transfer, as is about anything else in the circulatory system. Fetal mercury contents, although elevated, are lower than brain concentrations in the mother. Effects on fetal

development are unknown. All of the contemporary evidence from surveys and post hoc investigations indicates that female dentists, assistants, and hygienists who are pregnant are at no higher risk of miscarriage or fetal misdevelopment. Even so, it seems judicious to minimize any exposure of these women to any potential hazard such as mercury during pregnancy.

In philosophic terms, the threat that may eliminate amalgam use as a restorative material some time in the future is not a question of toxicity to humans but, rather, of environmental protection.⁹⁴ It is well known that improper disposal of contaminated waste greatly affects the environment. Federal regulations exist to control large-scale industries that pollute. However, a wide-ranging focus on small-scale polluters that could include local hospitals and dental offices has not yet been accomplished. Although their relative contributions are small, local community problems may mandate that dental offices either control all mercury effluent or cease using amalgam. Human beings are exposed constantly to mercury in their environments from a multitude of sources as a result of natural emissions and pollution by humans. These exposures include breathed air, consumed water, ingested food, and medical or dental products.

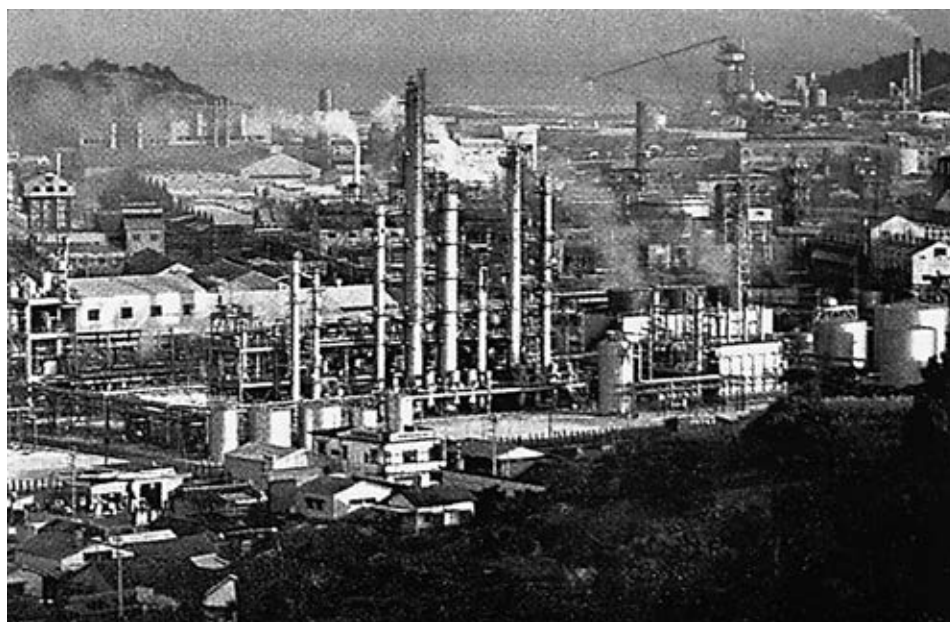
Typical concentrations of mercury in air vary considerably (pure air contains $0.002 \mu\text{g}/\text{m}^3$; urban air contains $0.05 \mu\text{g}/\text{m}^3$; air near industrial parks contains $3 \mu\text{g}/\text{m}^3$; air in mercury mines contains $300 \mu\text{g}/\text{m}^3$). The generally accepted threshold limit value for exposure to mercury vapor for a 40-hour work week is $50 \mu\text{g}/\text{m}^3$.⁸⁴

The human body is constantly excreting mercury from these exposures. The actual body burden at any time is a function of the dosage and time of exposure. Under almost all circumstances, the dosages are low and infrequent, and the body burden poses no health risk. Even if the exposure occasionally is above the threshold limit value, active excretion quickly reduces the body burden to normally low levels. In this scenario, any small contributions from amalgam restorations

are very low compared with other naturally occurring exposures, and the material is naturally excreted.

Mercury also occurs naturally in a wide range of foods, but not in the same chemical form in all cases. The greatest source of naturally occurring mercury, other than the ore, is mercury vapor released during volcanic eruptions. This vapor gradually is deposited in the world's oceans and accounts for the largest portion of dissolved mercury in water. The material is absorbed by small organisms such as plankton at the start of the food chain. It becomes more concentrated in larger fish higher in the food chain. Swordfish and tuna have essentially no natural enemies and are considered at the top of the ocean food chain. Within them, the concentration of mercury is typically $1000 \mu\text{g}/\text{kg}$ of mass. Eating large amounts of tuna or swordfish can increase an individual's body burden of mercury dramatically. Because methyl mercury compounds are routinely used as fungicides and herbicides to coat seeds used in farming, these compounds invariably are incorporated into vegetables, fruits, and grains. Mercury is then concentrated within the land-based animal food chain. The levels are typically $160 \mu\text{g}/\text{kg}$ in cattle and $25 \mu\text{g}/\text{kg}$ in humans.

Only under extremely rare circumstances have the symptoms of mercury toxicity been observed in humans (industrial pollution in Minamata Bay; inadvertent contaminated grain consumption in New Mexico and in Iraq). The Minamata Bay incident in Japan in 1952 is the most infamous (Online Fig. 18-39).⁸⁵ A local chemical plant (Chisso Corporation) disposed of its methyl mercury waste into the nearby bay, contaminating the shellfish and causing toxic levels of mercury in the fish eaten by the local population.⁹⁵ By the time the source was identified, 52 individuals had died, and 202 others were stricken by mercury poisoning. Since then, mercury poisoning of this kind is known as *Minamata disease*. The symptoms of mercury poisoning identified during this incident were (1) ataxic gait, (2) convulsions, (3) numbness in the mouth and limbs, (4) constriction in the visual field, and (5) difficulty



Online Fig. 18-39 Landscape of Minamata Bay, Japan (seen in the background) in relation to the Chisso Corporation, which was responsible for mercury contamination of the bay during discharges of pollutants. (From Putnam JJ: *Quicksilver and slow death*, National Geographic 142:507–527, 1972.)

speaking. None of these symptoms is particularly unique to mercury poisoning. It is extremely difficult to diagnose the problem without some special knowledge of an individual's risk to environmental exposure. Similar symptoms are typical of a wide range of other medical problems. It is easy for anti-amalgamists to improperly associate diseases such as multiple sclerosis with the intraoral presence of amalgam restorations.

Amalgam Waste Management

Although the use of mercury in amalgam restorations represents an almost insignificant risk to patients, the management of unused or recovered material in dental offices is a much more complicated situation. The path of mercury from the purchase of an amalgam product to the end of the clinical lifetime of a restoration has been monitored (Online Fig. 18-40, A).⁹⁶ Concerns about mercury management form the primary basis for the challenge to dentistry with regard to the continued use of amalgam restorations.

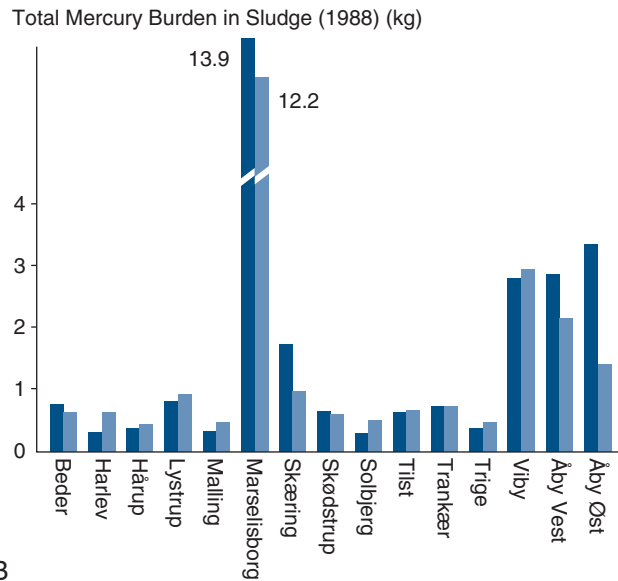
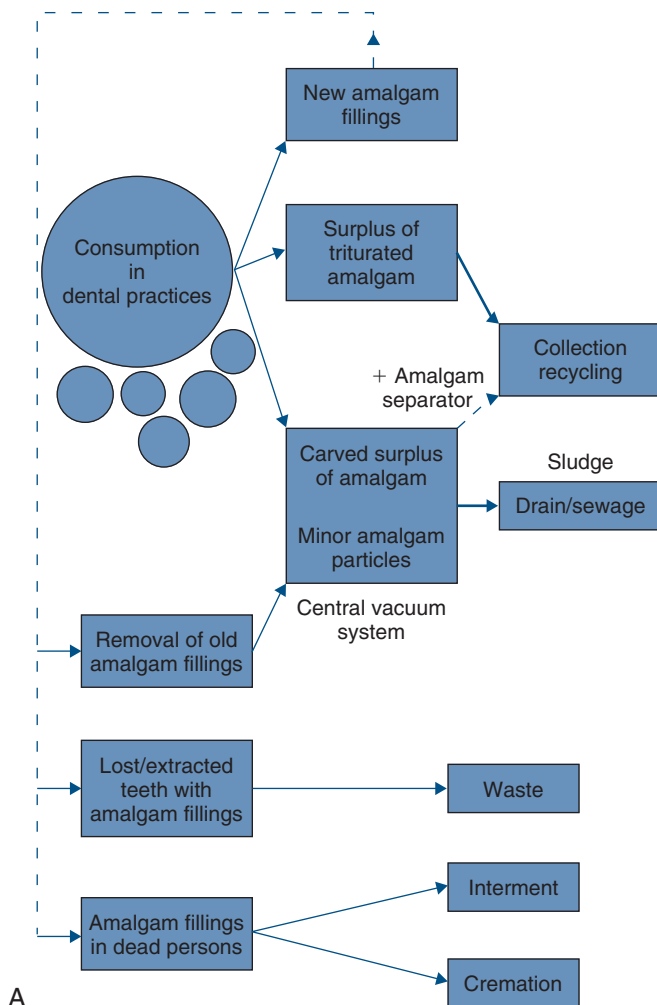
As individual political entities (countries, states or provinces, counties, towns) examine their own pollution problems, they will adopt restrictions that aim to limit future contributions of toxic metallic and organic wastes to the environment. The problem of pollution is the accumulation of waste within

a relatively closed system, rather than the concentration or amount of individual disposal.

Small amounts of mercury, silver, lead, or other toxic heavy metals are accumulated as part of an ever-increasing load in the local environment. This situation is exemplified in the case of amalgam. Scrap from amalgam replacement procedures or from the removal of failed restorations typically is disposed into the local sewer system (see Online Fig. 18-40, B) from a dental office. Amalgam debris may include large particles (approximately 70%, $\geq 100 \mu\text{m}$), medium-sized particles (approximately 20%, 10–100 μm), and fine material (approximately 10%, $< 10 \mu\text{m}$) particles, liquid mercury, or mercury dissolved in water.

Some of this material (large particles) can be trapped within chairside filters in dental offices. Typically, medium- as well as small-sized debris escapes into the sewer system. Because the materials are relatively dense, they settle into virtually all regions of the system. Within the office, amalgam waste collects in corrugations of the flexible tubing connected to intraoral suction devices, in plumbing traps, in plumbing lines along the side walls, and in all piping that connects to the local sewer line. Materials also collect along the entire path of the community sewer system up to the sewage treatment plant.

Materials arriving at the sewage treatment plant are extracted and become part of the waste sludge. This material,



Online Fig. 18-40 Monitoring of mercury associated with the dental office. **A**, Cycle of mercury in dentistry in dental amalgam. **B**, Contributions of mercury from dental offices in Denmark to wastewater in sewage systems compared with the total wastewater levels. Dark blue bars indicate dental contributions. Light blue bars indicate total levels. (From Arenholt-Bindslev D: Dental amalgam—environmental aspects, *Adv Dent Res* 6:125–130, 1992; and Heymann HO, et al: Two-year clinical study of composite resins in posterior teeth, *Dent Mater* 2:37–41, 1986; Hörsted-Bindslev P, et al: Dental amalgam—a health hazard? Copenhagen, Denmark, 1991, Munksgaard.)

besides containing heavy metal wastes, also is rich in nitrogen and phosphate. Because quantities of waste sludge are large, municipal wastewater treatment facilities are anxious to dispose of it as quickly as possible. Often, local farmers claim the material for the nitrogen and phosphate in it to be used as fertilizer. Otherwise, the material is burned. In either case, the probability that the solid or vapor will end up on local farming fields and be reincorporated into the food supply is very high. This “closed system” problem represents the real challenge to dentistry. Unless amalgam waste can be recaptured efficiently, the contribution from the dental field will be viewed as a significant form of pollution.

In the mid-1980s, Sweden was the first country to draw specific attention to potential contributions of dental mercury to the environment. As part of their overall mercury pollution management plan, the Swedish National Board of Health and Welfare in 1992 recommended the phase-out of amalgam use. For various similar reasons, countries such as Finland, Norway, Denmark, Switzerland, and Germany began to adopt a strict view on the potential impact of amalgam waste. These decisions simply fueled the amalgam debates occurring in the United States and Canada during the early 1990s. Although the European concerns were environmental ones, the anti-amalgamists conveniently reinterpreted these rulings as evidence of the hazard of amalgam use for restorations.

The real volume of amalgam waste in sewer systems is quite low. Because most other industries have been heavily regulated in this regard for many years, however, their contributions are extremely low. Analyses of industrial levels in Denmark revealed that approximately 90% of all mercury-containing waste arriving at wastewater treatment plants could be traced to contributions from dental offices.⁹⁷ Mercury waste in sewage systems is primarily from commercial or industrial sources, with smaller amounts from residential sources.

Upgraded intraoffice recapture systems (i.e., separators) have helped dramatically lower the actual contributions to the sewage system from dental practices.⁹⁸ These systems, however, have been installed only on a limited basis. They represent an initial investment to modify the plumbing and vacuum system of the office and require continual maintenance. Although these systems can be relatively inexpensive, the process of recapture increases the true cost of using and managing amalgam restorations.

Early separator systems appeared in Europe in the 1990s and involved sedimentation or centrifugation of wastewater in advance of the local sewer connection. Systems were relatively inefficient and rarely exceeded 75% recovery. Newer systems (using filters, mercury plating approaches, or ion-exchange technologies), in combination with chairside filters, provide much more efficiency (>92% and >98%).⁹⁸⁻¹⁰⁰ These systems can be installed quickly and with little difficulty in new dental practices.¹⁰¹ In older practices, however, many complicating factors may be present. Existing plumbing often is highly contaminated and may need to be removed. Cleaning products that remove adherent solids from plumbing are advertised, but no evidence of their effectiveness exists.

Even if a practitioner ceased to use amalgam as a restorative material, still millions of amalgams would remain in service in the United States alone. Because these restorations will need repair or replacement at some point in time, the challenge of managing amalgam recapture exists for every dentist. Phasing out of all amalgam restorations currently in service might take

25 to 35 years. Sewer systems themselves are contaminated from old disposals of mercury-containing and silver-containing waste. Because the materials are heavy and slow to dissolve, it has been estimated that it might require 25 to 35 years to flush out the sewer lines effectively. The problem of amalgam recapture and disposal will remain for many more years despite any new rules and philosophies governing amalgam use.

Regulations concerning amalgam management are not uniform nationally. Management includes purchasing, storing, use, recycling, disposal, and record keeping of dental amalgam operations. [Online Figure 18-41](#) presents an overview of the entire challenge and regulating agencies. Amalgam waste products are part of the (1) routine solid trash from a dental office, (2) air within the operatory, and (3) wastewater or sewage. The regulations are different for all situations.

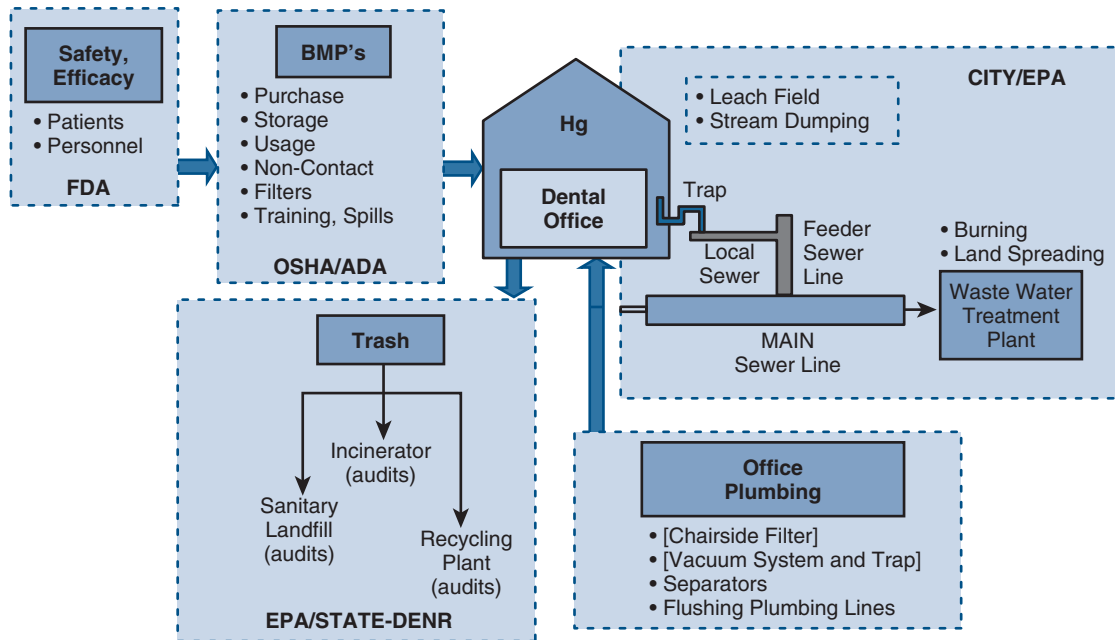
Historically, dental personnel have not effectively managed the amalgam capsules and other contaminated surfaces in the operatory. Spent capsules and mercury-contaminated cotton rolls or paper napkins have been thrown directly into the regular trash. They may be disposed with that trash, but they should be isolated to limit the vaporization of unreacted mercury into the office air. In most locations, that material can be placed into a sanitary landfill, but the restrictions are changing in many locations. The materials should not be incinerated. Mercury-contaminated materials should not be placed in medical waste bags because these are burned, and the mercury becomes vaporized. Office waste should not be burned locally because that also would release mercury into the air.

Air within the dental office contains some minute amounts of mercury vapor. Adequate fresh air should be mixed into the existing office air to produce a relatively rapid air turnover. Office air should not be mixed into a large system that could permit contaminated air to enter other offices in a larger office building unless it can be established that no risk exists in this regard.

Regulations for amalgam waste disposal vary (see [Online Fig. 18-41](#)). In general, the hierarchy is that regulations are stricter as one progresses from the federal, to state, to county, and finally to city levels. The U.S. Environmental Protection Agency (EPA) regulations govern discharges onto land, into water, and into air. Local EPA regulations are focused primarily on statewide water protection, registration of large-scale or small-scale polluters, and assay of problems. Cities increasingly are involved in setting standards, assessing local pollution levels, and levying fines to protect their local wastewater treatment facilities from unacceptable discharge burdens.

Three important problems for regulators of all waste discharges are (1) proper technical protocols to detect the chemical in question, (2) appropriate assay procedures to define the average discharge, and (3) meaningful limits for discharges. In some cases, the equipment is itself a source of mercury for the samples being tested. Many protocols have error levels greater than the detection limits. In other cases, collected samples do not appropriately represent the operating conditions of the wastewater source. A dental office should not be surveyed at 8 a.m. on Monday. The regulated limits should represent the risk. Dental mercury wastewater contributions should be measured in terms of volumes and not in terms of concentrations. Running twice as much water through the system would halve the effective concentration. The wastewater treatment plant, and ultimately the environmental impact, is a function

Hg ROAD MAP Managing Environmental Issues



Online Fig. 18-41 Summary of all the components of mercury management. A dental office must strictly follow current best management practices, minimizing liquid waste effluent by using separators and recycling and minimizing solid waste by recycling to minimize loads on sanitary landfills. The roles of all of the key agencies (FDA, EPA, OSHA, ADA) in the management process are indicated. (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)

of the quantity of material and not the aqueous dilution at the time of discharge.

Actual effluent from dental offices into a waste-water sewer has been strictly limited in some localities. The detection limit for mercury in water is $0.02 \mu\text{g/L}$. Typical regulatory limits enforced by some cities are $0.0002 \text{ mg/L} = 0.2 \mu\text{g/L} = 0.2 \text{ ppb}$ (parts per billion). A new dental office with fully functional recapture systems would get a pass, but an older dental office with limited recapture activities may not. Rural dental offices may not be connected to wastewater treatment systems at all, using direct disposal, a septic tank, or a drainage field. Drainage fields most likely would be prohibited as paths for dental office disposal because the probability of groundwater contamination is high.

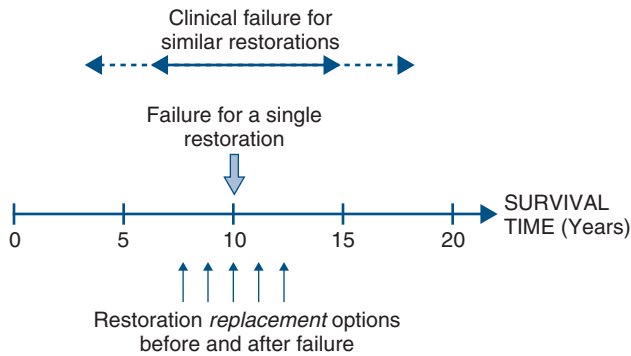
These important environmental considerations, combined with evidence that (1) current amalgams last three to five times longer than do low-copper amalgams, (2) caries rates are lower because of fluoridation effects, (3) anterior restorations now are made exclusively from tooth-colored materials, and (4) many posterior restorations are now made from tooth-colored materials, have resulted in a dramatic overall reduction in amalgam use. ADA surveys indicate that amalgam use decreased 45% from 1979 to 1990.¹⁰² This pattern of reduced use of dental amalgam does not, however, eliminate the profession's problem of mercury containment during amalgam removal.

As a response to environmental issues related to amalgam and because of the increasing patient demand for more esthetic restorative materials, pressure to provide alternatives to amalgam has increased since 1995. For all practical

purposes, use of amalgam for anterior restorations has disappeared since 1970 because of widespread use of composite, glass ionomers, and all-ceramic restorations. Amalgam's primary indication is for large intracoronal restorations on molar teeth or as foundations for crowns. For these situations, three types of alternatives to amalgam have been explored: metal alloys (gallium alloys; condensable self-welding metal alloy powders), modified composites (packable composites; nanocomposites; laboratory-processed composite inlays; fiber-reinforced composite inlays, onlays, or crowns), and all-ceramic restorations (milled restorations; castable or pressable ceramics; high-strength ceramics). None of these materials has fully displaced amalgam yet. Posterior composites, however, have gained much wider use.

Gallium alloys have mechanical properties similar to those of amalgam.¹⁰³⁻¹⁰⁵ Clinical trials with these materials have indicated problems with mixing and with early moisture sensitivity leading to excessive expansion.¹⁰⁶⁻¹¹⁰ Additionally, unidentified and potentially toxic corrosion products accumulate on intraoral surfaces.¹¹¹ Gallium alloy powder particles that are triturated with 65% gallium, 19% indium, and 15% tin produce a set material with phases of Ag_2Ga , CuPdGa_2 , beta-tin ($\beta\text{-Sn}$), silver-tin (Ag-Sn), and unreacted alloy.¹¹²

Clinical reports of some packable posterior composites show excellent 4- to 5-year performance as large amalgam replacements.^{113,114} These materials were resistant to wear and fracture, with extremely low levels of secondary caries or sensitivity. Similar products with newer filler designs and reduced shrinkage make the composite approach to amalgam replacement seem more and more likely in the near-term.



Online Fig. 18-42 Timeline to compare clinical failure, actual clinical replacement, and options for clinical replacement. Clinical failure and clinical replacement refer to individual restoration, which may not reflect the average condition for the larger group of similar restorations. Clinical longevity refers to the average time for replacement for a group of similar restorations being studied.

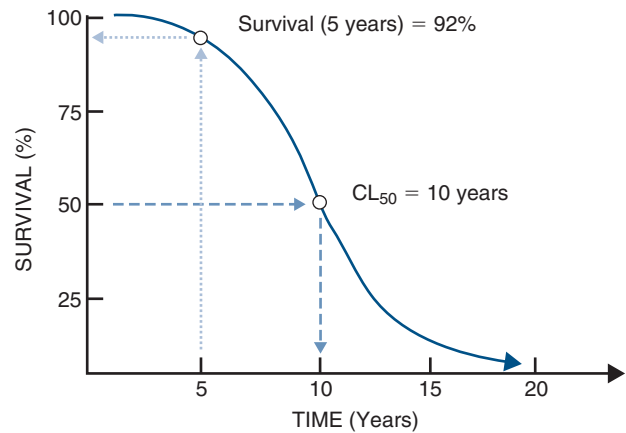
Clinical Considerations

Clinical longevity is a primary concern for selecting any restorative dental material. Clinical longevity is the median age for a “group” of related or similar restorations at which 50% of the restorations have been replaced because of clinical failure. Clinical longevity is determined by monitoring many restorations for clinical failure over a long period (longitudinal clinical research study) or by collecting information on random failures over a short period (cross-sectional clinical study).

Clinical failure is the point at which the restoration is no longer serviceable or at which time the restoration poses other severe risks if it is not replaced. Amalgam restoration–related failures include (1) bulk fracture of the restoration, (2) corrosion and excessive marginal fracture, (3) sensitivity or pain, (4) secondary caries, and (5) fracture of the tooth structure forming the restorative tooth preparation wall. The incidence of different failure modes depends on numerous factors. Restorations in caries-prone individuals may fail more often as a result of secondary caries. Restorations in caries-free individuals generally survive much longer, to the point that either fatigue results in bulk fracture of the restoration or the remaining tooth structure fractures from masticatory forces.

In many cases, amalgam restorations are not permitted to reach the point of clinical failure. They are replaced before that time in anticipation of failure (clinical replacement). An example is the replacement of a functionally sound restoration because of unacceptable esthetics. Restorations also have been replaced rather than being routinely maintained, depending on the government or private insurance coverage policy provisions. The clinical failure time is often longer than the clinical replacement time (Online Fig. 18-42).¹¹⁵ For any single restoration, clinical failure or replacement may be shorter or longer than the average clinical longevity value describing a group of restorations. Failure or replacement times range from a few months to 45 to 50 years. This distribution is typified by the curve in Online Figure 18-43. This average has been designated the value for clinical longevity for 50% of the restorations (CL_{50}).¹¹⁶

Many clinical failures of amalgam restorations occur because of some combination of electrochemical corrosion



Online Fig. 18-43 Distribution of clinical failures (survival or failure rate) for dental restorations. Survival curves can be described in terms of the clinical longevity in years for 50% of the restorations or the surviving population of restorations in percentage at a particular time. (Courtesy of S. C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)

and mechanical stress. The combination produces continual marginal breakdown that creates conditions for more frequent failure owing to secondary caries. In anticipation of this failure, amalgams with advanced marginal breakdown are often replaced. The average replacement age of conventional (low-copper) amalgams in clinical practice is 5 to 8 years (Online Table 18-7). Corrosion and marginal fracture are much less in high-copper amalgams. These amalgams more commonly fail because of bulk fracture, presumably related to fatigue. In recent years, evidence has been mounting that high-copper amalgams, regardless of initial compositional differences, have a CL_{50} of 24 to 25 years. High-copper amalgams not containing zinc do not last long.⁶³

Normally, early failure of amalgams is uncommon, but when it does occur, it is related to bulk fracture, improper preparation design factors, or postoperative sensitivity. Conventional amalgams initially have low tensile strength because of slow overall setting reactions. They must be protected from high stresses during the first few hours after placement. Spherical high-copper amalgams develop strength more rapidly and are relatively immune to early fracture from loading. If the final amalgam does not have adequate depth or width (or both) at the narrowest portion of its bulk, however, it is possible for intraoral loads to produce high resolved stresses causing fracture in the isthmus of the restoration. This is true of all amalgams.

During setting, most amalgams undergo little dimensional change. Improperly manipulated or improperly condensed amalgams, however, might undergo increased expansion. This could produce stresses on the tooth structure and create unusual postoperative sensitivity or pain. It should not be confused with slight sensitivity, related to the fact that an amalgam is a metallic restoration that may conduct heat or become electrochemically coupled, producing a minor current that may induce pulpal sensitivity for a few hours. After that time, corrosion products eliminate the problem. Until initial corrosion occurs, some oral fluid penetration may occur along the walls of the tooth preparation. If dentin is not sealed adequately, fluid flow in the tubules may be induced, and sensitivity could result; this should not occur

Online Table 18-7 Lifetimes Reported for Dental Amalgams Placed in General Clinical Practices

Citation, Year*	Study Type [†]	Amalgam Type	Restorations	Survival Level (n)	50% Longevity
Robinson, 1971	(Cross-sectional)	Low-Cu	145	25% at 20 yr	10 yr
Allan, 1977	(Cross-sectional)	Low-Cu	241	10% at 15-20 yr	5-8 yr
Crabb, 1981	(Cross-sectional)	(Low-Cu)	1061	—	7-8 yr
Elderton, 1983	(Cross-sectional)	(Low-Cu)	1206	52% at 4.5 yr	—
Patterson, 1984	(Cross-sectional)	(Low-Cu)	2344	—	7.5 yr
Bentley and Drake, 1986	(Longitudinal)	(Low- and high-Cu)	433	71%–92% at 10 yr	—
Mjor, 1981	(Cross-sectional)	Low- and high-Cu	3527	40% at >10 yr	—
Smales, 1991	Longitudinal	Low- and high-Cu	1042	>70% at 10 yr	—
Smales et al, 1991	Longitudinal	Low- and high-Cu	1801	75% at 10.9 yr	—
Smales et al, 1992	Longitudinal	Low- and high-Cu	1813	70% at 20 yr	20–24 yr (est.)
Dawson and Smales, 1992	(Longitudinal)	Low- and high-Cu	1345	75% at 6.6 yr	14.4 yr
Letzel et al, 1982	Longitudinal	Low- and high-Cu	360	73.6% at 7 yr	—
Letzel et al, 1990	Longitudinal	High-Cu	—	83%–91% at 10 yr	24 yr (est.)
Hawthorne and Smales, 1997	(Cross-sectional)	Low- and high-Cu	1371	50% at 22.5 yr	22.5 yr
Kreulen et al, 1998	Longitudinal	High-Cu	1117	83% at 15 yr	—

low-Cu, low copper; *high-Cu*, high copper.

*See the References list.

[†]Parentheses indicate that information was not stated definitively in reference.

with adequately sealed dentinal surfaces. The normal resolution of the problem of persistent sensitivity is replacement of the restoration.

High incidences of amalgam sensitivity with some spherical alloys have been reported occasionally, but the cause and effect have not been carefully documented. Complaints arise only sporadically and are not universal. No investigation has been able to identify the causes of or solutions to this problem. The prevalence of this type of sensitivity is presumed to be low.

External surfaces on amalgams should be relatively smooth. Smooth surfaces discourage the formation of crevice sites for electrochemical corrosion or for stress concentration during mechanical loading. The general rule for carving an amalgam is to produce only surfaces and grooves that can be made smooth. Detailed secondary tooth anatomy, which can be carved into amalgam surfaces, is usually more of a liability to longevity than an esthetic advantage.

For many years, the smoothness of the restoration surface as a means of reducing corrosion sites has been a concern. Until 1985, it was standard procedure to wait for more than 24 hours and then to polish the amalgam at a subsequent visit. Polishing has been replaced by burnishing the surface at the time of placement. Polishing amalgams occurs only when the surfaces are not observed to be smooth when inspected. Clinical studies have shown no detectable clinical advantage for polished restorations compared with initially smooth restorations.^{117,118}

Amalgam repair is possible to a limited extent. If secondary caries or fracture involves only a portion of an amalgam restoration, it is possible to leave the unaffected portion and prepare a tooth preparation that includes part of the old restoration as one of its external walls. Differences in amalgam

compositions and corrosion behaviors contribute to corrosion, but the effect seems to be insignificant.

At sites where support for remaining tooth structure is compromised, amalgam bonding systems have been proposed to increase retention and to strengthen weak tooth structure. No long-term clinical research results exist for the success of bonded amalgam restorations, but some increases in retention and resistance forms usually occur. When used, however, the bonded amalgam tooth preparation also should employ conventional secondary retention and resistance form features. Amalgam bonding agents (see the section on bonding systems) also are proposed for sealing tooth preparations, bonding new amalgam to old amalgam, or repairing marginal defects. Short-term clinical trials do not seem to show these effects.¹¹⁹ This text does not promote the bonding of amalgam restorations as a routine procedure.

Liners and Bases

Many restorative biomaterials that provide excellent properties for the bulk of a dental restoration may not protect the dental pulp during setting or during cyclic thermal or mechanical stressing. Pulpal protection requires consideration of (1) chemical protection, (2) electrical protection, (3) thermal protection, (4) pulpal medication, and (5) mechanical protection (Online Fig. 18-44). These concerns become more important as the tooth preparation extends closer to the pulp. Liners and bases are materials placed between dentin (and sometimes the pulp) and the restoration to provide pulpal protection or pulpal response. Protective needs for a restoration vary, depending on the extent and location of the preparation and the restorative material to be used. The characteristics of the

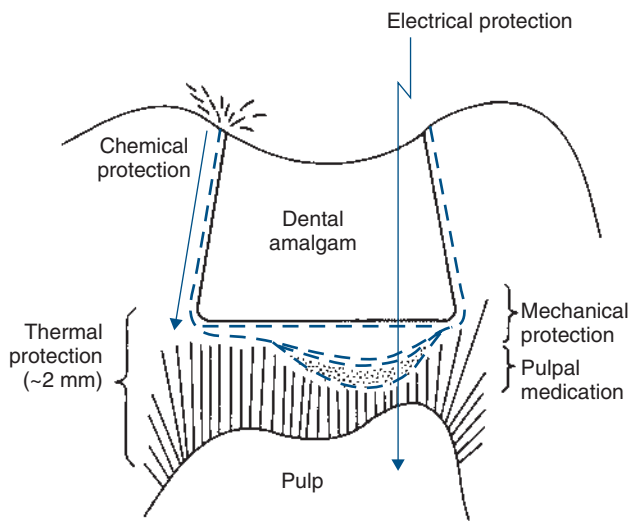
liner or base selected are determined largely by the purpose it is expected to serve. Because they share similar objectives, liners and bases are not fully distinguishable in all cases, but some generalizations can be made.

Terminology and Classification

Liners are relatively thin layers of material used primarily to provide a barrier to protect dentin from residual reactants diffusing out of a restoration or from oral fluids (or both) that may penetrate leaky tooth restoration interfaces. They also contribute initial electrical insulation, generate some thermal protection, and, in some formulations, provide pulpal treatment (Online Fig. 18-45). The need for liners is greatest with pulpally extended metallic restorations that are not well bonded to the tooth structure and that are not insulating, such

as amalgam and cast gold, or with other indirect restorations. Direct composite restorations, indirect composite or ceramic restorations, and resin-modified glass ionomer (RMGI) restorations routinely are bonded to the tooth structure. The insulating nature of these tooth-colored materials and the sealing effects of the bonding agents preclude the need for traditional liners and bases, unless the tooth preparation is extremely close to the pulp, and pulpal medication becomes a concern. This situation is described in more depth later in discussions of bonding agents. Thin film liners (1–50 μm) can be subdivided into solution liners (varnishes, 2–5 μm) and suspension liners (typically 20–25 μm). Thicker liners (200–1000 μm = 0.2 to 1 mm), selected primarily for pulpal medication and thermal protection, are sometimes identified as cement liners.

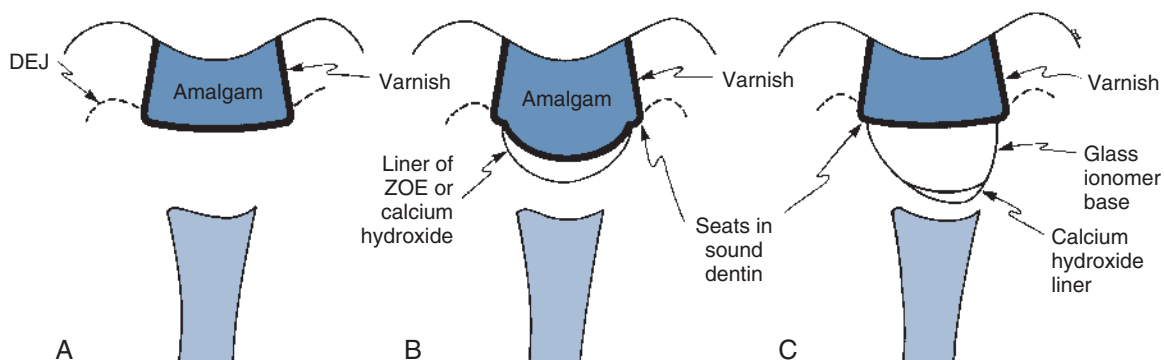
Bases (cement bases, typically 1–2 mm) are used to provide thermal protection for the pulp and to supplement mechanical support for the restoration by distributing local stresses from the restoration across the underlying dentinal surface. This mechanical support provides resistance against disruption of thin dentin over the pulp during amalgam condensation procedures or cementation procedures of indirect restorations. Metallic restorations may benefit from seating (resting) on sound dentin peripheral to the lined or based regions that result from excavating infected dentin (see Online Fig. 18-45). These seats may help distribute stresses laterally to sound dentin and away from weaker underlying structures. Various liners and bases may be combined in a single preparation, and the dimension between the restoration and the pulp may be a combination of natural dentin, liner, and base.



Online Fig. 18-44 Schematic view of needs for pulpal protection below the metallic restoration. Varnishes, liners, and bases may be added to the tooth preparations under amalgam for purposes of chemical, electrical, thermal, or mechanical protection or pulpal medication. (From Bayne SC, Barton RE: *Dental materials for direct restorations*. In Richardson RE, Barton RE, editors: *The dental assistant*, ed 6, Philadelphia, 1988, Lea & Febiger.)

Objectives for Pulpal Protection

To understand the actions of these agents, it is necessary to recall the anatomy and physiology of dentin. Normal coronal dentin includes dentinal tubules that contain cellular extensions (odontoblastic processes) of the cells (odontoblasts) that originally laid down dentin during dentinogenesis. These columnar cells remain as a layer along the periphery of the dental pulp, partially embedded in poorly mineralized dentin (predentin), and with processes extending outward into dentinal tubules. The processes are surrounded by dentinal fluid when they do not contact the walls of the tubules. In response



Online Fig. 18-45 Schematic examples of use of liners and bases for amalgam restorations. **A**, For shallow amalgam tooth preparations, varnish or sealer is applied to walls of preparation before insertion of restoration. **B**, For moderate-depth tooth preparations, liners may be placed for thermal protection and pulpal medication. (Note the seats in sound dentin for amalgam restoration.) **C**, In very deep preparations, light-cured calcium hydroxide is placed in the deepest region in which infected dentin was excavated, and then the base of glass ionomer is inserted. Amalgam bonding systems are being advocated as a substitute for liner and varnish except for calcium hydroxide liner in the deepest region (judged to be within 0.5 mm of the pulp).

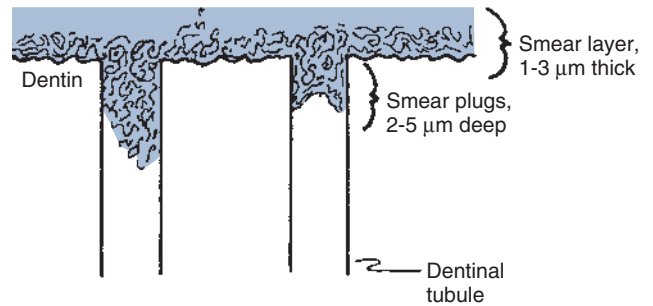
to mild, long-term chemical or mechanical insults, the processes slowly recede toward the pulp while occluding the tubules with peritubular dentin by depositing hydroxyapatite crystals. If the insult is strong or near to the pulp (or both), the odontoblastic processes are retracted more rapidly from that region, and a thin local bridge of hydroxyapatite is created across the affected tubules. Both these responses are natural defense mechanisms to insulate the pulp from chemical, thermal, mechanical, or biologic challenges.

If the insult produces fluid flow, in or out of the dentinal tubules, the pressure change is sensed by mechanoreceptors within the pulp, and the patient experiences sensitivity. If leakage of chemical irritants from biomaterials or bacteria occurs, the pulp complex can become inflamed. To protect against these events, it is paramount to seal the outer ends of the tubules along the dentinal tooth preparation wall.

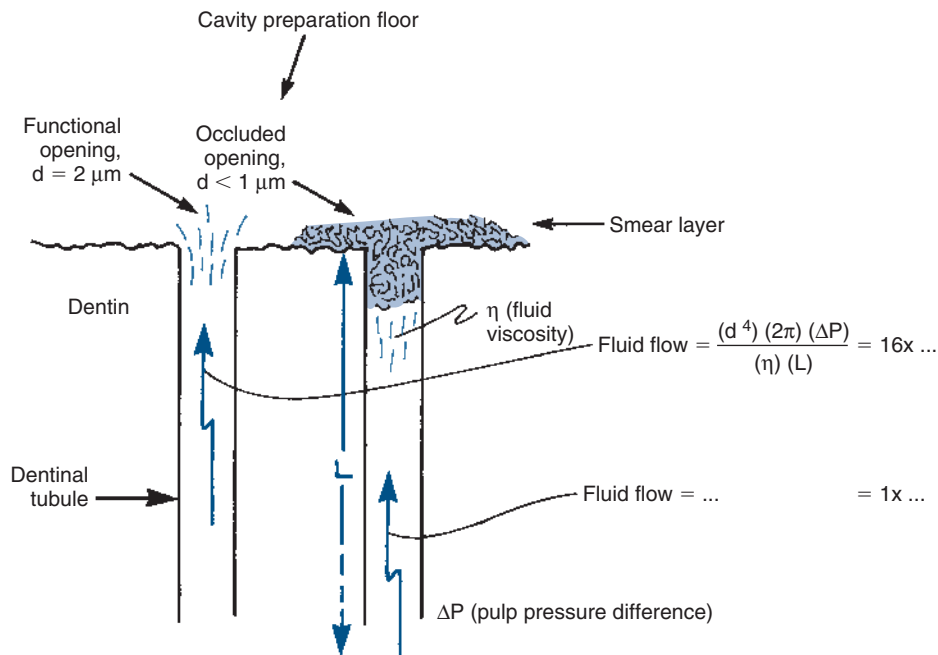
Tooth preparation with rotary instruments generates cutting debris, some of which is compacted unavoidably into a layer on the cut surface. That layer of material is called *smear layer* and is typical of any cut surface, dental or otherwise. Enamel and dentin smear layers are left in place for unbonded amalgam restorations. The dentinal smear layer (Online Fig. 18-46) produces some degree of dentinal tubule sealing, although it is 25% to 30% porous. Flow or microleakage in or out of tubules is proportional to the fourth power of the diameter of the opening (Online Fig. 18-47). Halving the diameter of the opening produces a 16-fold reduction in flow.^{31,120,121} The smear layer is an effective barrier. Because it is partially porous, however, it cannot prevent slow long-term diffusion. For amalgam restorations that can leak along their enamel margins, the smear layer should be sealed to produce chemical protection. Traditional liners may be used, but dentin and amalgam bonding systems (discussed later) can produce the same or better effect and are becoming substitutes for liners.

To produce a thin film liner, liner ingredients are dissolved in a volatile nonaqueous solvent. The solution is applied to the tooth structure and dries to generate a thin film. Any liner based on nonaqueous solvents that rely on evaporation for hardening is designated as a solution liner (or varnish). Liners based on water have many of the constituents suspended instead of dissolved and are called *suspension liners*. Liners also are intended to provide thermal protection and need to be thicker in dimension.

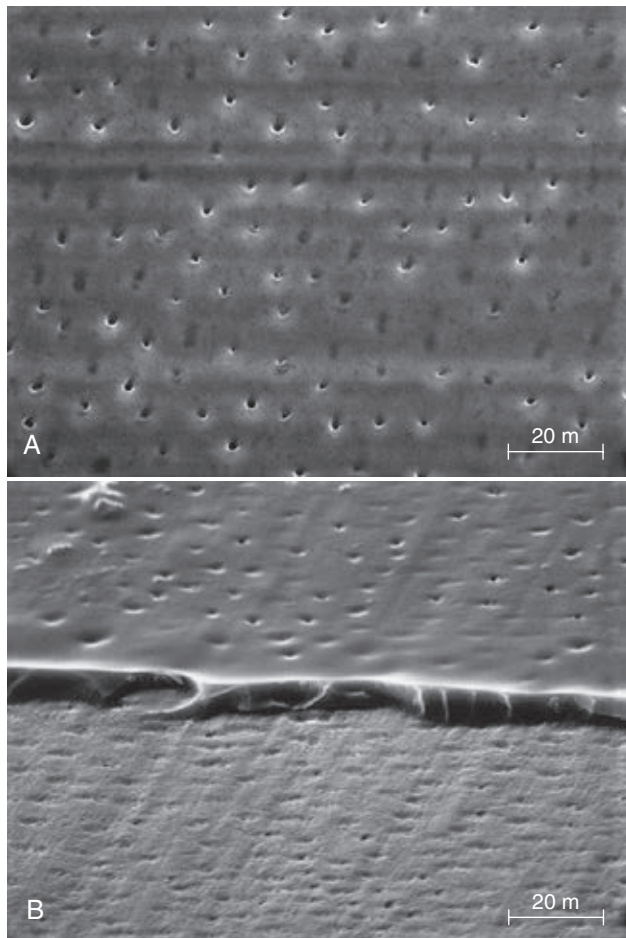
Most varnish coatings are produced by drying solutions of copal or other resin dissolved in a volatile solvent; these were used more frequently in the past than they are now. Copalite (HJ Bosworth, Skokie, IL) was more widely used than other varnishes and contains 10% copal resin in a combination of ether, alcohol, and acetone. The resin content is kept intentionally low to produce a thin film on drying. Thin films work best because they are flexible and dry rapidly. Thick films tend to trap solvent during rapid superficial drying and become brittle when they finally dry. Most solvent loss occurs in 8 to 10 seconds and does not require forced air assistance. A thin



Online Fig. 18-46 Schematic view of the dentin smear layer.



Online Fig. 18-47 Schematic view of fluid flow physics for dentinal tubules. The flow rate is a function of tubule diameter (d), pulpal pressure difference (ΔP) to ambient pressure, viscosity of dentinal fluid (η), and tubule length (L). A twofold reduction in opening diameter results in a 16-fold reduction in fluid flow.



Online Fig. 18-48 Copalite varnish partially occluding the dentinal tubules. **A**, Scanning electron microscopy of one layer of Copalite varnish over the smear layer that seals approximately 55% of the tubules. **B**, Scanning electron microscopy of two layers of Copalite varnish adjacent to region protected only by the smear layer. (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)

film of 2 to 5 μm is formed over smear layers along the tooth preparation wall. Because some moisture is in the smear layer, and varnishes are hydrophobic, the film does not wet the surfaces well. A single coat effectively covers only 55% of the surface (Online Fig. 18-48). A second thin layer is recommended to produce sealing of 80% to 85% of the surface. Because of the use of bonding systems or desensitizing systems (discussed later) with amalgams, however, the use of varnishes decreased considerably in the 1990s.

Suspension liners can produce the same effect, but dry more slowly and produce thicker films. The typical film thickness is 20 to 25 μm , in contrast to the 2- to 5- μm film produced by solution liners (varnishes). Both types of liner often are extended out over the cavosurface margins of the preparation. Excess material on external surfaces is not necessary but is difficult to avoid. It is easily abraded off. The primary purpose of the liners is to provide a protective seal on the exposed dentinal surface. The liner layer at the restoration–enamel interface also provides a means of electrically isolating metallic restorations from external electrical circuits with restorations in the adjacent teeth. Otherwise, amalgam restorations

may produce small electrical currents during the first few days that cause patient pain or discomfort. This sensitivity rapidly disappears as electrochemical corrosion or tarnish or both modify the surfaces of amalgam.

A key function of enamel and dentin is thermal insulation of the pulp. Most restorative materials are not as insulating as dentin, and thermal insults may occur during intraoral temperature changes. The need for insulation is greatest for metallic restorations. Thermal insulation is proportional to the thickness of the insulating material. Approximately 2 mm of dentin, or an equivalent thickness of material, should exist to protect the pulp (see Online Fig. 18-45). This thickness is not always possible, but 1 to 1.5 mm of insulation is accepted as a practical thickness. As the tooth preparation extends closer to the pulp, a thick liner or a base is used to augment dentin to the proper thickness range. Such a liner or base cannot harden by evaporation of solvent or water because it would not dry effectively. Material used for this purpose hardens by a chemical reaction or is light-cured.

In addition to thermal protection, liners are formulated to provide pulpal medication whenever possible. Two important aspects of pulpal medication are the relief of pulpal inflammation and facilitation of dentinal bridging for physiologic protection. The materials (eugenol and calcium hydroxide) most commonly used to provide these two functions are not mutually compatible and cannot be used in the same formulation.

Eugenol is used to alleviate discomfort resulting from mild-to-moderate pulpal inflammation. Eugenol is a para-substituted phenolic compound that is slightly acidic and produces palliative or obtundent actions on the pulp when used in very low concentrations. High concentrations can be chemically irritating. Several eugenol-containing biomaterials are based on the reaction of eugenol with zinc oxide (zinc oxide–eugenol [ZOE]) to produce liners, bases, or cements. In the liner compositions, small amounts of eugenol are released during setting and over several days. For this reason, these liners were used in the past in sites where tooth preparations were moderately deep. Currently, moderate-depth needs for a liner or base are met with the use of an RMGI, as described later.

In the deepest portions of the preparation or when a microscopic pulp exposure is suspected, it is more important to encourage dentinal bridging by using calcium hydroxide compositions. Calcium hydroxide in saturated solutions (suspensions) is extremely caustic ($\text{pH} > 11$), but when ionized in low concentrations, it stimulates the formation of reparative dentin. Traditionally, calcium hydroxide liners are formulated to undergo a chemical setting reaction but allow minor amounts of calcium hydroxide to be released from the liner surface to produce the desired effect. Calcium hydroxide liners generally are based on the reaction of calcium ions from calcium hydroxide particles with phenolic moieties on mono-functional or multi-functional molecules. Excess calcium hydroxide is in the composition so that some of it is always available as a source of calcium and hydroxyl ions. These liners may degrade severely over long periods, to an extent that they no longer provide mechanical support for the overlying restoration. It is recommended that a calcium hydroxide liner be overlaid with an RMGI base.

Water is an important component for the chemical setting of eugenol-based and calcium-based liners. The setting

reaction of ZOE is accelerated by moisture. Most formulations contain reaction modifiers to produce setting in a reliable way, but moisture does not interfere with the reaction. For calcium hydroxide-based liners, the setting reaction involves calcium ions. To start the reaction, some calcium hydroxide must be dissociated by moisture from air or from moist dental surfaces. If the site has been dried excessively, a moist cotton pledget may have to be introduced to make the liner set correctly. Eugenol and calcium hydroxide cannot be incorporated into the same formulation because eugenol rapidly chelates calcium ions in a strongly exothermic reaction. The choice of a eugenol-based versus calcium hydroxide-based liner is dependent on the relative depth of the tooth preparation.

Newer liners place less emphasis on pulpal medication and focus more on chemical protection by sealing, adhesion, and mechanical protection. Sealing may prove to be the most important property overall. As long as restorations are primarily ceramic or polymeric materials, they will provide excellent thermal insulation. Newer compositions rely on mechanically strong acrylic resin matrices, and that choice makes the release of eugenol or calcium hydroxide ions from the composition much more difficult or impossible.

Historically, restorative material bases have been generated by mixing dental cements at higher-than-normal powder-to-liquid ratios to increase the final compressive strength and to reduce the concentration of potentially irritating liquids. The thick mixes of some materials are sticky and at times lead to problems with adaptation to the preparation walls and with control of the amount and contour of base material.

Zinc phosphate cement and resin-reinforced ZOE cement were widely used for bases before the 1960s. Polycarboxylate cement bases gained popularity starting in the 1970s. Glass ionomer cement became more popular from 1985 to 1994. Highly modified forms of glass ionomer cement (light-cured RMGIs or compomers) provide chemical adhesion, good mechanical strength, potential fluoride release, well-controlled setting, and rapid achievement of strength.

Before the development of RMGIs, the functions of liners and bases were relatively distinct but have since begun to converge. Previously, in a deep preparation, a calcium hydroxide liner would be placed first. Then, a base would be added to provide mechanical support and stress distribution. The base would be covered with varnish at the same time the tooth structure walls were varnished (except that when using zinc phosphate cement the varnish would be applied before the cement), and the amalgam would be placed. Currently, light-cured calcium hydroxide and glass ionomer materials are being used to line and base relatively deep preparations (see [Online Fig. 18-45, C](#)).

For indirect restorations, provisions must be made to prevent dislodgment of the base during impression taking or removal of a temporary restoration. Mechanical undercuts or bonding of the base material to prepared dentin is used depending on the type of base material (see [Fig. 17-11](#)).

Composition, Structure, and Properties

Representative examples of the composition, structure, and important properties of solution liners (varnishes), liners, and bases are presented in [Online Tables 18-8, 18-9, and 18-10](#).

Online Table 18-8 Composition, Structure, and Properties of a Typical Solution Liner (Varnish)*

Copal Resin Varnish (Copalite)	
COMPONENTS	
Solid (10%)	Copal resin
Solvent (90%)	Ether, acetone, alcohol
Setting reaction	Physical (evaporation)
STRUCTURE	
Arrangement	Amorphous film
Bonding	Covalently bonded
Composition (phases)	Single phase
Defects	Pores and cracks
PHYSICAL PROPERTIES	
Thermal	[Insulator]
Electrical	[Insulator]
LCTE (ppm/°C)	[High]
Wetting	[Poor]
CHEMICAL PROPERTIES	
Solubility (% in water)	[Low]
Mechanical Properties	
Tensile strength (MPa)	<1
Elongation (%)	<0.1%
BIOLOGIC PROPERTIES	
Toxicity	[None, if solvent eliminated safely]

*Relative properties are reported in brackets.
LCTE, Linear coefficient of thermal expansion.

Clinical Considerations

Clinical judgments about the need for specific liners and bases are linked to the amount of remaining dentin thickness (RDT), considerations of adhesive materials, and the type of restorative material being used. Recommendations for various restorative procedures are summarized in [Online Table 18-11](#). As will be discussed later, dentin sealers are being used more frequently instead of dentin bonding systems or varnishes to seal amalgam tooth preparations. Except in the deepest portions of preparations for composite restorations, only dentin bonding systems are being used.

In a shallow tooth excavation (which includes ≥ 1.5 –2 mm of RDT), pulpal protection, other than in terms of chemical protection, is not necessary. For an amalgam restoration, the preparation is coated with two thin coats of a varnish, a single coat of a dentin sealer, or a dentin bonding system, and then restored. In most cases, a dentin sealer is the material of choice (e.g., Gluma by Heraeus-Kulzer, South Bend, IN; Hurriseal by Beutlich Pharmaceuticals, Waukegan, IL). For a composite restoration, the preparation is treated with a bonding system (etched, primed, coated bonding agent) and then restored. A sealer for amalgams and a bonding system for composites provide chemical protection. To provide any adhesion of

Online Table 18-9 Composition, Structure, and Properties of Typical Liners*

	Calcium Hydroxide (VLC Dycal)	Traditional GI (Fuji Lining LC)	Reinforced ZOE (IRM)
COMPONENTS			
Components 1 and 2	Paste (with Ca(OH) ₂ , LC resin, and polyphenolics)	Powder (Al-silicate glass); liquid (polyalkenoate acid, LC resin)	Paste (with ZnO); paste (with eugenol)
P/L or paste/paste ratio	(1 component)	1.4/1 by weight	6/1 by weight
Setting reaction	Acid-base reaction	Acid-base reaction	Acid-base reaction
STRUCTURE			
Arrangement	Amorphous matrix Crystalline fillers	Amorphous matrix Crystalline fillers	Crystalline matrix Crystalline fillers
Bonding	Covalent; ionic	Covalent; ionic	Covalent; ionic
Composition (phases)	Multiphase	Multiphase	Multiphase
Defects	Pores; cracks	Pores; cracks	Pores; cracks
PHYSICAL PROPERTIES			
LCTE (ppm/°C)	[Low]	[Low]	[Low]
Thermal conductivity	[Insulator]	[Insulator]	[Insulator]
Electrical conductivity	[Insulator]	[Insulator]	[Insulator]
Radiopacity (mm Al)	—	4	—
CHEMICAL PROPERTIES			
Solubility (% in water)	0.3-0.5 [high]	0.08 [low]	[Modest]
Shrinkage on setting (μm/mm)	—	24 [low]	—
MECHANICAL PROPERTIES			
Elastic modulus (MPa)	588	1820	—
Hardness (KHN ₁₀₀)	—	—	—
Elongation (%)	—	—	—
Compressive strength, >24 hr (MPa)	138	128	71
Diametral tensile strength (MPa)	—	24	—
Flexural strength (MPa)	—	46	—
Dentin shear bond (MPa)	—	5.8	—
BIOLOGIC PROPERTIES			
Biocompatibility	[Acceptable]	[Acceptable]	[Acceptable]

*Relative properties are shown in brackets. The values reported are from a variety of published sources from 1988 to 2000, including manufacturer's product bulletins. Comparisons should be made only in terms of the overall application requirements and not in terms of any single property.
LCTE, linear coefficient of thermal expansion; MPa, megapascal; ppm, parts per million; ZOE, zinc oxide-eugenol.

amalgams to the surfaces of the tooth preparation, amalgam bonding systems must be used instead.

In a moderately deep tooth excavation for amalgam that includes some extension of the preparation toward the pulp so that a region includes less than ideal dentin protection, it may be judicious to apply a liner only at that site using ZOE or calcium hydroxide. Either one may provide pulpal medication, but the effects would be different. ZOE cement releases minor quantities of eugenol to behave as an obtundent toward the pulp. It also provides thermal insulation. In a composite tooth preparation, eugenol has the potential to inhibit polymerization of layers of bonding agent or composite in contact with it. Calcium hydroxide is normally used if a liner is indicated. If the RDT is very small or if pulp exposure is a potential problem, calcium hydroxide is used to stimulate reparative dentin for any restorative material. A thickness of 0.5 to 1 mm

of set calcium hydroxide liner is sufficient to treat a near or actual pulp exposure and provide adequate resistance for amalgam condensation forces. Under these circumstances (when a minimum thickness of material is protecting the pulp), for an amalgam restoration, a spherical amalgam type is recommended for use because less condensation pressure is required. A sealer is then applied before placing a final amalgam restoration. In the case of a composite procedure, a bonding system is used.

If extensive dentin is lost because of caries, and the tooth excavation extends close to the pulp, a cement base should be applied over the already placed calcium hydroxide liner. If an adhesive cement base is chosen (i.e., polycarboxylate cement or RMGI cement) for amalgam or composite restorations, the adhesive cement base should be applied over the liner and tooth structure to permit chemical adhesion to occur. The

Online Table 18-10 Composition, Structure, and Properties of Typical Bases*

	Zinc Phosphate Cement (Modern Tenacin)	Polycarboxylate Cement (Durelon)	Glass Ionomer Cement (Ketac-Cem)	Resin-Modified Glass Ionomer Cement (Vitremer)
COMPONENTS				
Component 1	ZnO powder	ZnO powder	F-Al-Si glass powder	F-Al-Si glass powder [†]
Component 2	H ₃ PO ₄ /H ₂ O	Polyacrylic acid/H ₂ O	Polyacrylic acid/H ₂ O	Monomers [‡] /H ₂ O
P/L ratio	[High]	[High]	[High]	2.5
Setting reaction	Acid-base	Acid-base	Acid-base	Acid-base; free radical
STRUCTURE				
Arrangement	Crystalline matrix Crystalline fillers	Amorphous matrix Glass fillers	Amorphous matrix Crystalline fillers	Amorphous matrix Glass fillers
Bonding	Ionic	Covalent; ionic	Covalent; ionic	Covalent; ionic
Composition (phases)	Multiphase	Multiphase	Multiphase	Multiphase
Defects	Pores and cracks	Pores and cracks	Pores and cracks	Pores and cracks
PHYSICAL PROPERTIES				
Thermal	[Insulator]	[Insulator]	[Insulator]	[Insulator]
Electrical	[Insulator]	[Insulator]	[Insulator]	[Insulator]
LCTE (ppm/°C)	[Low]	[Low]	10 [low]	[Low]
CHEMICAL PROPERTIES				
Solubility (% in water)	0.10 [low]	[Low]	0.70 [low]	0.2 [low]
MECHANICAL PROPERTIES				
Modulus (MPa)	—	—	—	—
Hardness (KHN ₁₀₀)	—	—	—	—
Percent elongation (%)	—	—	—	—
Compressive strength (MPa)	77	[100]	120	200
Diametral tensile strength (MPa)	—	[17]	—	35
BIOLOGIC PROPERTIES				
Safety	[Acceptable]	[Acceptable]	[Acceptable]	[Acceptable]
*Relative or estimated properties are shown in brackets.				
[†] Including a redox catalyst.				
[‡] Polycarboxylic acid/HEMA/methacrylates/water/ethanol/photo-initiator.				

Online Table 18-11 Summary of Pulpal Protection Procedures (Medicament/Liner/Sealer)

	Shallow Excavation (RDT >2 mm)	Moderate Excavation (RDT 0.5-2 mm)	Deep Excavation (RDT <0.5 mm)
Amalgam	No/No/Sealer	No/Base/Sealer	CH/Base/Sealer
Composite	No/No/DBS	No/No/DBS	CH/No/DBS
Gold inlays and onlays	No/No/Cement	No/Base/Cement	CH/Base/Cement
Ceramic, PR, FRP	No/No/DBS, CC	No/No/DBS, CC	CH/No/DBS, CC

Note: Pulpal protection includes pulpal medication, dentin sealing, thermal insulation, electrical insulation, and mechanical protection.

Sealer = Gluma, Hurriseal, or others; base = Vitrebond, Durelon, or others; cement resin-modified glass ionomer.

CC, composite cement (e.g., Rely X Luting Cement); CH, Dycal liner; DBS, dentin-bonding system; FRP, fiber-reinforced prosthesis; PR, processed resin; RDT, remaining dentin thickness.

sealer or bonding agent is not applied until after the base is in place. In indirect restorative procedures requiring multiple appointments, any necessary base must be placed with its own retentive features ensured either by mechanical preparation features or by bonding; this guarantees that it will not be displaced during impression procedures or during the removal of temporary restorations.

Survival of liners and bases under restorations has never been well understood. Even during restoration removal, it is difficult to remove the restorative materials completely and to assess the acceptability of the liners and bases. Solution liners (varnishes) are relatively brittle and thin and may provide only chemical protection for days to weeks. That should be sufficient, however, for their purpose. Sealers maintain their integrity much better than varnishes. Bonding agents may survive for years. Liners and bases may be sufficiently intact to limit the extent of tooth re-preparation to only the outline necessary for removal of the old restorative material. Traditional calcium hydroxide liners are suspected to continue to dissolve and may lose 10% to 30% of their volume over 10 or more years.¹²² Radiolucent lines often are observed in dental radiographs at the border of liners. Liners may need to be replaced or augmented if such changes are obvious when the restoration is replaced. Long-term changes in cement liners and cement bases are not well characterized. It may be judicious under these circumstances to remove most liners and bases during the repeat restoration procedure.

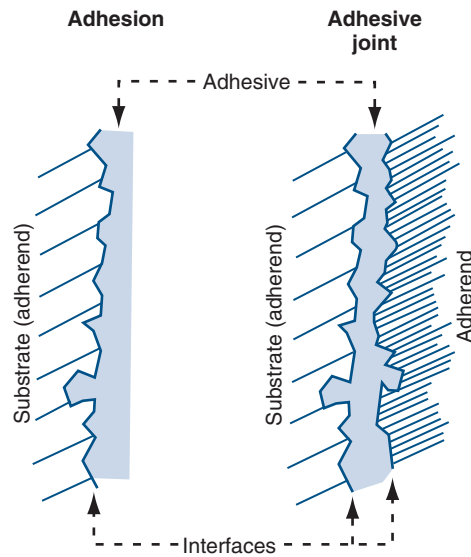
Dental Adhesion Terminology

Adhesion is a process of solid or liquid interaction of one material (adhesive or adherent) with another (adherend) at a single interface.¹²³ Most instances of dental adhesion also are called *dental bonding*. Adhesive bond strength is evaluated by debonding the system.

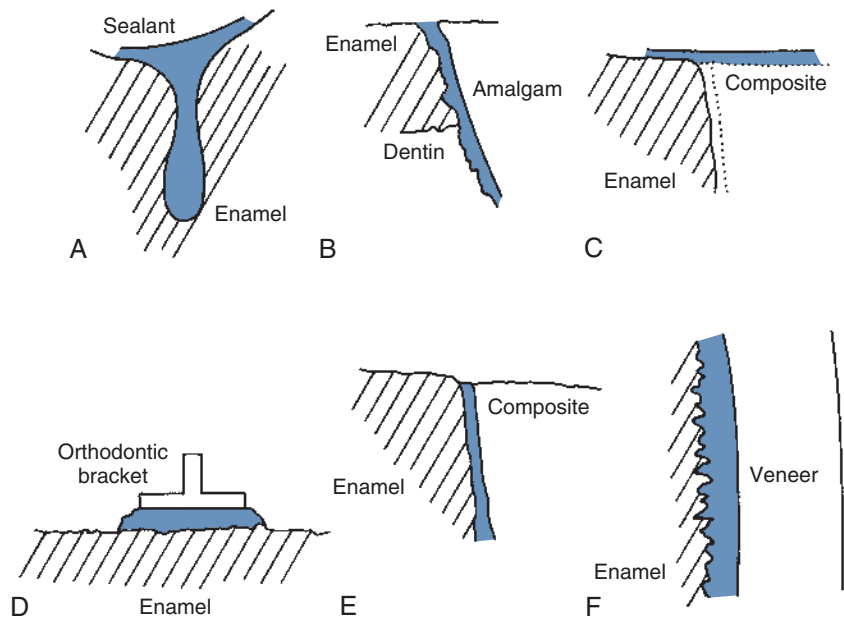
Most situations involving dental adhesion really involve adhesive joints. An adhesive joint is the result of interactions of a layer of intermediate material (adhesive or adherent) with

two surfaces (adherends) producing two adhesive interfaces (Online Fig. 18-49). Examples of the classification of different dental uses are presented in Online Figure 18-50. A pit-and-fissure sealer bonded to etched enamel is an illustration of dental adhesion. An enamel bonding agent that bonds together etched enamel with composite is a classic dental adhesive joint.

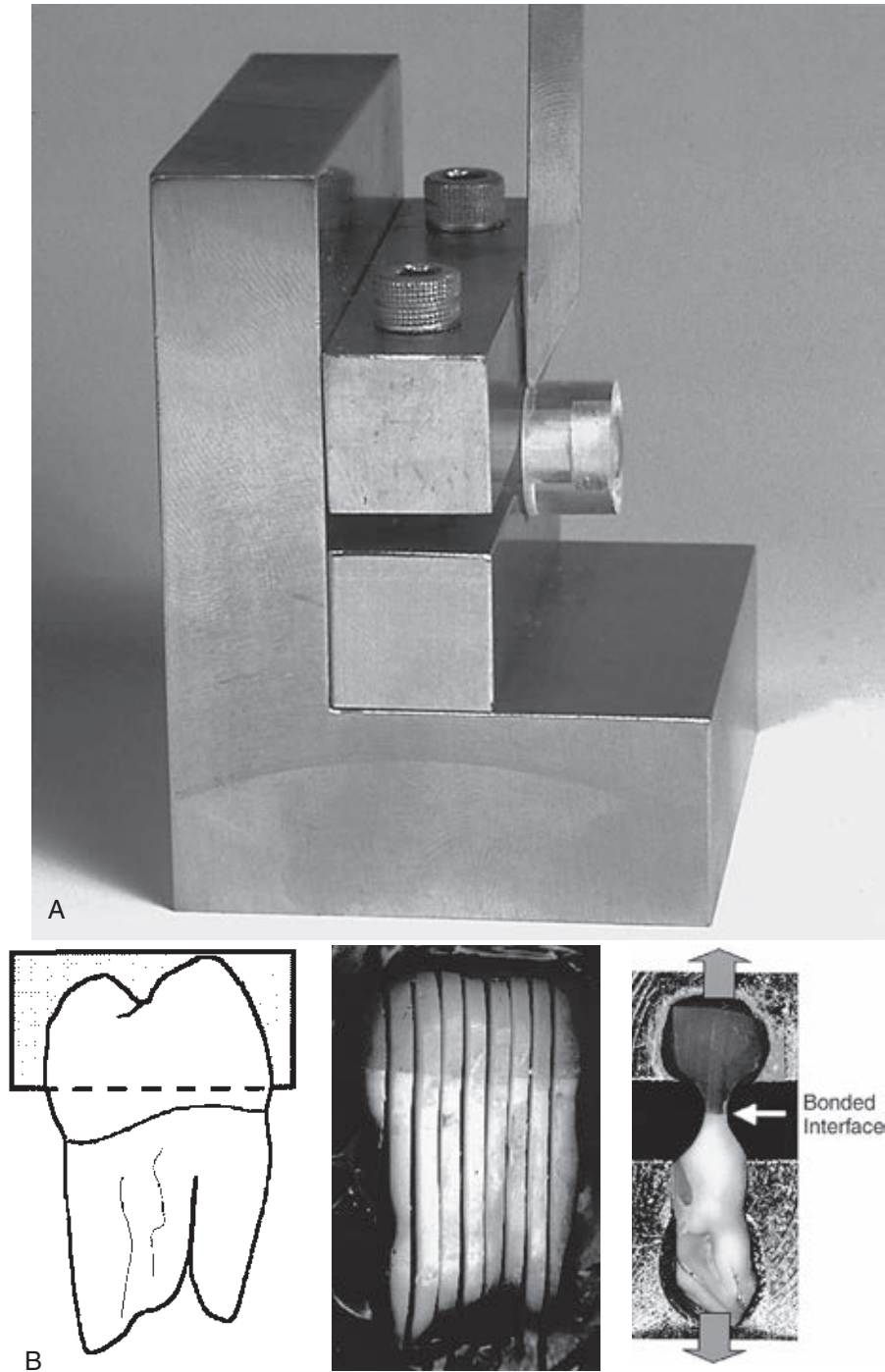
Bond strength is calculated as the initial mechanical load that generates final fracture divided by the simple, geometrically defined, cross-sectional area of the bond. In most cases, the true contact area between the materials involved may be much greater because of a mechanically rough interface. The roughness, however, is not considered in the calculation. The type of bond strength test is categorized in terms of the initial



Online Fig. 18-49 Schematic summary of dental adhesion (one adherend, one interface, one adhesive) and dental adhesive joint (two adherends, two interfaces, one adhesive). (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)



Online Fig. 18-50 Examples of classification of dental adhesion (A–C) and dental adhesive joints (D–F). A, Fissure sealant. B, Varnished wall of amalgam preparation. C, Surface sealer on composite restoration. D, Orthodontic bracket bonding resin. E, Enamel bonding system for a composite restoration. F, Bonded porcelain veneer.



Online Fig. 18-51 Examples of enamel or dentin bond strength testing. **A, Macroshear:** A knife-edged wedge is moved parallel to the bonded surface (e.g., dentin) and used to load the composite attached with a bonding system over a 4-mm diameter bonded area (12.4 mm^2) to the point of failure. **B, Microtensile bond strength testing:** The crown is removed to create a surface in dentin parallel to the occlusal surface of the tooth. The crown is replaced with composite bonded to dentin. The tooth is sectioned through the width and length of the crown to produce longitudinal sections containing composite, bonding system, and dentin. The longitudinal section is ground from the edges to produce a neck in the region of bonded interface with a small cross-sectional area (e.g., 0.1 mm^2). The elongated test sample is bonded at its broad ends to the test apparatus and pulled in tension to the point of failure. (Courtesy of B. Rosa, Londrina-PR, Brazil.)

mechanical loading direction and not the resolved loading direction. Almost all bond strength tests are categorized as tensile or shear bond strengths (Online Fig. 18-51). Samples that have dimensions similar to dental restoration sizes are considered macrotests. In a practical sense, most macrotensile

bond strengths are often only approximately half of the value of shear bond strengths. Samples that have much smaller test area dimensions are referred to as *microtests*. Microtests such as microtensile bond strength tests (see Online Fig. 18-51) usually produce strengths two to three times larger than in

macrotests. This occurs because the microsamples have a much lower flaw concentration, and during bond strength testing, almost all fractures occur by crack propagation from flaws in the neighborhood of the adhesive. Any comparison of bond strengths should be in terms of equivalent testing conditions.¹²⁴ Microshear tests are used as well.

Classification

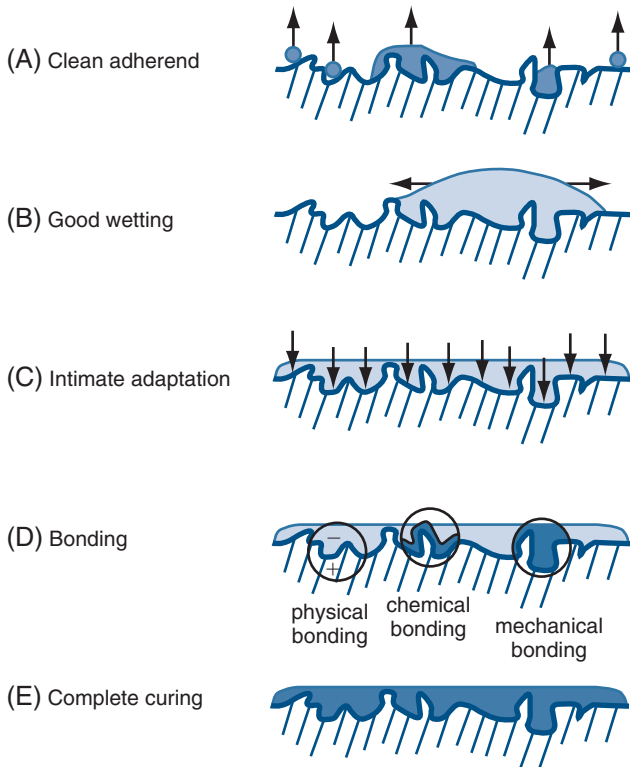
The local interactions that occur at the interface are classified in terms of the types of atomic interactions that may be involved. Adhesion is classified as physical, chemical, or mechanical bonding. Physical bonding involves van der Waals or other electrostatic interactions that are relatively weak (Online Fig. 18-52). It may be the only type of bonding if surfaces are smooth and chemically dissimilar. Chemical bonding involves bonds between atoms formed across the interface from the adhesive to the adherend. Because the materials are often dissimilar, the extent to which this bonding is possible is limited, and the overall contribution to bond strength is normally quite low. Mechanical bonding is the result of an interface that involves undercuts and other irregularities that produce interlocking of the materials. The microscopic degree to which this occurs dictates the magnitude of the bonding. Almost every case of dental adhesion is based primarily on mechanical bonding. Chemical bonding

may occur as well but generally makes a limited contribution to the overall bond strength.

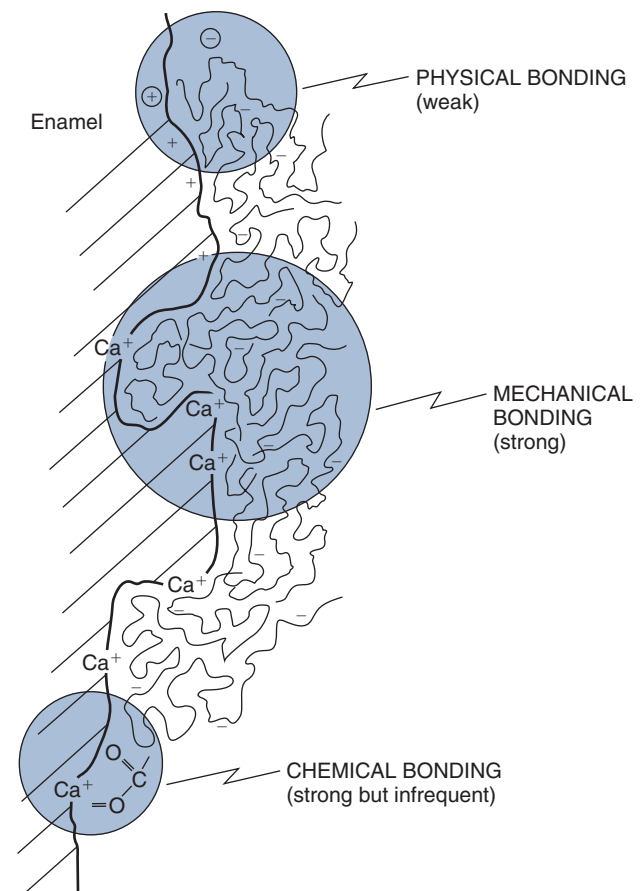
The common method for producing surface roughness for better mechanical bonding is to grind or etch the surface. Grinding produces gross mechanical roughness but leaves a smear layer of hydroxyapatite crystals and denatured collagen that is approximately 1 to 3 μm thick. Acid etching (or conditioning) dissolves this layer and produces microscopic relief with undercuts on the surface to create an opportunity for mechanical bonding.¹²⁵ If the mechanical roughness produces a microscopically interlocked adhesive and adherend with dimensions of less than approximately 10 μm, the situation is described as *micromechanical bonding* (*micromechanical retention* or *microretention*).

Requirements for Adhesion

Refer to Online Figure 18-53. To develop good adhesion (good bonding), it is necessary to form a microscopically intimate interface. The adhesive must be able to approach the molecules of the substrate within a few nanometers. Forming the interface is described in terms of the adhesive wetting the adherend.



Online Fig. 18-52 Key steps to the development of good adhesion. **A**, Clean adherend (devoid of smear layer or contaminants). **B**, Effective wetting of substrate by adhesive. **C**, Intimate adaptation of the adhesive to the intricacies of the substrate (avoiding voids or entrapped air). **D**, Effective mechanical bonding. **E**, Complete curing of the adhesive. (Modified from Bayne SC: *Bonding to dental substrates*. In Craig RG, Powers JM, editors: *Restorative dental materials*, ed 11, St. Louis, 2001, Mosby.)



Online Fig. 18-53 Schematic summary of contribution of physical, mechanical, and chemical bonding to interfacial adhesion. Physical bonding occurs when the negative and positive sites on the polymer and on the tooth structure are attracted electrostatically. Mechanical bonding occurs when the bonding agent is mechanically interlocked into micro-undercuts on tooth surfaces. Chemical bonding occurs as reactive sites on polymer form primary bonds with surfaces of tooth structure.

To produce effective bonding, wetting must be adequate. Wetting is a measure of the energy of interaction of the materials (see Online Fig. 18-9, B). Materials that interact significantly, producing chemical bonds and reducing their total energy, are said to wet one another. A liquid that wets a solid spreads readily onto the solid surface. If a state of complete wetting occurs, the contact angle approaches zero degrees.

A second requirement for adhesion is that the surfaces being joined are clean. Often, this is a difficult situation to produce and maintain. Clean surfaces are at a high-energy state and rapidly absorb contaminants from the air, such as moisture or dust. If contaminants are not excluded, the adhesive interface becomes weak. A standard process for cleaning any surface is the application of solvents or acids to dissolve or dislodge contaminants.

Bond Strengths

Most often, the bond strengths of materials are measured by shearing the adhesive or adhesive joint to produce fracture. Bond strength is measured as a single cycle stress to fracture. In the clinical situation, fatigue may be much more important, however, than single-cycle loading. Currently, fatigue is too complex to be simulated routinely for laboratory bond strength tests. The fracture strength measured depends on the path of the fracture. For an adhesive joint such as composite bonded to dentin with a dentin bonding agent, the bulk materials' strengths control the fracture path. Dentin is stronger than composite, which is stronger than the dentin bonding agent. If the interfaces are well bonded, the fracture occurs within the dentin bonding agent or is driven into the adherends. If one or both of the interfaces are not well bonded, the fracture occurs along the weakest interface.

If the dentin bonding agent is chemically matched to the composite, it is wet well by the composite, chemically intermixes with it, and produces true chemical bonding that creates a strong interface. Bond strengths for the interface of bonding systems with dentin depend on the degree to which wetting occurs. Cut dentin contains a smear layer, is moist, and is not micromechanically rough. Selective etching removes some or all of the smear layer, locally controls the wetness, and produces a micromechanically rough surface. Dentin is, however, still hydrophilic (water loving). The dentin bonding agent must be designed to be hydrophilic. This quality produces a chemically intimate and micromechanically well-bonded interface. Most current dentin bonding systems have been designed with etching, priming, and bonding steps to accomplish this.

As the interfacial bond strength of an adhesive joint becomes stronger, the bulk strength of the adhesive becomes the limiting factor to adhesive joint strength. One way of improving the bond strength is to decrease the adhesive thickness to the point that a fracture cannot propagate through it in a practical sense. If the adhesive is thin or tortuous in geometry or both, any crack is constantly driven into one or the other adherends. The joint begins to behave more like the simple adhesion of the two materials on either side of the adhesive. This is the status for current dentin bonding agents. By impregnating a finely etched dentin surface, the final thickness of the dentin bonding agent approaches 1 μm. Fractures are now diverted into dentin, and bond strengths of 25 to 40 MPa are common.

Online Table 18-12 Summary and Comparison of Macroshear Bond Strengths for Different Materials and Systems Involved with Dental Adhesion*

Adherend/(Adhesive)/(Adherend)	Macroshear Strength (MPa)
Enamel	90–200
Dentin	170
Composite	30–120
Traditional glass ionomer	—
Resin-modified glass ionomer	—
Dental amalgam	[125]
Enamel/ Enamel SL	4–6
Dentin/ Dentin SL	4–6
Enamel/ EBS/ Composite	18–22
Enamel/ ABS/ Composite	10–12
Enamel/ ABS/ Amalgam	2–22
Enamel/ No SL/ Traditional Glass ionomer	8–12
Enamel/ EBS/ Orthodontic Bracket	18–20
Enamel/ Composite Cement/ Maryland Bridge	—
Dentin/ DBS/ Composite	22–35
Dentin/ SL/ Traditional Glass ionomer	[6]
Dentin/ No SL/ Resin-modified Glass ionomer	10–12
Composite/ EBS/ Resurfacing Composite	10–27

*Estimated values are shown in brackets. The combination of adherend, adhesive, and overlying adherend is indicated in the left column. ABS, amalgam bonding system; DBS, dentin bonding system; EBS, enamel bonding system; SL, smear layer.

An alternative approach to improve bonding is to increase considerably the thickness of the bonding system (50–100 μm) by applying multiple coats of the material. This approach seems to work by behaving like a stress-relieving liner and increasing the toughness of the system. Clinical trials with systems based on this approach have been successful over several years.¹²⁶

The problem for dentistry is that different clinical situations may require different chemical characteristics for an adhesive to achieve good wetting. Materials that are good dentin or enamel bonding systems may not be good porcelain-bonded-to-metal repair bonding agents or amalgam bonding agents. Online Table 18-12 presents dental adhesion or adhesive joint situations with examples of bond strengths. These situations are described in the following paragraphs.

Bonding Systems

In dentistry, the agents producing adhesive dental joints are referred to as *bonding systems* and have been classified historically on the basis of the primary adherend (enamel-only bonding systems, dentin-only bonding systems, and dentin-and-enamel bonding systems).

ENAMEL BONDING SYSTEMS

Enamel-only bonding systems consist of an unfilled (or lightly filled) liquid acrylic monomer mixture placed onto acid-etched enamel. The monomer flows into the interstices between and within the enamel rods.

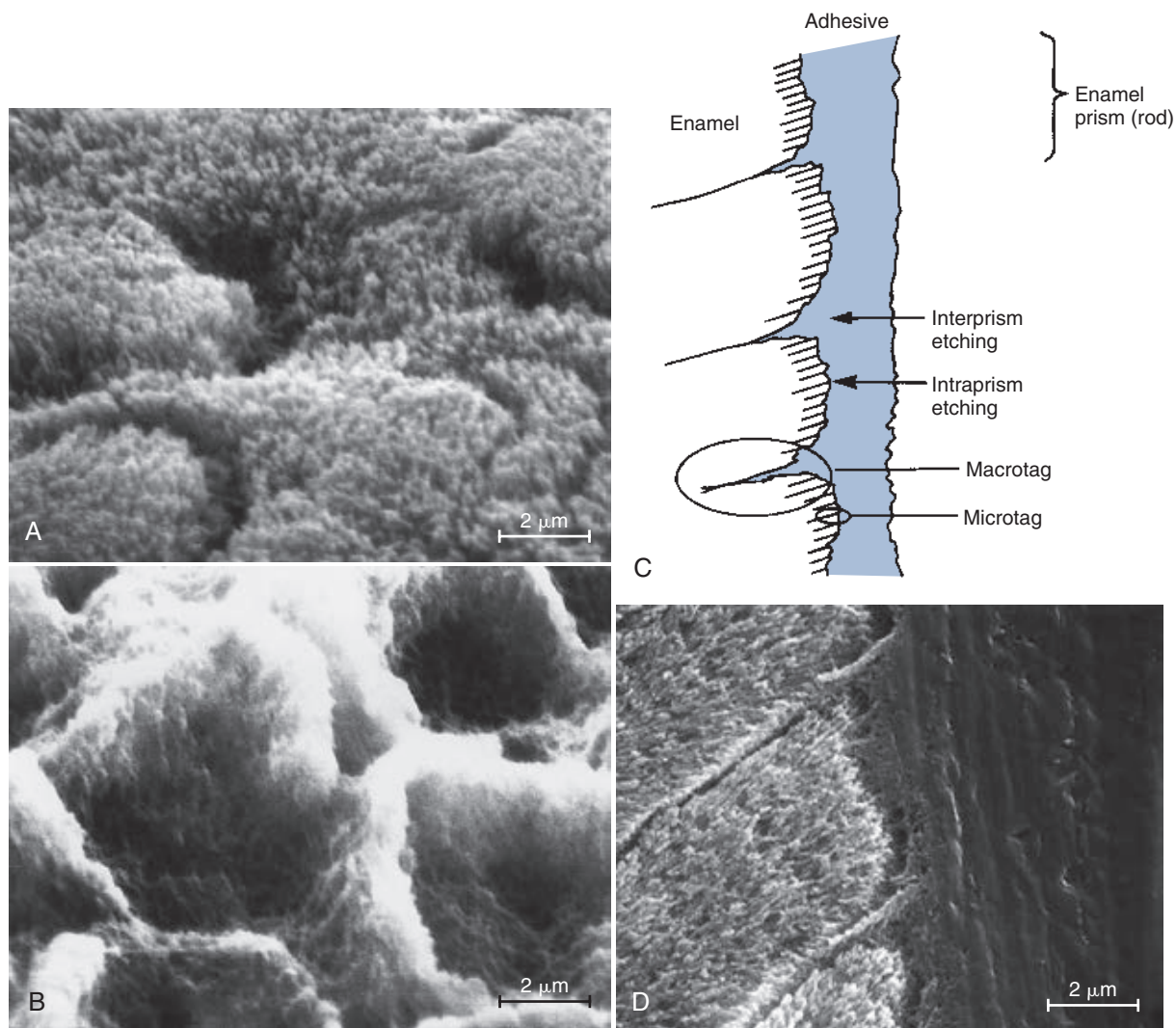
Enamel bonding depends on resin tags becoming interlocked with the surface irregularities created by etching. Resin tags that form between the enamel rod peripheries are called *macrotags* (Online Fig. 18-54).¹²⁷ A much finer network of thousands of smaller tags forms across the end of each rod where individual hydroxyapatite crystals have been dissolved, leaving crypts outlined by residual organic material. These fine tags are called *microtags*. Macrotags and microtags are the basis for enamel micromechanical bonding. Microtags are probably more important because of their large number and great surface area of contact. During the 1970s and 1980s, before these details were known, bonding studies concentrated more on the length of macrotags and the patterns of

etching (type I = core etching; type II = periphery etching; type III = mixed patterns).¹²⁸ Macrotag length is unimportant because fracture occurs in the neck of the tag. Most macrotags are only 2 to 5 μm in length. Rod etching patterns are generally not important to the resulting bond strength.

The bonding system co-polymerizes with the matrix phase of the composite, producing strong chemical bonding. The macroshear bond strength to enamel for the joint is 18 to 22 MPa and is affected by the film thickness of the bonding system and the shear strength of the adjacent enamel rods. The theoretical upper limit for joint strength is probably approximately 50 MPa. The current bond strengths of approximately 20 MPa seem to be acceptable clinically. More than 20 years of clinical monitoring has not revealed any significant degradation of well-formed mechanical bonds owing to fatigue.

DENTIN-AND-ENAMEL BONDING SYSTEMS

Dentin-and-enamel bonding systems, also called simply *dentin bonding systems*, include ingredients that etch (E),

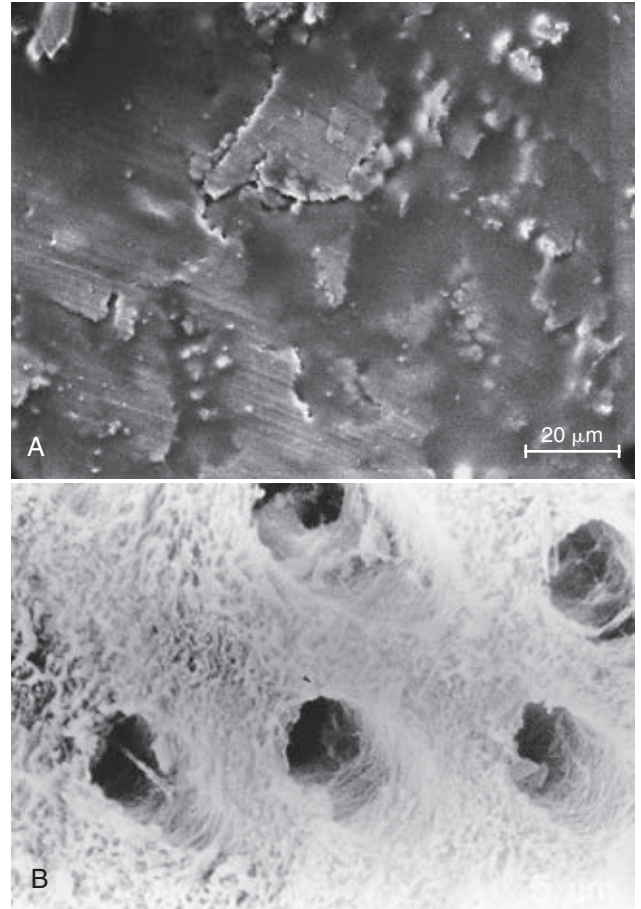


Online Fig. 18-54 Micromechanical retention of bonding systems to dental enamel. **A**, Scanning electron microscopy view of etched enamel shows relief between the enamel rods and within their ends. **B**, Scanning electron microscopy view of enamel bonding agent, from which etched enamel has been removed, with cup-shaped macrotags and thousands of fine microtags on each one. **C**, Schematic cross-sectional view of macrotags and microtags. **D**, Scanning electron microscopy cross-sectional view of interface of enamel bonding agent with enamel revealing microtags between macrotags. (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)

prime (P), and bond (B) to dentin and simultaneously produce enamel bonding. Their bonding agent (B) is similar to what was originally used for enamel-only bonding systems and involves an unfilled (or lightly filled), liquid acrylic monomer mixture placed onto an acid-etched and primed dentin surface. The bonding system primer (P) depends on hydrophilic monomers, such as 2-hydroxyethyl methacrylate (2-HEMA, or HEMA), to easily wet hydrophilic dentinal surfaces that contain some moisture. Although the primer, the bonding agent, or both may flow into the dentinal tubules, the bond strength is primarily achieved by micromechanical bonding to the intertubular dentin (between tubules) along the cut dentinal surface. Despite the fact that many dentin bonding systems have been formulated to allow chemical reactions to take place with dentin, this has made little or no apparent contribution to the final bond strength.¹²⁹ Generally, 90% or more of dentin bond strength is presumed to be from mechanical bonding.

As noted earlier, mechanical preparation of dentin (or enamel) leaves behind a highly distorted debris layer (smear layer) that covers the surface and conceals the underlying structures (Online Fig. 18-55, A). Early enamel-only or dentin-only bonding systems were hydrophobic and were applied directly to the surface of the dentin smear layer. Macroshear bond strengths were found to be less than 6 MPa because that is the strength of the smear layer to sound dentin. Subsequent efforts at dentin etching (E) removed the smear layer, but bond strengths of only 10 to 12 MPa were produced until bonding systems included hydrophilic primers (18–20 MPa). Ideally, dentin etching should produce micromechanical relief for bonding between tubules (within intertubular dentin) but without excessive demineralization of tubular or peritubular dentin. Coupled with hydrophilic primers, bond strengths increased to 22 to 35 MPa. The theoretic limit for strength of future dentin bonding systems may be much higher (80–100 MPa) and greater than that for enamel because dentin is more resistant to shear fracture. The clinically important limit for dentin bonding is unknown. Because of the presence of more water in dentin than enamel, however, the bonding layers are much more complex, and the clinical longevity of dentin bonding systems may not be as long as that of enamel.

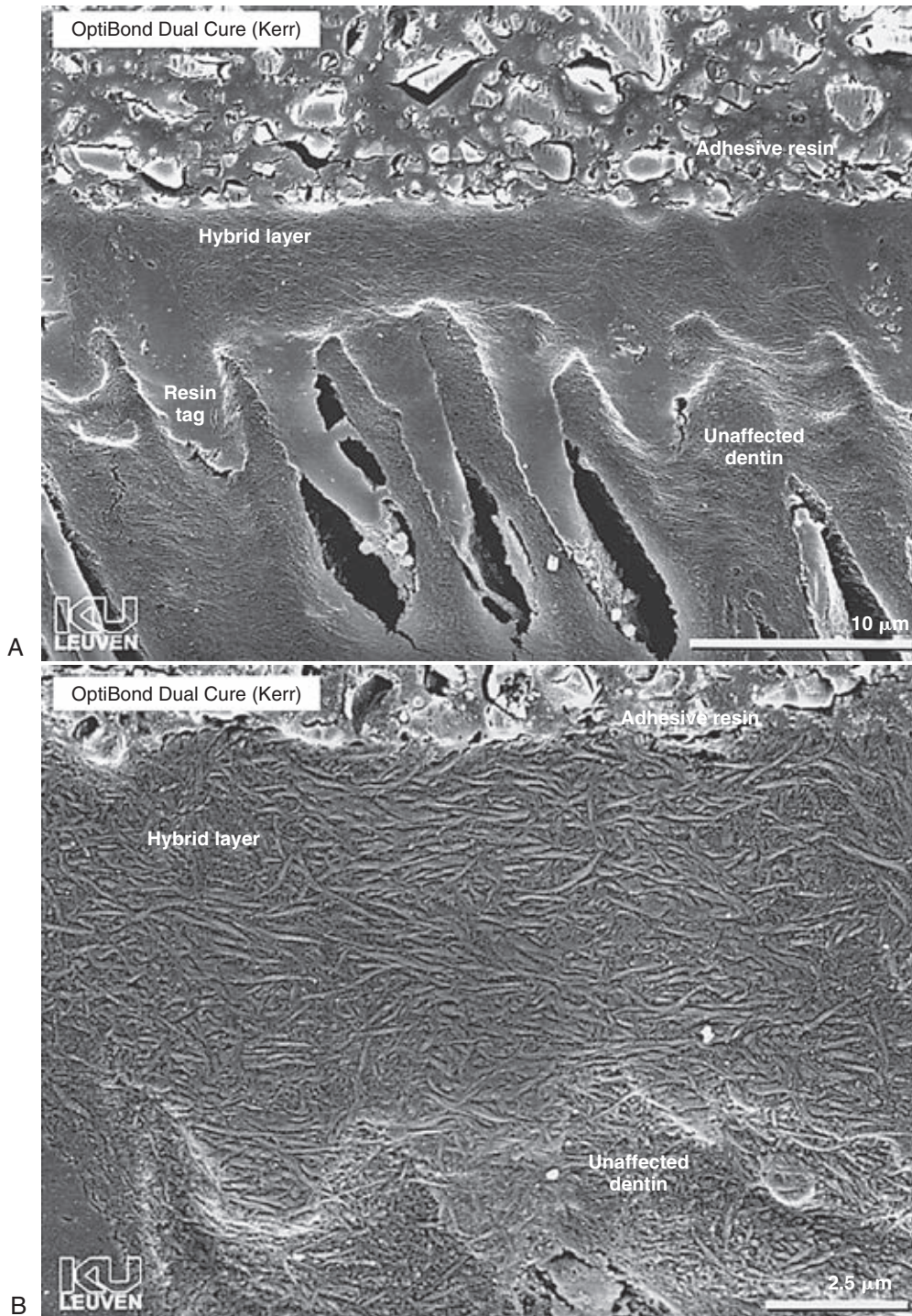
As portrayed in Online Figure 18-56, the priming action in dentin bonding systems is designed to penetrate through any remnant smear layer and into intertubular dentin and to fill the spaces left by dissolved hydroxyapatite crystals.¹³⁰ This action allows acrylic monomers to form an interpenetrating network around dentin collagen. When polymerized, this layer produces what Nakabayashi et al referred to as the hybrid zone (interdiffusion zone or interpenetration zone).¹³¹ Depending on the particular chemistry of a bonding system, the hybrid layer depth may vary from 0.1 to 5 μm . Excessive etching may decalcify dentin to a depth of 1 to 10 μm . If this decalcified dentin zone is not filled (bonded) entirely by the priming agent, it may act as a weakened layer or zone contributing to fracture. In addition, the impact of etching on the remaining strength of the collagen fibers is unknown. The key ingredient for priming in many dentin bonding systems is HEMA (Online Fig. 18-57, A). This molecule is an analog to methyl methacrylate except that the pendant methyl ester is replaced by an ethoxy ester group to make it hydrophilic. It is relatively volatile and has some tendency to produce mild sensitivity.¹³²⁻¹³⁶



Online Fig. 18-55 Scanning electron microscopy views of dentin in various stages of etching. **A**, Unetched dentin with smear layer. **B**, Over-etched dentin revealing intertubular spaces and enlarged dentin tubule openings. (**A**, Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI; **B**, Courtesy of K. Bruggers, School of Dentistry, University of North Carolina, Chapel Hill, NC.)

Dentists and assistants should be aware that it is very mobile, can diffuse through rubber gloves, and causes skin dryness and cracking in many individuals.¹³⁷ During the use of primers and bonding agents, high-volume evacuation should be employed to minimize HEMA vapor contact.

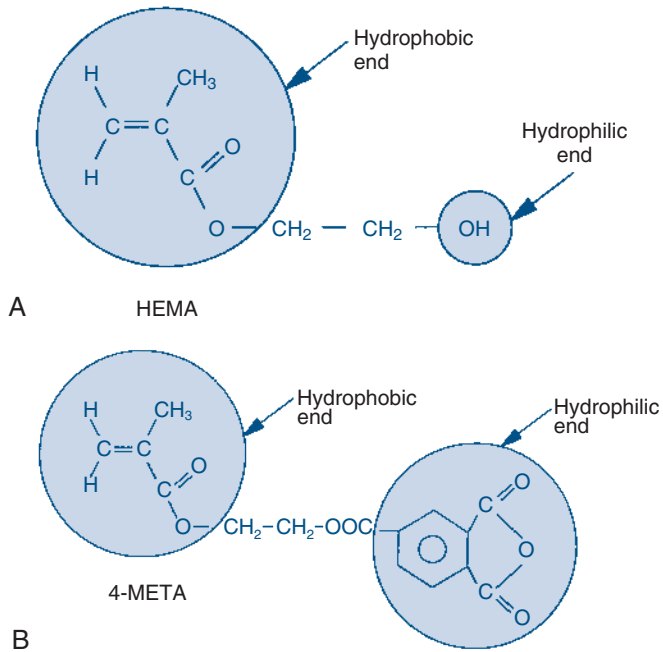
Bonding (Online Fig. 18-58, A) normally has been conducted in three distinct steps (three-component systems, E + P + B) involving etching (E), priming (P), and bonding (B). Phosphoric acid solutions have been used to remove the smear layer on enamel and dentin efficiently (total-etch). Dentin is maintained in a wet condition (wet bonding) or is rehydrated. Priming and bonding agents contain solvents and require multiple applications ($n = 2-5$ layers) to create continuous films effectively over the entire surface of dentin. Priming agents vary considerably, but generally range from 65% to 90% solvent.¹³⁸ Choices for solvent systems (acetone, ethanol, water, or combinations) do affect the wetting efficiency. During the 1990s, the number of stages was reduced by combining the actions of various steps. Two-component systems were devised that employed phosphoric acid etching plus priming or bonding (total etch, E + nPB) or etching or priming with bonding (self-etching, nEP + B). In the latter case, the term *self-etching primer* (SEP) was adopted to describe the



Online Fig. 18-56 Cross-sectional views of micromechanical retention of dentin bonding system. **A**, Schematic view of composite, hybrid layer with microtags, and tubules with resin microtags after dentin dissolution. **B**, Schematic view of resin-impregnation phase, which is responsible for most adhesion, showing the microtags within intertubular dentin as resin wrapped around collagen fibers. (Courtesy of B. Van Meerbeek, Department of Operative Dentistry and Dental Materials, Catholic University of Leuven, Leuven, Belgium.)

bonding system. This is achieved by employing acidic monomers in water-dominated solvent systems that now must dissolve or disrupt the smear layer, dissolve hydroxyapatite in the intertubular zone and tubules, and polymerize to generate a hybrid zone. Dentin bonding systems are available that combine all three stages of dentin bonding into a single package (one-component system). These also rely on

self-etching monomers but are classified as self-etching adhesive systems (SEAs), to distinguish them from SEPs. SEPs and SEAs potentially simplify bonding to enamel and dentin, but they are not yet optimized for other substrates such as ceramic, composite, or amalgam. Three-component systems, which allow procedural modifications to accommodate for different substrate properties (multi-purpose bonding systems),



Online Fig. 18-57 Examples of acrylic monomers used in bonding systems because of their hydrophilicity. **A**, HEMA. **B**, 4-META.

continue to be used. Designing a truly universal one-component bonding system that performs well in all possible bonding situations remains a challenge.

Total-etch bonding systems seem to generate more reliable bonding because of the greater efficiency of smear layer removal by phosphoric acid solutions. The acid is very low pH (typically 0.2–0.8) and has great buffering capacity to remain at low pH throughout the etching step. Monomer acids for self-etch systems are neither as acidic nor as strong in buffering capacity and less likely to remove the smear layer and smear plugs completely. Smear plugs provide some protective sealing and seem to help eliminate any possibility of postoperative sensitivity. Self-etch systems may not produce as reliable bonding as total-etch systems. These events are schematically summarized in [Online Figure 18-58, B](#).

For bonding systems to produce a hybrid layer efficiently, it is crucial to keep the dentin hydrated. Often, the rinsing and drying of dentin that follows tooth preparation or specific etching steps results in dehydrated superficial layers of dentin. Etched dentin no longer contains intercollagen hydroxyapatite crystals (50 volume %). It consists only of the remaining collagen (29 volume %) and water (21 volume %).¹³⁹ Dehydration, whether intentional or not, causes the remaining collagen sponge to collapse, with collagen molecules forming a mat and excluding the monomers necessary for hybrid layer formation. Etched dentin must be kept moist or be intentionally rehydrated. Rehydration can be accomplished with a moist cotton pledget or applicator tip in contact with the surfaces for approximately 10 seconds or by using rewetting agents. If dentin moisture is inadequate, the hybrid layer does not form, and the bonding system fails to seal and bond. It is suspected that inadequate precautions in this regard in many bonding instructions during the early 1990s may have contributed to the premature failure of many dentin bonding systems.

Recommendations for air-thinning during the application of dentin bonding components (particularly primers and bonding agents), have been made. These materials contain substantial solvent and often pool in crevices such as line angles of tooth preparations. Aggressive air-thinning, however, actually removes material from dentinal surfaces. All current bonding system instructions simply recommend gentle air-drying to facilitate solvent evaporation without disturbing the bonding material surfaces. SEPs and SEAs are primarily in water solutions and benefit by gentle air-drying for about 10 seconds.

Dentin sealers have been popular as a means of minimizing postoperative sensitivity. They are applied onto dentin before bonding procedures are undertaken. Their mechanism of action is not clear. Glutaraldehyde-containing materials are proposed to act on the contents within the ends of the dentinal tubules, however, encouraging sealing of the tubules. Occasionally, these materials may interfere subsequently with the bonding abilities of dentin bonding systems or certain dental cements.

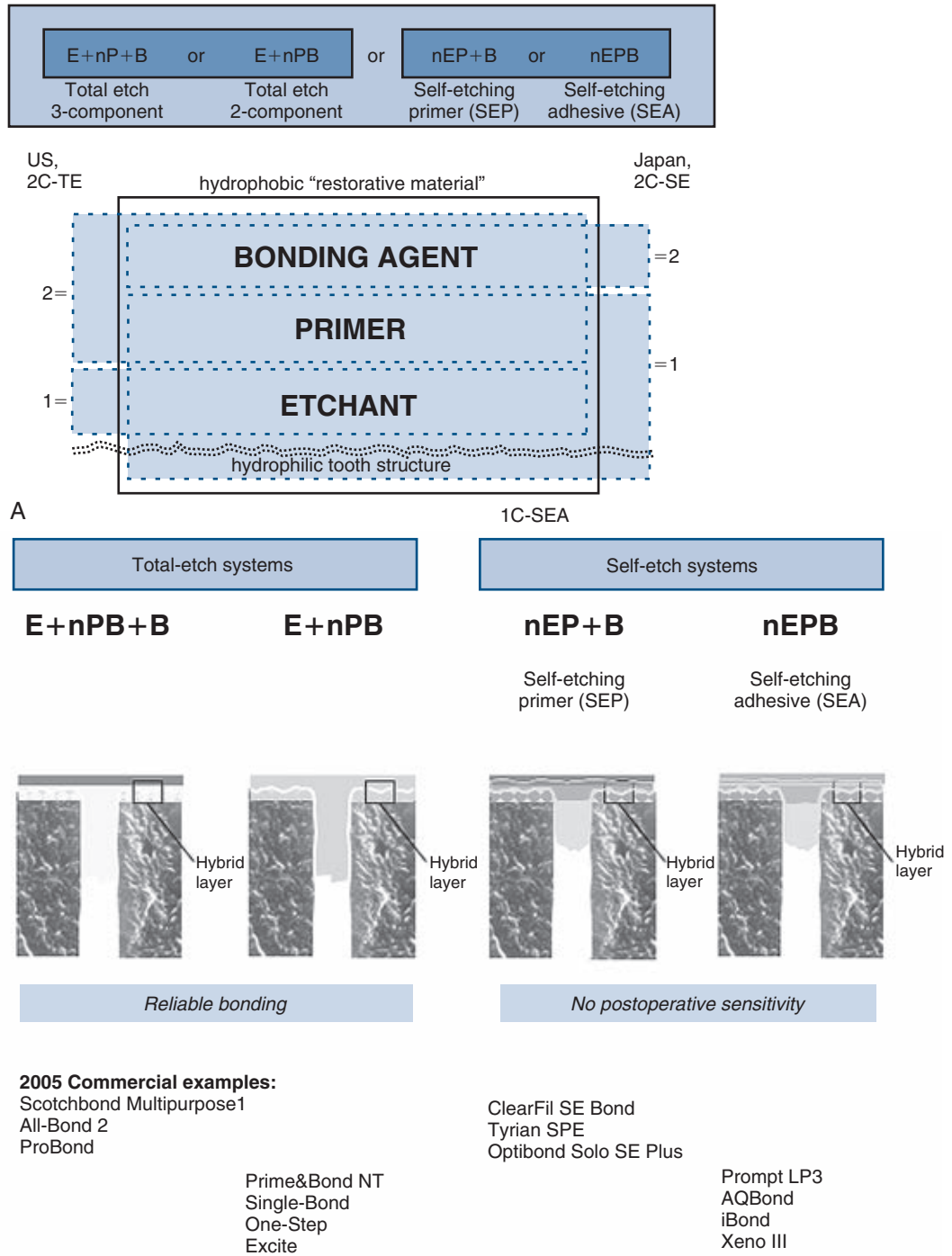
AMALGAM BONDING SYSTEMS

Amalgam bonding systems may be used to seal underlying tooth structure and bond amalgam to enamel and dentin. They require dual characteristics to achieve optimal wetting. Amalgam is strongly hydrophobic, whereas enamel and dentin are hydrophilic. The bonding system must be modified with a wetting agent (co-monomer) that has the capacity to wet hydrophobic or hydrophilic surfaces. Typical dentin bonding systems may be used, but special 4-methoxyethyl trimellitic anhydride (4-META)-based systems are used frequently. This monomer molecule contains hydrophobic and hydrophilic ends (see [Online Fig. 18-57, B](#)).

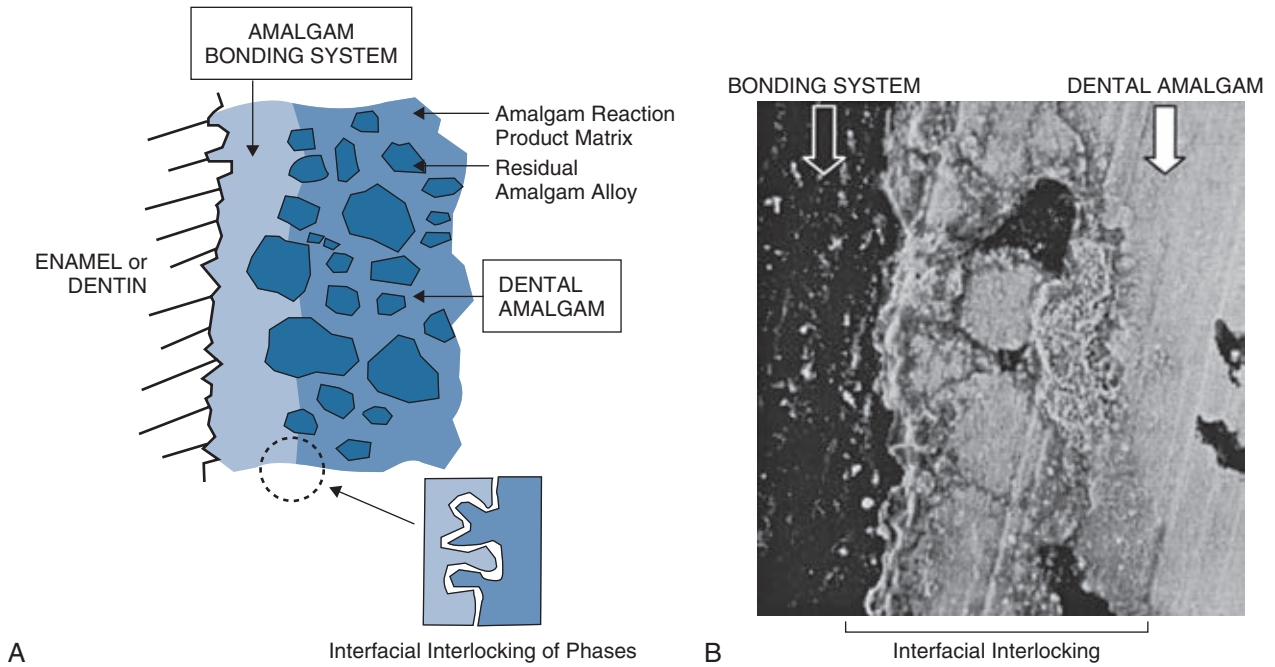
Macroshear bond strengths for joining amalgam to dentin are relatively low (2–6 MPa). Although good bonding to the tooth structure occurs, micromechanical bonding at the interface of amalgam and the bonding system is poor. Most debonding occurs by fracture along this interface. Because no chemical bonding occurs at this interface, it is important to develop micromechanical bonding. To accomplish this, the bonding system is applied in much thicker layers (10–50 μm) so that amalgam being condensed against the resin adhesive layer forces the fluid components of amalgam to squeeze into the unset bonding adhesive layer and produce micromechanical laminations of the two materials ([Online Fig. 18-59](#)). Thicker bonding agent films can be produced by adding thickening agents to the unset bonding materials or by applying many (five to eight) applications of bonding material.

The primary advantages for amalgam bonding agents in most clinical situations are the dentin sealing and improved resistance form, but the increase in retention form is not significant. Adhesion of amalgam to tooth structure is unnecessary in clinical circumstances where satisfactory retention and resistance forms of tooth preparation already exist. The primary indication for amalgam bonding is when weakened tooth structure remains, and bonding may improve the overall resistance form of the restored tooth. Even so, routine bonding of all amalgam restorations is not justified.

If the sealing of amalgam preparations is the sole purpose for bonding, an alternative is the use of dentin sealers. The earliest version of such a system was the primer component of a dentin bonding system (now marketed as Gluma



Online Fig. 18-58 Summary of the historical evolution of bonding systems. **A**, The original bonding system design was a three-component design (etchant, primer, bonding agent; abbreviated as 3C-TE = E + nP + B) based on employing phosphoric acid solution (total-etch = TE) to etch enamel and dentin. This sequence cleans the smear layer off of dentin and enamel, relieves the surface by dissolving part of the hydroxyapatite phase of enamel and dentin for micromechanical bonding, penetrates the hydrophilic surface with primer, and bridges the hydrophilic primer to the hydrophobic restorative material with an intermediate film called a bonding agent. U.S. dental manufacturers combined primer and bonding agent solutions to produce two-component total-etch systems (2C-TE = E + nPB). Japanese dental manufacturers substituted an acidic monomer for phosphoric acid (SE = self-etching) that would etch first and then behave as a polymerizable monomer (2C-SE = nEP + B = SEP = self-etching primer). The first all-in-one package or self-etching adhesive system (3C-SE = SEA) appeared in Europe in the late 1990s. The current emphasis is to combine SEP or SEA systems into the matrix phase of restorative materials and eliminate the need for a bonding system at all. **B**, Explanation of the events during dentin bonding. Dentin contains a thin smear layer (left most figure) with some of the material forced into tubule openings to generate a smear plug. The smear layer interferes with the development of strong bonding to the intertubular dentin (between the tubules) and is removed by etching. Total-etching systems dissolve the smear layer and inadvertently remove the smear plug. Primers flow into the intertubular space to wrap around collagen and produce a hybrid layer, but at the same time fill the openings of the tubules. That material is neither well cured nor well adapted to the dentinal surfaces and does not contribute much to dentin bond strength. Self-etching systems (SEP and SEA) use much weaker acids (acidic monomers) and are challenged to dissolve or penetrate the smear layer and intertubular dentin, much less dissolve the smear plug. They often have less well-formed hybrid layers but do provide better overall sealing because much of the smear plug remains in place. (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)



Online Fig. 18-59 Amalgam bonding. **A**, Schematic view of the adhesive joint created with amalgam bonding system. Micromechanical bonding holds the bonding agent to the surface of the etched and primed tooth structure. Thick unset bonding agent becomes interdigitated along the interface with residual amalgam alloy particles and amalgam matrix to create micromechanical interlocking. **B**, Cross-section of set amalgam (right) intermixed with set bonding agent (left) to create micromechanical bonding. (**A**, Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI; **B**, Courtesy of J. Perdigão, Division of Operative Dentistry, University of Minnesota, Minneapolis, MN.)

Desensitizer, Heraeus Kulzer). Since the introduction of that product, several others have been developed; these are essentially primer monomers or polymers dissolved in solvent that penetrate and seal dentinal tubules. The action of this film is similar to that of varnish except that the film has much better wetting characteristics and produces a more impervious surface. The film covers enamel and dentin but is still categorized as a dentin sealer. Because the same material may be used over open dentinal tubules on exposed root surfaces to eliminate fluid flow and desensitize dentin, dentin sealers also are known as *dentin desensitizers*. An expansive list of other products includes those that are also considered dentin desensitizers but are not routinely used to seal dentin under amalgam restorations.

Bonding systems used below insulating restorations such as composite do not use traditional liners and bases except when the tooth excavation is extremely close to the pulp (RDT <0.5 mm). In that case, a traditional calcium hydroxide liner is used for pulpal medication, to stimulate reparative dentin (see Online Fig. 18-45).

PORCELAIN AND CERAMIC REPAIR SYSTEMS

Fractured regions on porcelain-fused-to-metal (PFM) or two-phase all-ceramic restorations may be repaired by etching the surface with hydrofluoric acid to clean and produce micromechanical relief, silanating the etched ceramic material to enhance wetting and create chemical bonding, applying a bonding system, and adding composite to replace the missing material. This is not a long-term solution to the problem, but it does provide an immediate alternative to complete replacement of the original restoration. Wetting of ceramic materials by bonding materials is different from that for dentin and may

not work well with all bonding systems. If the substrate being repaired includes exposed metal alloy on a portion of a PFM restoration, the metal should be sandblasted and etched to enhance retention.

CAST RESTORATION BONDING OR LUTING SYSTEMS

Cast restorations are retained in teeth by appropriate preparation design and by dental cements, whose structure and properties are detailed later in this chapter. Adhesion includes cement adaptation to surface irregularities of enamel and dentin (dental luting cement) in a way that helps prevent the restoration's withdrawal along the original path of insertion. Cements also may be chemically adhesive (polycarboxylate or glass ionomer), but most cement bond strength results from mechanical adhesion. Luting is limited by the relatively poor wetting, high viscosity, and relative thickness of luting cement. If the cement does not wet well, fractures propagate easily next to the cement along the restoration or dentinal interfaces. If the cement is more hydrophilic and wets dentin well, fractures propagate within cement and follow the weakest portion in the joint. The adhesive joint is improved further by using the strongest cements (composite or resin cements), roughening and etching the casting surfaces and dentinal surfaces, using bonding systems on both surfaces, and minimizing the cement thickness in the adhesive joint.

These same principles apply to all other situations involving adhesion and adhesive joints in dentistry (see Online Fig. 18-50), such as sealants, bonded orthodontic brackets, denture adhesives, PFM bonding, and osseointegration of implants. In some cases, adhesion involves several interfaces and is complex.

Pit-and-Fissure Sealants

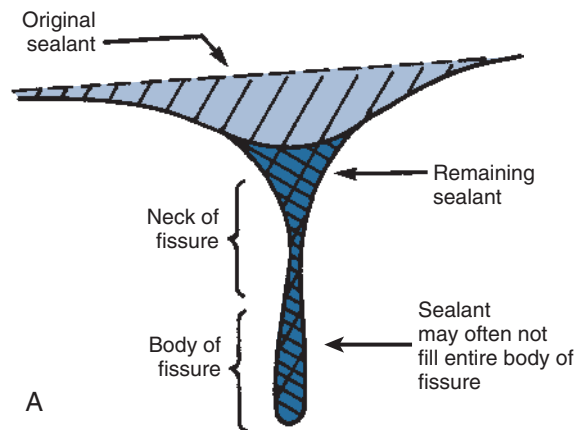
Terminology

Pit-and-fissure sealants were first proposed for dentistry in the late 1960s. They provide an alternative to tooth preparation and restoration techniques for elimination of caries-prone pits and fissures on occlusal surfaces. Pits and fissures, which are not self-cleansing, are considered caries-prone. Normally, they accumulate organic debris and oral bacteria, providing an ideal site for the development of caries. The objectives of pit-and-fissure sealants are simply to eliminate the geometry that harbors bacteria and to prevent nutrients reaching bacteria in the base of the pit or fissure. Sealants are used to occlude portions of these sites that are not self-cleansing. Any material placed to seal these sites tends to overfill the area. Because sealant has only modest wear resistance, contact area wear and food abrasion may wear it away quickly from naturally self-cleansing areas where it is not needed. Key areas remain occluded, however, resulting in continued benefits.

The principal feature of a sealant required for success is adequate retention. Most pits and fissures have some degree of macroretention. Penetration to the deepest recesses of these sites is limited, however, by debris in the fault, inadequate access, or sealant viscosity. Micromechanical retention is required as well. After gross debridement, isolation, and acid etching of surfaces, sealant is applied, but it tends to run into self-cleansing areas as well. If necessary, the sealant must be adjusted such that it does not interfere with normal occlusal contacts or disrupt occlusal paths. Remaining sealant blocks bacterial accumulation occurring in otherwise non-self-cleansing locations (Online Fig. 18-60).

Classification

Sealants are categorized in terms of polymerization method, as self-curing or visible light-curing. Early sealants were based on methyl methacrylate or cyanoacrylate cements. Most contemporary compositions are unfilled (or only lightly filled) and based on di-functional monomers such as those used for the matrix of composites. The principal monomer in these systems (e.g., BIS-GM; see the section on historical development) was largely replaced in the late 1990s by BIS-GMA-like analogs for political reasons, as will be discussed shortly. The principal monomer may be diluted with lower molecular weight species (e.g., triethylene glycol dimethacrylate [TEGDMA, also abbreviated TEGDM]) to reduce the viscosity. Small amounts of a colorant such as titanium dioxide may be added to make the appearance slightly different from occlusal enamel. Otherwise, the clear sealant is difficult to locate during clinical inspection and evaluation on recall. Self-curing compositions have the advantage of curing quickly enough that they are retained in sites whose orientation may encourage flow away from the area. Self-curing materials have to be applied when they are fluid enough to penetrate the pit or fissure so that they begin to cure before running away from the site. This combination of characteristics sometimes causes problems in obtaining adequate penetration. If occlusal surfaces are appropriately oriented during the procedure to control flow, light-curing materials are actually simpler to use. They can be applied and allowed to flow for a convenient time before exposure to a visible light source for curing.



Online Fig. 18-60 Fissure sealants. **A**, Schematic view of idealized fissure after sealing and after loss of excess sealant. **B**, Scanning electron microscopy cross-section of sealed fissure. The sealant does not penetrate into the entire fissure. Excess sealant on occlusal surface has been mostly worn away to the boundary of the self-cleansing zone. (**A**, From Bayne SC, Barton RE: *Dental materials for direct restorations*. In Richardson RE, Barton RE, editors: *The dental assistant*, ed 6, Philadelphia, 1988, Lea & Febiger; **B**, Courtesy of S. Mitchell, School of Dentistry, University of North Carolina, Chapel Hill, NC.)

Composition, Structure, and Properties

Because the primary clinical property is flow into small access spaces, a penetration coefficient is normally calculated for comparison of products. It describes the relative rate of flow in a standard-sized orifice. Penetration is a function of

Online Table 18-13 Penetration Coefficients for Sealants and Surface Sealers

Sealant System	Penetration Coefficient (cm/s)
Adaptic bonding agent	12.8
Delton pit-and-fissure sealant	7.22 10
Concise enamel bond	6.4 4.8
Nuva Seal	3
Concise white sealant	2.43
Adaptic glaze	0.62

Adapted from Fan PL, et al: Wetting properties of sealants and glazes, *Oper Dent* 4:100–103, 1979; O'Brien WJ, et al: Penetrativity of sealants and glazes, *Oper Dent* 3:51–56, 1978; Retief DH, Mallory WP: Evaluation of two pit and fissure sealants: an in vitro study, *Pediatr Dent* 3:12–16, 1981.

capillary action and viscosity. If the site is well cleaned, etched, rinsed, and dried, acrylic monomers such as bisphenylglycidyl dimethacrylate (BIS-GMA) tend to wet the surface reasonably well. Even if the opening in the pit or fissure is small, if the wetting is adequate, capillary action tends to draw the material into the orifice. The viscosity must be low enough, for a long enough time, for the material to penetrate into the defect site. Penetration coefficients for first-generation sealants are provided in [Online Table 18-13](#).

Complete penetration of the sealant is not absolutely critical. It is possible to occlude only the neck region of a fissure and produce clinically acceptable results. An example of a fissure is shown in [Online Figure 18-60, A](#). An example of a typical cross-sectional view is shown in [Online Figure 18-60, B](#). Quite often, the local geometry creates a defect with a wide orifice.

Glass ionomer sealants have not performed as well for pit-and-fissure applications. They generally have displayed poorer abrasion resistance, have been brittle, and have been prone to fracture. Traditional composites, by themselves, are not good sealants because they do not penetrate as easily into pits and fissures because of their comparatively high viscosity. They may be involved, however, in treating pit-and-fissure caries, especially when used with a bonding adhesive, because the bonding system adhesive is similar to a sealant material. If a fissure is minimally carious, excavation of the caries and restoration with a small composite provides conservative management of the defective enamel region.

Low-viscosity versions of composites, flowable composites (see the section on composites later in this chapter), have been advocated for a wide range of applications including pit-and-fissure sealants. They have better wetting, sufficient flow, adequate abrasion resistance, and effective fracture resistance. One of the earliest flowable composites was a pit-and-fissure sealant, to which a modest amount of filler had been added.

The properties of sealants are essentially those of the resin matrix component of composite materials. Evidence that water absorption, chemical degradation, or other events observed with composites detract from the longevity of these materials does not exist. Some controversy existed concerning the BIS-GMA monomers in sealants. In 1994, a single report

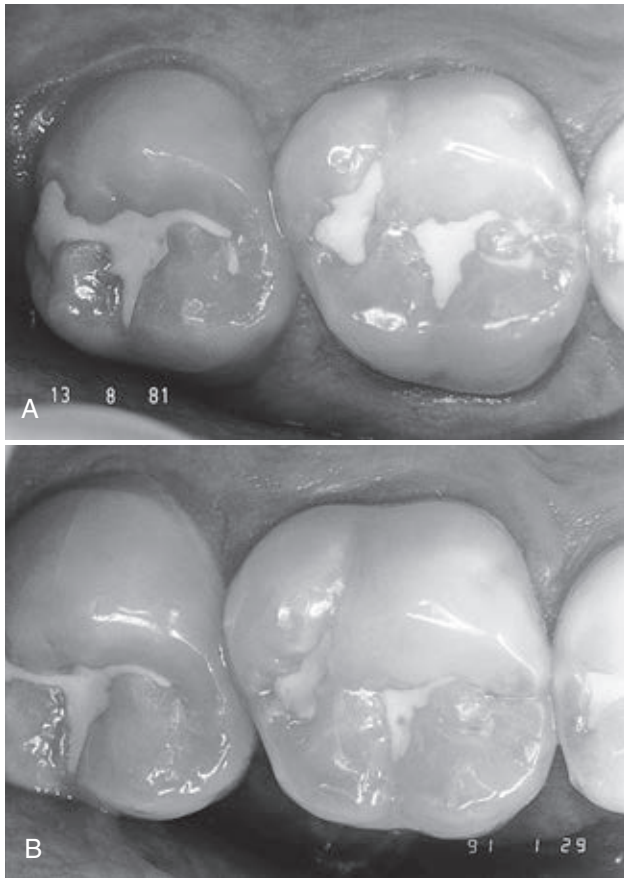
suggested that BIS-GMA (produced from bisphenol-A and glycidyl methacrylate reaction) could be decomposed into its constituents releasing bisphenol-A. Bisphenol-A is known to be an estrogenic material.¹⁴⁰⁻¹⁴² Further investigation revealed many scientific problems with this report, such as the misidentification of triethylene glycol dimethacrylate (TEGDMA) as bisphenol-A. To avoid political controversy over the safety of these materials, manufacturers quickly switched to alternative monomers that did not include bisphenol-A as a precursor. Another problem with the original report was that measured levels of monomer released from sealants seemed unusually high. It was not noted during the sampling procedure that the air-inhibited superficial layer (see the section on composites) of resin had not been removed by wiping with a cotton roll before sampling the sealants. This small layer generally is wiped away or quickly lost during the first few chewing strokes. This material is not representative of the actual cured sealant material below. Even so, sealants are not totally innocuous. Some of the diluent monomer (TEGDMA) remains unreacted (residual monomer) and is slowly diffused out of the sealant. The small amount and the very long period of release (see the earlier section on biocompatibility) suggest that only minimal health risk would ever be involved.

Clinical Considerations

During the early 1970s, numerous clinical studies were initiated to determine the relative reduction in caries possible with sealant use and the clinical longevity of sealants. Simonsen reported excellent clinical success after 15 years with teeth sealed only with a single application of sealant.¹⁴³ Prevention of occlusal caries at defects depends simply on the exclusion of bacteria or their nutrients ([Online Fig. 18-61](#)). Numerous clinical investigations have shown that as long as pits and fissures remain completely sealed, 100% prevention of caries at those sites is possible.^{144,145} As long as the sealant is retained and seals the necks of pits and fissures against leakage, it achieves this end. Sealant types differ in short-term and long-term retention.¹⁴⁶

Absolutely no evidence indicates that sealant ever completely wears away. If the sealant is lost or leaks, the site is again at risk for caries. The sealant may be lost because of failure of the acid etching or the micromechanical retention to the acid-etched surface. It is common for saliva or moist air contamination to interfere with the effects of acid etching. Loss of sealant from areas that are not self-cleansing is, however, minimal.

The ideal time to apply sealants is soon after occlusal surfaces erupt into the oral environment. At that time, very little of the tooth has erupted, however, and it is difficult or impossible to use a rubber dam for moisture control. Cotton rolls or absorbent wedges or both may be used instead. Without special care, some contamination of the acid-etched enamel commonly occurs. This contamination prevents resin penetration into micromechanical spaces and leads to premature failure. During recalls, if the sealant has been lost, it can be reapplied. With careful management and repair of sealed surfaces, it is possible to achieve 100% reduction in occlusal caries in those areas. It is suspected that in some cases, careful sealant recalls, re-evaluations, repairs, and necessary replacements do not occur in a timely manner. In these cases, it is possible that leaking sealants may place the underlying pits and fissures at greater-than-normal risk. This is an unfortunate sequela of



Online Fig. 18-61 Example of function of sealant on first molar after 5 years (A) and 15 years (B) of clinical service. Some abrasion of sealant has occurred in occlusal areas that appear self-cleaning. (From Simonsen R: Retention and effectiveness of dental sealant after 15 years, *J Am Dent Assoc* 122 (10):34-42, 1991.)

presuming that sealant application automatically provides long-term service.

Sealants also are a common strategy for managing older patients whose risk for caries increases as a result of reduced saliva flow and more difficulty in maintaining effective oral hygiene. No clinical studies, however, have shown the effectiveness of sealants in these circumstances. Sealants also have been applied to smooth-surface tooth structures in an attempt to eliminate caries. For smooth surfaces, however, fluoridated water is effective in reducing caries prevalence. Sealants that have been applied to smooth surfaces are abraded by food, toothbrushes, or both and may be lost at relatively rapid rates. Because toothbrush bristles are large, they do not affect the sealants in pits and fissures.

Fluoride-containing sealants have been investigated. The contribution of fluoride in these circumstances may be small at best. Clinical studies in which sealants were used to seal fissures that were minimally carious produced complete inhibition of the caries process. Fluoride modification of the enamel would not seem to be beneficial. Another important consideration for sealant use is the degree to which children and adolescents are susceptible to caries. Strong evidence supports the presence of two categories of young patients, one with a caries predisposition much greater than the other. This

latter category of patients would benefit the most from the use of pit-and-fissure sealants. One sure indication of apparent caries susceptibility is a dental history of caries on the occlusal surfaces of primary teeth.¹⁴⁷⁻¹⁴⁹ If all individuals were being examined routinely by a dentist, their record would provide simple evidence to determine whether or not to apply sealants to the permanent teeth. Older patients with reduced saliva flow are at increased risk for caries and should be considered candidates for sealants.

Sealants also are used to repair or seal leaking or failing dental restorations.¹⁴⁶ Sealants have shown great usefulness in sealing poor margins of amalgam restorations for 15 years.¹⁵⁰ In some cases, sealants also have been used successfully to seal surfaces of incipient carious lesions adjacent to existing restorations.

Despite the enormous long-term benefit for patients with sealed pits and fissures, this prevention method was used routinely by only approximately 16% of dental practices in the United States in 1992. When the first sealants were placed several decades ago, a high level of technical difficulty led to early failure. For many years, some dentists expressed limited enthusiasm for prevention. Frustration was associated with delayed commitment by insurance carriers to reimburse dental practices for these procedures. It is now accepted that sealants provide outstanding service, when done properly, for very low costs. In societies committed to dental care, this is a core strategy for early management of caries. Annual local and national drives to provide free or low-cost applications have re-energized interest in sealants.

An interesting adjunct preventive technique has been the use of fluoride varnishes.^{151,152} Fluoride varnishes first appeared in clinical practice in the late 1960s in Europe, about the same time as pit-and-fissure sealants, but were not adopted for use in the United States until the late 1990s.¹⁵³ Because of the fluoride-releasing levels of these materials, they are treated as medical devices and strictly regulated by the FDA. Clinical trials on effectiveness have been exclusively conducted in children, to date, and have shown excellent effectiveness.¹⁵⁴ The only clinical disadvantage is the temporary discoloration of teeth.

Fluoride-containing varnishes (e.g., Duraphat [Colgate Oral Pharmaceuticals, New York, NY], Fluor Protector [Ivoclar Vivadent, Amherst, NY]) are intended only as temporary films on teeth that extend the contact time of fluoride with existing tooth structure.¹⁵⁵ They remain on the tooth structure for many hours, affording more opportunity to produce fluoride-modified hydroxyapatite that is more acid resistant (i.e., more caries resistant) and accelerating the remineralization of early carious lesions. These are generally considered as effective as or more effective than topical fluoride treatments. These varnishes contain a film-forming agent (e.g., as ethyl cellulose or collodion), releasable fluoride, solvents, and wetting agents. The varnish is applied to teeth with a brush, cotton-tip applicator, or syringe-type applicator in a couple of minutes, during which time it dries to coat the tooth surfaces. To maintain the fluoride effect, the varnish should be reapplied at least every 6 months.²⁶ The main cariostatic effect of fluoride varnishes is the remineralization of early carious lesions. Fluoride varnishes almost always are used in combination with other preventive strategies such as sealants, fluoride-containing dentifrices, topical fluorides, and fluoride mouthrinses, and their effect is only one contribution to caries reduction on pits and

fissures and on smooth surfaces. Its relative contribution may be only 30% of the overall reduction in caries.¹⁵⁶

Composites

Terminology

A *composite* is a physical mixture of materials. The parts of the mixture generally are chosen with the purpose of averaging the properties of the parts to achieve intermediate properties. Often, a single material does not have the appropriate properties for a specific dental application. A schematic view of a generalized composite was presented earlier in [Online Figure 18-5](#).

Composites typically involve a dispersed phase of filler particles distributed within a continuous phase (matrix phase). In most cases, the matrix phase is fluid at some point during the manufacture or fabrication of a composite system.

A dental composite traditionally has indicated a mixture of silicate glass particles within an acrylic monomer that is polymerized during the application. The silicate particles provide mechanical reinforcement of the mixture (reinforcing fillers) and produce light transmission and light scattering that adds enamel-like translucency to the material. The acrylic monomers make the initial mixture fluid and moldable for placement into a tooth preparation. The matrix flows to adapt to tooth preparation walls and penetrate into micromechanical spaces on the surfaces of etched enamel or dentin.

Because the flow of uncured composite is limited, most composite manufacturers provide a bonding system. Bonding systems are primarily unfilled acrylic monomer mixtures, similar to the matrix of the composite, that are preplaced onto etched tooth surfaces to form a 1- to 5- μm film. It micromechanically interlocks with the etched surfaces, seals the walls of the preparation, and co-polymerizes with the composite restorative material that fills the tooth preparation. Dentin and enamel bonding systems may be provided as part of the composite product package.

Although dental composite or composite is the technically correct term for these materials, various terms have been widely accepted as well. Composites often have been called *composite restorative materials*, *filled resins*, *composite resins*, *resin composites*, *resin-based composites*, and *filled composites*. These alternative terms become more confusing as the field of dental polymers becomes more sophisticated and simultaneously more complex. In this book, the term *composite* is used. Most biomaterials are composites of some type. If these compositions are modified to include special polymer phases, they may be called *resin-containing composites*. Glass ionomer cements have been modified with polymer-containing fillers and monomer-containing matrices. They are classified as hybrid or resin-modified glass ionomers but could equally well be described as modified composites.

Many dental tissues are actually biologic composites. Enamel is a composite of 11% water, 2% noncollagenous proteins, and 87% hydroxyapatite crystals by volume. Dentin is a composite of 21% water, 5% noncollagenous proteins, 27% collagen, and 47% hydroxyapatite crystals by volume.

Historical Development

Early attempts at esthetic filling materials that predated acrylic resins and composites were based on silicate cements. These

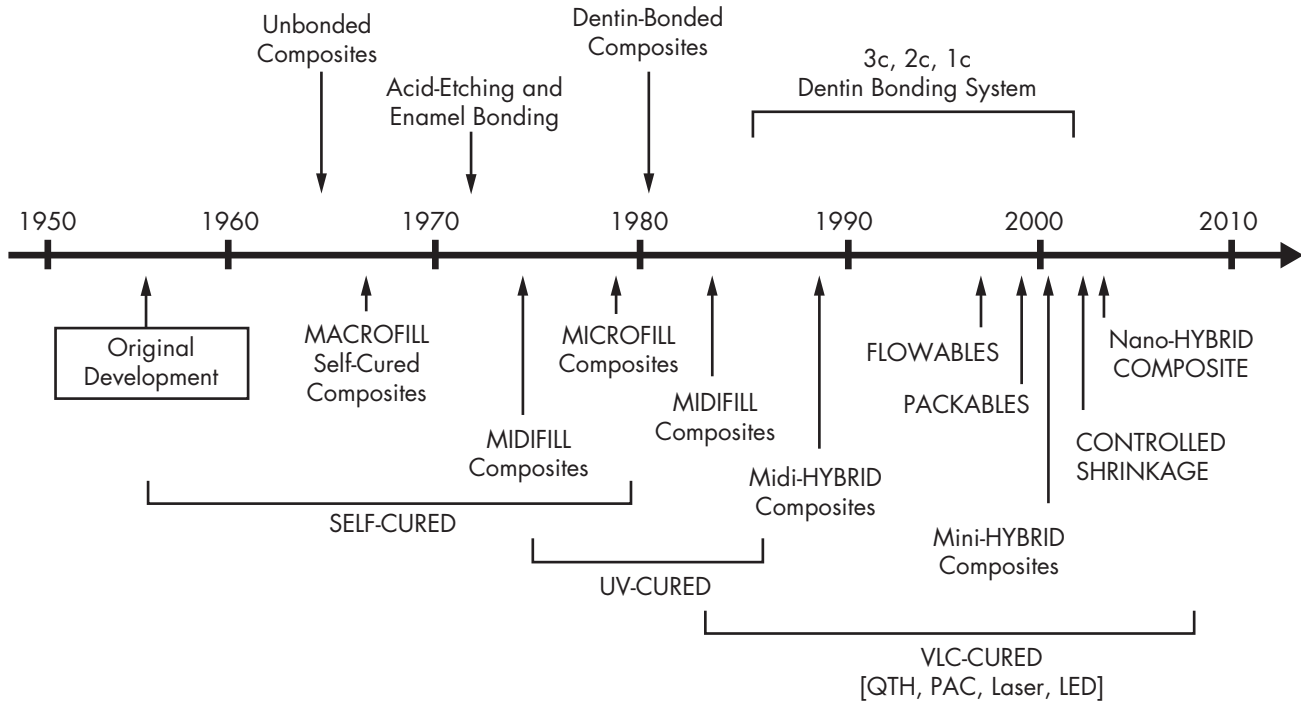
cements resulted from reactions of phosphoric acid with acid-soluble glass particles to form a silica gel matrix containing residual glass particles. Solubility problems with these materials led to the introduction of unfilled acrylic systems based on PMMA. Methyl methacrylate monomer contracted excessively during polymerization, permitting subsequent marginal leakage. Also, PMMA was not strong enough to support occlusal loads. Reinforcing ceramic fillers, principally containing silica, were added to the composition. Retrospectively, the original PMMA materials now are called *unfilled acrylics*. If the amount of filler or filler-like phase added to a resin matrix is small, the overall composition is considered unfilled; 1% to 2% filler-modified sealant compositions are still classified as unfilled. [Online Figure 18-62](#) is a schematic summary of the evolution of composites, their curing systems, and their associated bonding systems. During the 50-year history, the feature that dominated composite design was the reduction in average particle size of fillers and increased levels of fillers.

Methyl methacrylate-based matrices were supplanted by BIS-GMA. BIS-GMA is a di-functional monomer originally produced as the reaction product of bisphenol-A and glycidyl methacrylate ([Online Fig. 18-63, A](#)).¹⁵⁷ Several analogs of BIS-GMA have been investigated (modified BIS-GMA). Another similar di-functional molecule used in composites is urethane dimethacrylate (UDMA). UDMA replaces the bisphenol-A backbone with a linear isocyanate one (see [Online Fig. 18-63, B](#)). BIS-GMA and UDMA are extremely viscous. For practical purposes, they are diluted with another di-functional monomer with an aliphatic backbone, TEGDMA, of much lower viscosity (see [Online Fig. 18-63, C](#)).

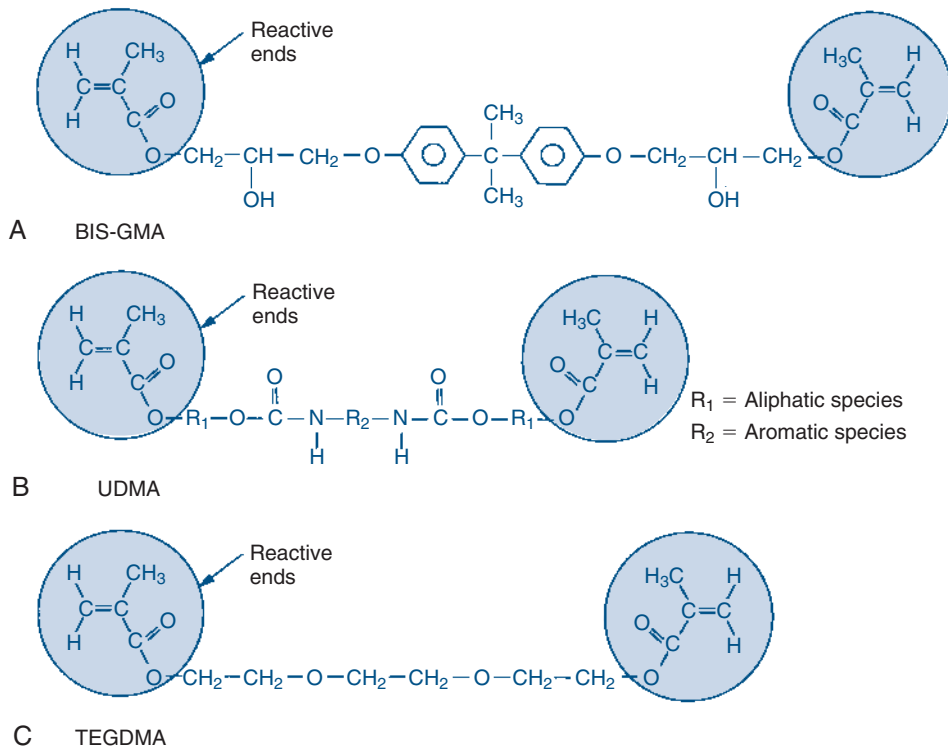
To gain the full advantage of a composite formulation, it is important to provide interfacial bonding between the phases. In modern composites, silica particles are precoated with monomolecular films of silane coupling agents ([Online Fig. 18-64](#)). These molecules are di-functional. One end is capable of bonding to hydroxyl groups, which exist along the surface of the silica particles, and the other end is capable of co-polymerizing with double bonds of monomers in the matrix phase. Coupling agents work best with silica particles. All composites have been based on silica-containing fillers.

Filler compositions often are modified with other ions to produce desirable changes in properties. Lithium and aluminum ions make the glass easier to crush to generate small particles. Barium, zinc, boron, zirconium, and yttrium ions have been used to produce radiopacity in the filler particles. Excessive modification (by replacement of the silicon in the structure) can reduce the efficacy of the silane-coupling agents.

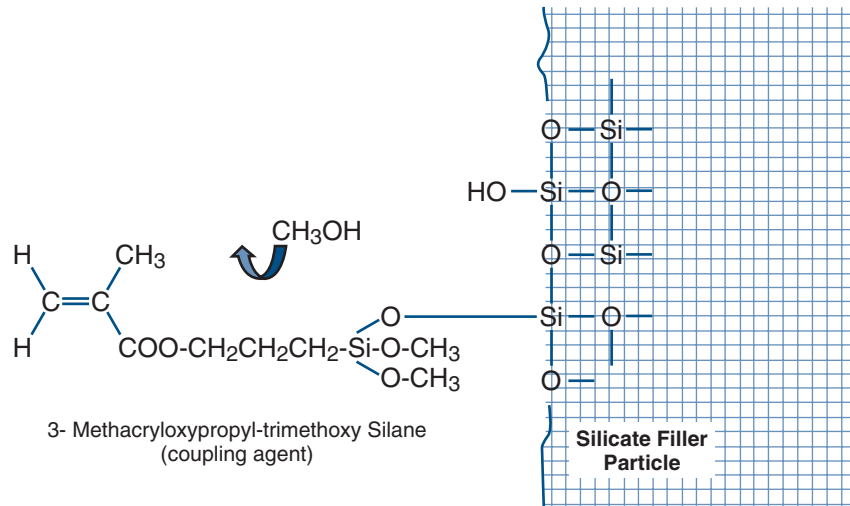
Pure silica occurs in several crystalline forms (e.g., cristobalite, tridymite, quartz) and in a noncrystalline form (glass). Crystalline forms are stronger and harder but, when used, result in composites that are difficult to finish and polish ([Online Fig. 18-65, A](#)). Most composites are now produced using modified silicate glass. The fluidity of a mixture of filler and matrix monomer is affected by the fluidity of the monomer and the amount of filler incorporated. The friction between the filler particle surfaces and the monomer is a principal factor controlling fluidity. As the filler surface area increases, the fluidity decreases. Large filler particles have a relatively small amount of particle surface area per unit of filler particle volume. As an equivalent volume of smaller filler particles is used to replace larger ones, the surface area increases rapidly.



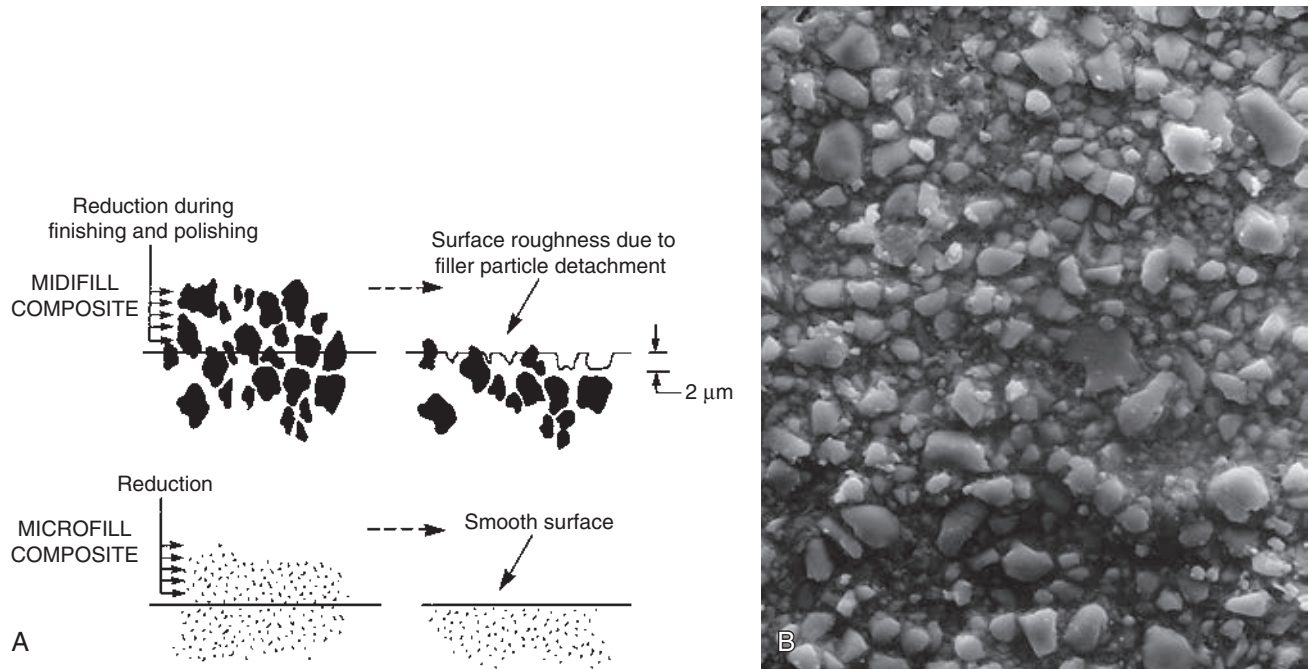
Online Fig. 18-62 Summary of the historical evolution of dental composites, curing methods, and accompanying bonding systems. The long-term general trend has been to reduce filler particle sizes (to improve polishability and wear resistance) and increase filler levels. Today's composites are beginning to employ more nanofiller. Curing methods evolved from chemically cured (or self-cured) designs to UV-light-cured and then visible-light-cured designs. Self-cured designs produce better degree-of-conversion and more homogeneous curing. Visible-light curing has provided special control of curing. However, quartz-tungsten-halogen lights for visible-light-curing are still dominant, but LED curing units are rapidly becoming the most popular. (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)



Online Fig. 18-63 Chemical formulas of di-functional monomers commonly used in composites. **A**, Bisphenylglycidyl dimethacrylate (BIS-GMA) monomer. **B**, Urethane dimethacrylate (UDMA) monomer. **C**, Triethylene glycol dimethacrylate (TEGDMA) monomer. (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)



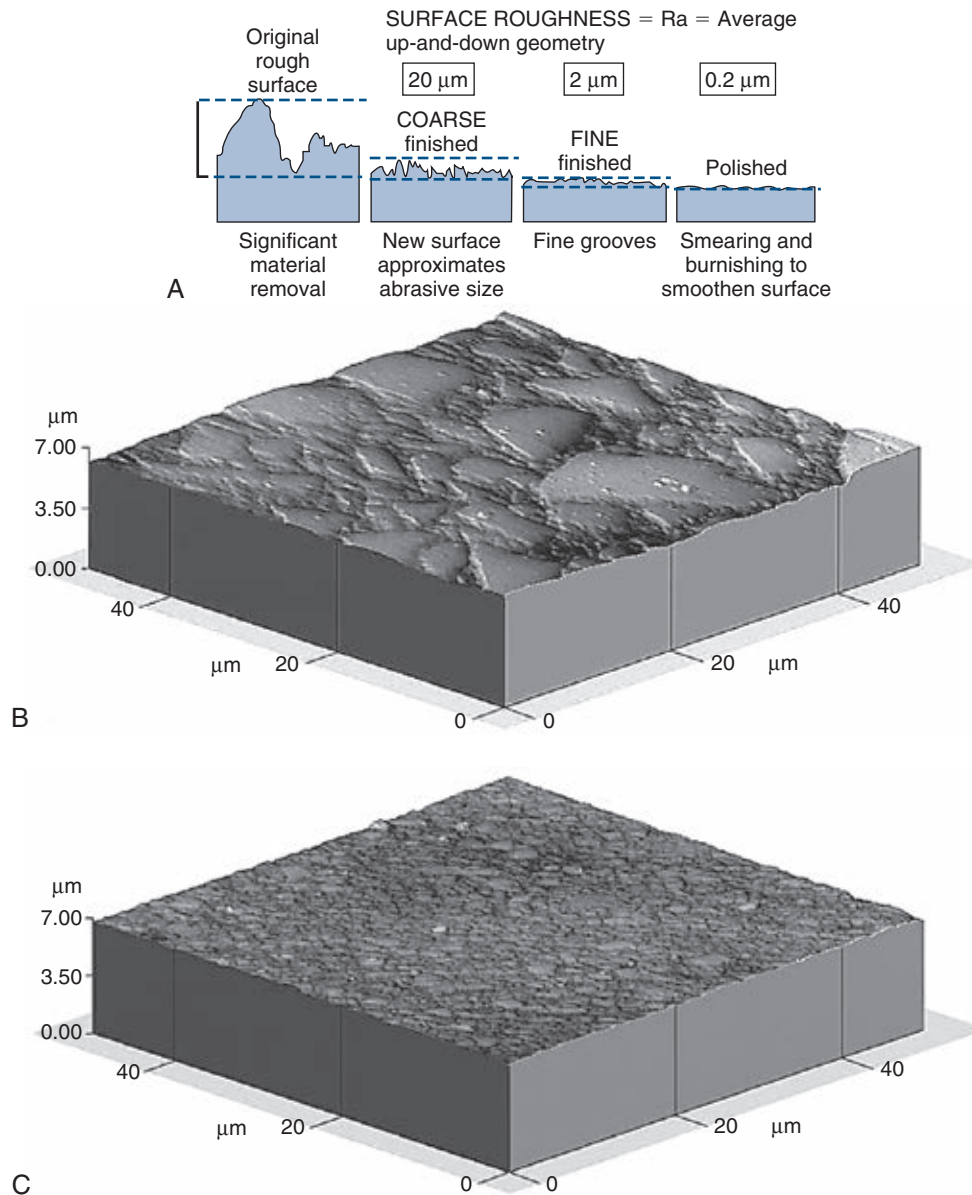
Online Fig. 18-64 Silane coupling agents are relatively small molecules that must be added to the surfaces of the filler particles before the filler is mixed into the monomer matrix. Silane is mixed into water, acidified, washed onto the particle surfaces, heated to encourage reaction, and rinsed. As shown, a typical silane coupling agent has a double bond on one end (*left*) and three methoxy groups on the other end (*right*). The methoxy groups can condense (etherify) with pendant hydroxyls on the surface of the silicate filler particles. Methanol is produced as a byproduct and eliminated. On average, only about half of the three methoxy groups actually react with the surface. Although the silanation step has always been suspected to be poorly controlled in composite production, most composites show some evidence of chemical bonding at the interfaces. Under rigorous basic conditions (pH >8), it is possible to reverse this reaction and degrade the silane, but this condition is rarely encountered intraorally. (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)



Online Fig. 18-65 Schematic summary of the microscopic events during finishing and polishing operations. **A**, Schematic illustration of effect of abrasive particle size on surface finishing of midfill versus microfill composite surfaces. **B**, Scanning electron microscopy view of coarsely finished midfill composite surface. (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)

When filler particles with diameters that are one tenth as large are substituted, the surface area increases by a factor of 10. The situation is exacerbated further for microfiller particles made from silicon dioxide (SiO₂), which tend to agglomerate into chains.

Placement of composites cannot be accomplished so precisely that adjustments to anatomic contours would not be needed after curing. Typically, the restoration is produced by intentionally overfilling the tooth preparation with a small amount. The anatomic contours are accomplished



Online Fig. 18-66 Finishing and polishing of composite surfaces. **A**, Rough surface gradually is cut away by progressively finer abrasives (coarse and fine finishing). Polishing produces little cutting but does tend to smear material (burnishing) from remaining high spots into low spots and create a smooth surface. The final surface finish is measured as the average up-and-down surface roughness (R_a) remaining by profiling select areas of the surface. **B**, Atomic force microscope image of finely finished midfill composite (note the relief of filler particle margins produced by the finishing process) with an average roughness (R_a) corresponding to $0.2\ \mu\text{m}$. **C**, Atomic force microscope image of finely finished minifill composite. (Courtesy of J.Y. Thompson, College of Dental Medicine, Nova Southeastern University, Fort Lauderdale, FL.)

by gross cutting (grinding), fine cutting (finishing), and smoothing (polishing) the material after polymerization (Online Fig. 18-66, A).

Particle sizes in composites affect other properties in addition to fluidity. Filler particle size has a direct effect on the surface roughness of the ground, finished, or polished composite. Filler particles are harder than the matrix. During finishing, some particles may be left protruding from the surface, whereas others are stripped out of the surface leaving holes. If the particles are very small, the resulting surface roughness is of little concern. This effect is illustrated schematically in Figure 4-65, B. Otherwise, the rough areas may contribute to light scattering and collection of organic debris or stain.

The effectiveness of the restoration finishing and polishing procedures depends on careful use of successively finer abrasive materials to eliminate larger scratches or defects and replacing them with smaller ones. This process is schematically summarized in Online Figure 18-66, A. Final finish of the composite surface is a result of the combination of filler particle size effects and finishing scratches. Average roughness of the surface is recorded in terms of the extent of hills and valleys measured on surface profiles. The measurements can be collected with profilometers (e.g., Surfalyzer) or atomic force microscopes. An example of an atomic force microscope image and the calculated surface roughness, R_a , is shown in Online Figure 18-66, B and C. Clinically, surfaces with average

roughness values of less than 1 μm are considered very smooth. It is common to be able to achieve surface smoothness in the range of 0.2 to 0.6 μm by using submicron polishing pastes on materials that include submicron filler phases.

Classification

Composites generally are classified with respect to the components, amounts, and properties of their filler or matrix phases or by their handling properties. The most common classification method is based on filler content (weight or volume percent), filler particle size, and method of filler addition. Composites also could be defined on the basis of the matrix composition (BIS-GMA or UDMA) or polymerization method (self-curing, UV light-curing, visible light-curing, dual-curing, or staged-curing), but these classification systems communicate less information about the material properties.

Almost all important properties of composites are improved by using higher filler levels. The only practical problem is that as the filler level is increased, fluidity decreases. Highly filled compositions typically contain large filler particles, but as previously stated, this composition results in a rougher finished surface. Smaller filler particles are used to guarantee that composites have a relatively smooth finished surface. This choice compromises the filler level possible, however, and the material's properties.

The degree of filler addition is represented in terms of the weight percent (wt%) or volume percent (vol%) of filler. Because silica fillers are approximately three times as dense as acrylic monomer (or polymer), 75 wt% filler is equivalent to approximately 50 vol% filler. Properties of composites are proportional to the volume percent of the phases involved. It is much easier to measure and formulate composites using weight percentages rather than volume percentages, and in dentistry, the weight percent is reported much more commonly. A conversion of filler levels and corresponding classifications of composites is presented in Online Table 18-14.

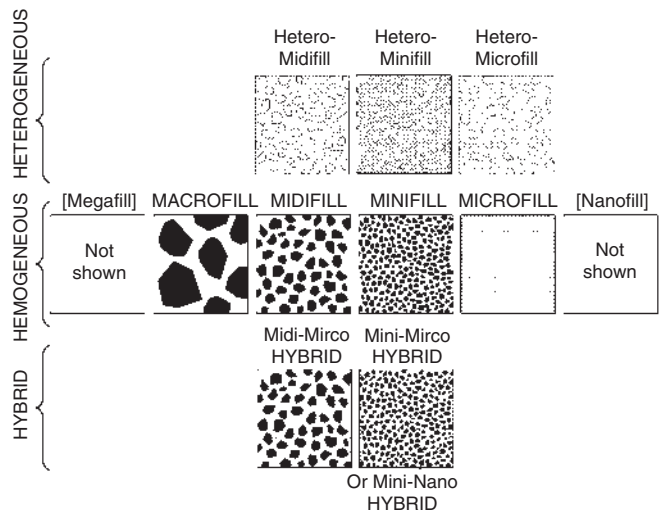
Filler particle sizes for the earliest composites averaged 10 to 20 μm in diameter, with many of the larger particles 50 μm (Online Figs. 18-67 and 18-68). Initially, it was not deemed necessary to distinguish the particle size range or ranges of composites because all commercial products were in approximately the same range. During the evolution of formulations toward better finishing characteristics and greater resistance to wear, increasingly smaller filler particles were used. Because the early filler particles were relatively large, composites based on those large fillers became known as *macrofill materials*. The terms *macrofill* and *macrofiller* are preferred to *macrofilled* because they properly describe the size of the filler particle and not the method of producing the mixture. During the course of composite evolution, nomenclatures and classification systems have been neither consistent nor uniform.¹⁵⁸⁻¹⁶⁴ In the following sections, composites are classified in terms of their particle size range or comparative finishing characteristics.

Classification of composites based on the filler particle size or agglomerate size range has been partially developed by several authors.¹⁵⁹⁻¹⁶⁷ That system is extended here to include the particle size by order of magnitude, acknowledging the mixed ranges of particle sizes and distinguishing precured composite pieces as special filler particles. Composite filler particles are considered macrofillers in the range of 10 to 100 μm , midfillers from 1 to 10 μm , minifillers from 0.1 to 1 μm ,

Online Table 18-14 Examples of Filler Level Ranges for Typical Composites in Terms of Weight and Volume Percent*

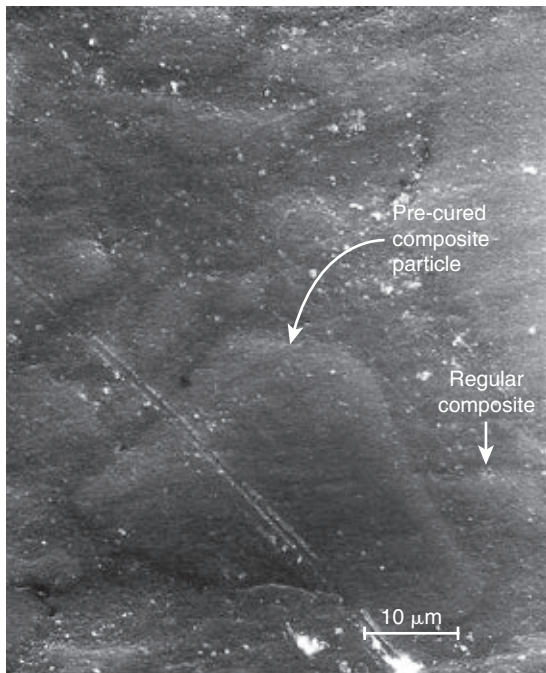
Weight %	Volume %	Composites
0	0	[Unfilled resin, bonding agents, pit-and-fissure sealants]
—	10	[Sealants filled with colorants]
—	20	—
50	30	Homogeneous microfills
—	40	Flowables (first generation)
75	50	Macrofills, midfills
—	60	Hybrids, heterogeneous microfills, flowables (second generation)
85	70	Hybrids, packable composites
—	80	—
—	90	[Enamel]
100	100	—

*The composites are reported using a classification system based on filler particle sizes. Systems that are not dental composites are reported in brackets. Volume percent filler is always less in amount than weight percent filler for the same composition because the glass filler is denser than the resin matrix. Typically, 75 weight percent filler is equal to 50 volume percent filler, as shown in the table.



Online Fig. 18-67 Examples of dental composite classification based on filler particle size. Composites are grouped on the basis of (1) primary particle size (homogeneous), (2) mixtures of precured with uncured composite (heterogeneous), (3) mixtures of major particle sizes (hybrids), and (4) other special modifications (e.g., chopped fiber is added) to the composite (not shown). Filler particles may be clusters or agglomerates as well. (Courtesy of S. C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)

microfillers from 0.01 to 0.1 μm , and nanofillers from 0.001 to 0.01 μm . Very large individual filler particles, called *mega-fillers*, also have been used in special circumstances. Accordingly, composites are classified by particle size as megafill, macrofill, midfill, minifill, microfill, and nanofill. Composites



Online Fig. 18-68 Scanning electron microscopy cross-sectional view of heterogeneous microfill composite. (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI; and D.F. Taylor, School of Dentistry, University of North Carolina, Chapel Hill, NC.)

with mixed ranges of particle sizes are called *hybrids*, and the largest particle size range typically is used to define the hybrid type (e.g., minifill hybrid) because microfillers have normally been the smaller portion of the mixture. It is more revealing, however, to state both portions of the mixture (e.g., mini-micro hybrid or mini-nano hybrid). If the composite simply consists of filler particles and uncured matrix material, it is classified as *homogeneous*. If it includes precured composite or other unusual filler, it is called *heterogeneous*. If it includes novel filler modifications in addition to conventional fillers, it is called *modified*, such as fiber-modified homogeneous minifill.

After the early macrofill composites, the next generation had fillers that were 8 to 10 μm in average size (midfillers) and were originally designated fine particle composites to imply their improved finishing characteristics. These new materials quickly became popular and were used primarily for anterior restorations in place of silicate cements and direct-filling resins. The category soon became known as *traditional* or *conventional composites*, but that designation has become confusing as newer composites continue to evolve with even smaller particle size ranges. The next step in composite evolution was to use 0.02- to 0.04- μm diameter particles to produce microfill composites. The term *microfiller* already was in common use for these particles in nondental applications. Microfill composites also were called *fine finishing composites*. The small filler particle size produced high viscosities in the uncured mixes of BIS-GMA with TEGDMA and required the addition of a greater amount of monomer diluent, along with a reduced overall filler content to maintain a workable consistency.

To circumvent part of the viscosity problem, two strategies were developed. The first was to blend precured microfill

composite with uncured material. Precured particles were generated by grinding cured composites to a 1- to 20- μm -sized powder. The precured particles become chemically bonded to the new material, provide islands with better properties, and can be finely finished. These variants are known as heterogeneous microfills (or organic filler composites). An example is shown schematically in Online Figure 18-67 and in a scanning electron micrograph in Online Figure 18-68. Unmodified microfills are called *homogeneous microfills*. A second approach has been to sinter small filler particles into large but porous filler particles, impregnate them with monomer, and add the new particles to a microfill composite. Within the local region of the sintered filler particle, the material is highly filled and yet capable of being polished.

After it was realized that highly filled microfills were difficult to use, composites were formulated with mixtures of particles in the microfiller range and 2- to 5- μm range. These bimodal distributions allowed higher filler levels and still permitted good finishing. All types of mixtures are known collectively as *hybrid composites*. In 2005, the average particle or cluster size for filler mixtures for current materials was in the range of 0.1 to 1 μm . These composites are called *mini-micro hybrids* (or *minihybrids* and occasionally misnamed *microhybrids*).

More recently, composites have been developed with nanofillers that range in size from 0.005 to 0.020 μm .¹⁶⁸ Some biomaterials that claim to use nanotechnology do not use nanofiller particles but, rather, report their filler particle sizes simply in terms of nanometers (e.g., 100 nm). Nanosized and near-nanosized fillers are produced for sol-gel processing of silica, polyhedral oligomeric silsesquioxanes (POSS; Hybrid Plastics, Hattiesburg, MS), or metal-oxide nanoparticles.^{40,169,170} Nanofiller seems to be ideal for finishing, wear resistance, and mechanical properties. Nanoparticles also may be clustered or aggregated into large units that can be blended with nanoparticles to produce hybrids as well. Actual nanoparticles can be different compositions, producing further complexity in the design. Ultimately, nanofiller should replace all other filler types in composites.

Although the vast preponderance of filler in composite is equiaxed rough particles, interest in fiber-reinforced systems is increasing. The main advantage of fibers is that they have excellent strength in the primary fiber direction. It is difficult to pack the fibers or orient their direction efficiently. Small additions of fibers to regular fillers are effective in improving properties. The limiting factor is that fibers may be used only with dimensions greater than 1 μm because of the concerns for carcinogenicity of submicron fibers such as asbestos. Most current fibers have diameters of 5 to 10 μm and effective lengths of 20 to 40 μm .

Single crystals generally have symmetric shapes and are commonly long plates, behaving in a similar manner to fibers. Their singular advantage is that they are much stronger than noncrystalline or polycrystalline fibers. The strongest example of a crystal-modified composite is an experimental composition that employs silicon carbide single crystals.^{74,129} The crystals are colored and not well suited for esthetic compositions. In clinical uses in which esthetics are not important, however, these crystal-modified composites could be extremely valuable.

Another consequence of advances in the control of filler particle size, particle size distribution, particle morphology,

and monomer technology has been the introduction of composites with specific handling characteristics. These include flowable composites and packable composites. Flowable composites are a class of low-viscosity materials that possess particle sizes and particle size distributions similar to those of hybrid composites but with reduced filler content (first-generation flowable composites), which allows the increased amount of resin to decrease the viscosity of the mixture. In general, the mechanical properties of first-generation flowable composites were inferior to those of standard hybrid composites.^{171,172} Since 2002, second-generation flowable composites have been formulated in such a way that their properties are almost equal to those of traditional composites. Because flowable composites are made with specific handling characteristics in mind, their range of advertised clinical uses varies. Within the range of materials classified as flowable composites, the materials with lower filler content (first-generation) are intended for uses such as pit-and-fissure sealants or small anterior restorations. Materials with higher filler content (second-generation) have been suggested for use in Class I, II, III, IV, and V restorations, although they are better suited for only conservative restorative procedures. The most popular applications for flowable composites continue to be as the first increment during a composite restoration procedure or as a repair resin for margins or non-occluding surfaces.

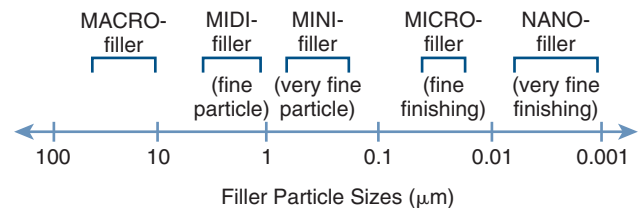
Packable composites, also referred to as *condensable composites*, were developed in a direct effort to produce a composite with handling characteristics similar to amalgam—“packable” or “condensable.” These amalgam alternatives are intended primarily for Class I and II restorations. The composition and properties reported for early examples of this class of composites suggest that they represent little or no improvement over traditional hybrid composites.^{55,173} The distinguishing characteristics of packable composites are less stickiness and higher viscosity (stiffness), compared with traditional hybrid composites, which allows them to be placed in a manner that resembles amalgam placement, although they do not truly undergo condensation similar to amalgam. Because of this, “packable composite” is a more appropriate description of this class of composites.

Examples of the filled composite designations are shown in Online Figure 18-67. The mean filler particle sizes of those designations are shown in Online Figure 18-69. Mean filler particle sizes often may not correspond to any actual particle size because of polydispersed distributions. Online Figure 18-70 shows examples of the particle size distributions for several composites. There is no practical limitation on the complexity of filler particle compositions or particle size distributions. New composites may be better described simply as *polydisperse*.

In addition to inorganic or composite fillers, it is possible to add crystalline polymer fillers. Some newer composites include crystalline polymer to supplement traditional fillers. Crystalline polymer is not nearly as strong as inorganic filler, but it is stronger than amorphous polymer material.

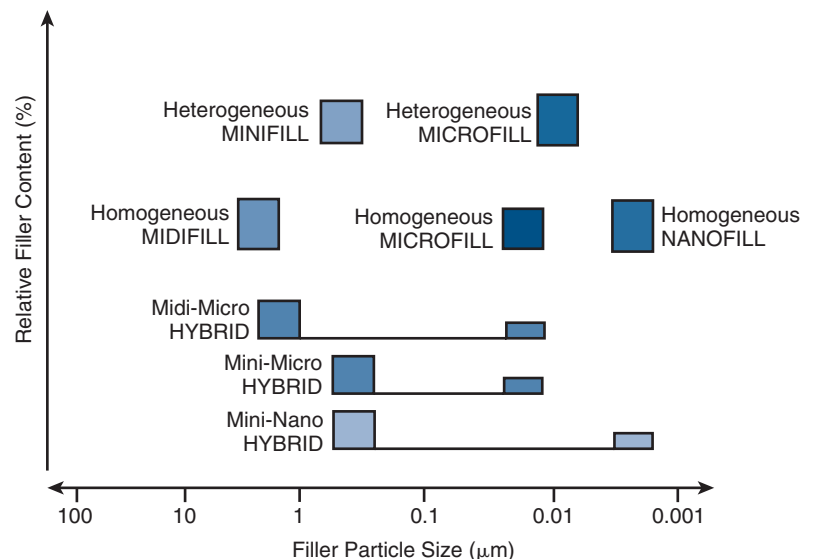
Microfill and hybrid composites tend to use microfillers of silicon dioxide. These silica microfillers can be produced in a variety of ways and are designated with different names. Two basic forms are used in dental compositions. Colloidal silica is chemically precipitated from a liquid solution as amorphous silica particles. Pyrogenic silica is precipitated from a gaseous phase as amorphous particles.¹⁷⁴ The properties of each form are slightly different, but the differences have not yet been shown to produce different clinical properties for composites.

For posterior composite restorations, it also is possible to place one or two large glass inserts (0.5- to 2-mm particles) into composites at points of occlusal contact or high wear. These pieces of glass are referred to as *inserts* (or *megafillers*).



Online Fig. 18-69 Composite filler ranges versus particle size (shown on a logarithmic scale). (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)

Online Fig. 18-70 Examples of relative filler contents and particle size distributions for a variety of fabrication strategies (homogeneous, heterogeneous), filler options (midfiller, minifiller, microfiller, or nanofiller), and combinations (hybrids of different-sized particles or clustered filler or both). The relative filler content is represented by the area within the boxes and not the position on the scale. The mini-micro hybrid filler is composed of a mixture of approximately 70% minifiller (approximately 0.5 μm) and approximately 30% microfiller (approximately 0.2 μm), which represents approximately 50% to 55% of the entire composite and is greater than the total filler content in a homogeneous microfill. (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)



Although they have shown improved wear resistance to contact area wear, the techniques are more complicated and do not totally eliminate wear in the contact-free area (CFA). The bonding of the composite to the insert is questionable.

Matrix monomers for composites used in the United States traditionally have been based on BIS-GMA as the primary monomer. UDMA has been more popular in Europe for composites. Initially, better adhesion or resistance to color change was predicted for the UDMA formulations, but clinical studies have not been able to document these advantages.

Matrix monomers can be polymerized in a variety of ways. The original composites adopted self-curing chemistry that was typical of dental denture base compositions. These composites have been called *self-cured*, *chemically cured*, or *two-component systems*. Amine accelerators that were used to increase polymerization rates contributed to discoloration after 3 to 5 years of intraoral service. An alternative system was introduced that used UV light (UV-light-cured) to initiate polymerization. The curing units required had limited reliability and presented some safety problems. They were replaced with visible light-cured or light-cured systems.

Light-cured composites are the most popular today, but their success depends on the access of high-intensity light to cure the matrix material (Online Fig. 18-71). If the composite thickness exceeds 1.5 to 2 mm, the light intensity can be inadequate to produce complete curing, especially with darker shades of composite. Filler particles and coloring agents tend to scatter or absorb the curing light in the first 1 to 2 mm of material. Darker shades and microfills are more difficult to cure. Access to the interproximal areas is limited and may require a special technique to guarantee adequate light-curing energy. Because of these problems, increasingly composite compositions are dual-cured, combining self-curing and

light-curing. The self-curing rate is slow and is designed to cure only the portions not adequately light-cured. Another approach is to provide staged curing. In some instances, composite finishing can be complicated by relatively hard, fully cured material. By filtering the light from the curing unit during an initial cure, it is possible to produce a soft, partially cured material that can be easily finished. Later, the filter is removed, and the composite curing is completed with full-spectrum visible light.

Light-Curing Variables

A key consideration for light-curing in dentistry is the plethora of variables associated with the operation. Light-curing can be accomplished with quartz-tungsten-halogen (QTH) curing units, plasma arc curing (PAC) lights, lasers, and light-emitting diode (LED) curing units. Examples of LED units are shown in Online Figure 18-72. The spectral output (intensity versus wavelength) (Online Fig. 18-73) of different commercial units may vary, but each one attempts to maximize the light in the absorption range of the photoinitiator within the composite being cured. Most current composites employ camphoroquinone as the photoinitiator, and it absorbs photons of light energy, predominantly at about 470 nm.

The challenge to cure light-cured biomaterials effectively is illustrated by the numerous variables shown in Online Figure 18-74. Light-curing variables are logically grouped in terms of those associated with (1) the curing equipment, (2) clinical manipulation of the curing light, and (3) restoration effects on curing light absorption. Each of these is considered separately in the following paragraphs.

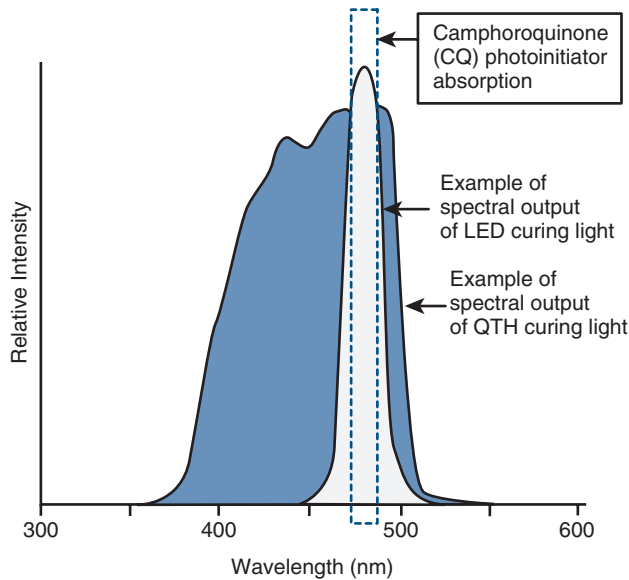
Different categories of curing lights produce a spectrum of light in different ways. The problems of the first three types are illustrated by considering QTH (quartz-tungsten-halogen) light-curing systems. Within the light-curing unit is a power supply that heats a tungsten filament in a quartz bulb containing a halogen gas. The output of the bulb depends on the voltage control and operational characteristics of the bulb. New bulbs are not equivalent. Older curing units often show voltage variations. A typical QTH bulb is rated for 80 to 100 hours (approximately 2.5 years of average clinical practice use) but may last two to three times as long under ideal conditions. Within the light-curing unit, the light from the bulb is collected by reflecting it from a silverized mirror behind the bulb toward the path down the fiberoptic chain to the tip. It is crucial that the mirror surface be kept clean. This surface becomes heated during the operation of the light and then cools down between uses. It often condenses the vapors from mercury, bonding system solvents, or moisture in the operatory air onto its surface, dulling or clouding its surface. This surface can be cleaned routinely with alcohol or methyl ethyl ketone solvents on cotton swabs to renew its reflection effectiveness. The reflector is parabolic in geometry (Online Fig. 18-75), rather than being hemispherical, to focus the light toward a small fiberoptic entry. Of the light produced, less than 0.5% is suitable for curing, and most is converted at some point into heat. To minimize any heating that might occur during light-curing, two filters are inserted in the path of the light just in front of the fiberoptic system. The UV and infrared bandpass filters eliminate significant amounts of unnecessary light and convert it into heat within the unit. A small fan is used to dissipate unwanted heat from the filters and the



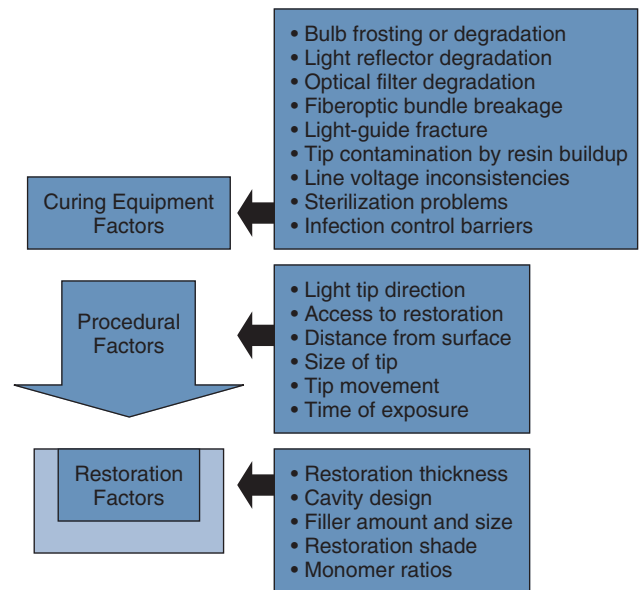
Online Fig. 18-71 Example of visible light-curing unit for use with composites, bonding agents, and other light-curing materials. The main power supply is connected to a pistol-grip light gun that generates a beam that is passed through the fiberoptic light guide. A shield is supplied to protect against direct observation of high-intensity light at the tip. Note: Always reference the manufacturer's directions for use for the curing unit and composite. (Courtesy of Kerr Corp., Orange, CA.)



Online Fig. 18-72 Examples of four current light-emitting diode (LED) curing units. **A**, Elipar S10 LED (Courtesy 3M ESPE, St. Paul, MN). **B**, Demi Plus LED (Courtesy Kerr Corporation, Orange, CA). **C**, VALO LED (Courtesy Ultradent Products, Inc., South Jordan, UT). **D**, FLASHlite 2.0 LED. (Courtesy Den-Mat Holdings, LLC, Santa Maria, CA). Most LED curing units are battery-operated and portable. Note: Always reference the manufacturer’s directions for use for the curing unit and composite.



Online Fig. 18-73 Example of spectral output of quartz–tungsten–halogen (QTH) versus light-emitting diode (LED) light-curing units compared with absorption range for camphoroquinone photo-initiator, which is used in most light-cured bonding agents and composites. Unabsorbed light is converted principally into heat energy. (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)

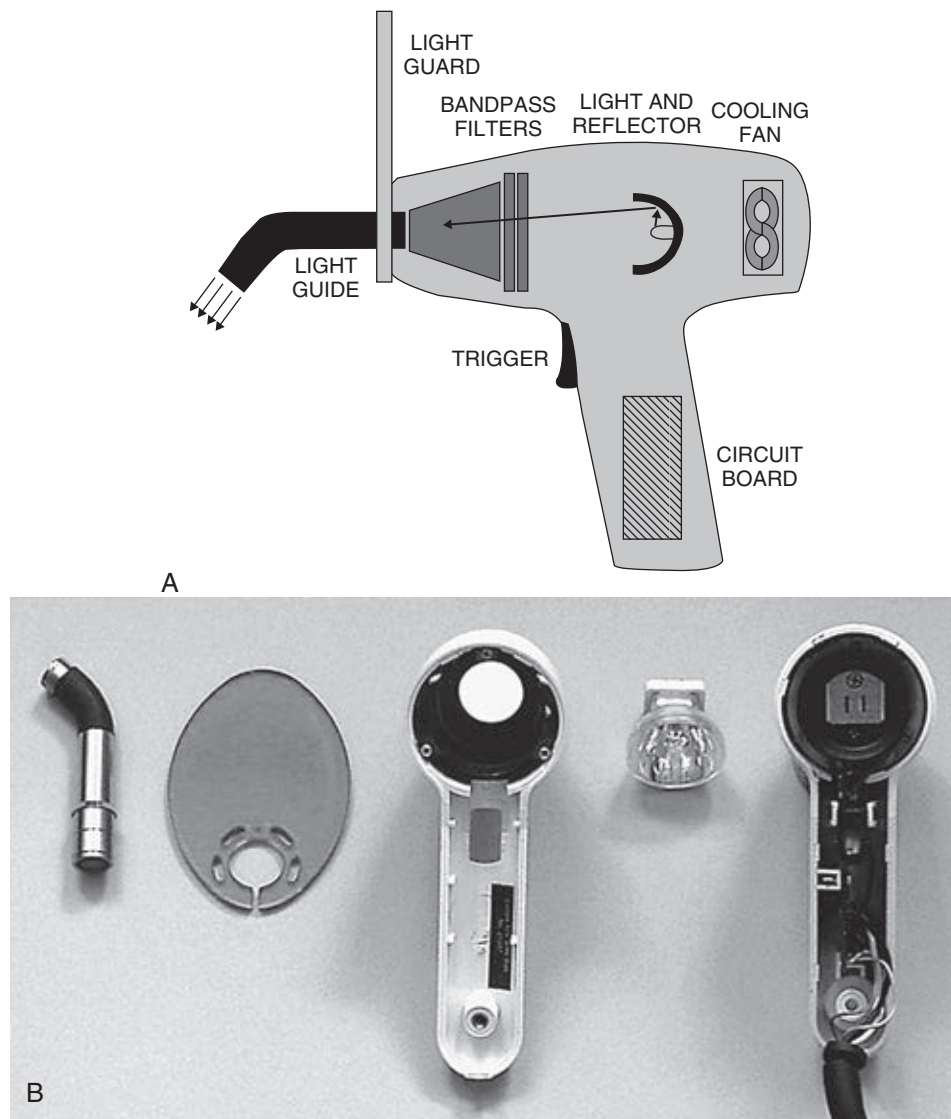


Online Fig. 18-74 List of variables associated with visible-light-curing linked to the equipment, manipulation procedure, and restorative material.

reflector. Bandpass filters can be made from special glass or plastic coatings on clear glass. Filters may degrade as they become fatigued by numerous heating and cooling cycles.

Light passed through the fiberoptic bundle is emitted from the tip of the curing unit. Some light intensity is lost through the fiberoptic system. The output characteristics of the tip are generally not uniform, with high-intensity light observed in the center of the bundle. Resin contamination on the curing unit tip tends to scatter the light, reducing the effective output considerably. The tip should be cleaned of cured resin, when necessary, using an appropriate rubber wheel on a slow-speed handpiece.

The curing light output can be monitored directly with a built-in or portable radiometer or by trial curing of some composite material. The former approach is much more sensitive to curing problems. Most modern curing lights include a convenient radiometer as part of the unit that measures the number of photons per unit of area per unit of time. It does not discriminate the light energy that is matched to the photoinitiator but measures all light energy. The real value of the measurement is limited. Generally, QTH curing lights functioning in the normal range have outputs of 400 to 800 milliwatts per square centimeter (mW/cm²). A good rule of thumb is that the minimum output should never be less than 300 mW/cm². A radiometer is designed to measure the photon level per unit time through a standard 11-mm diameter

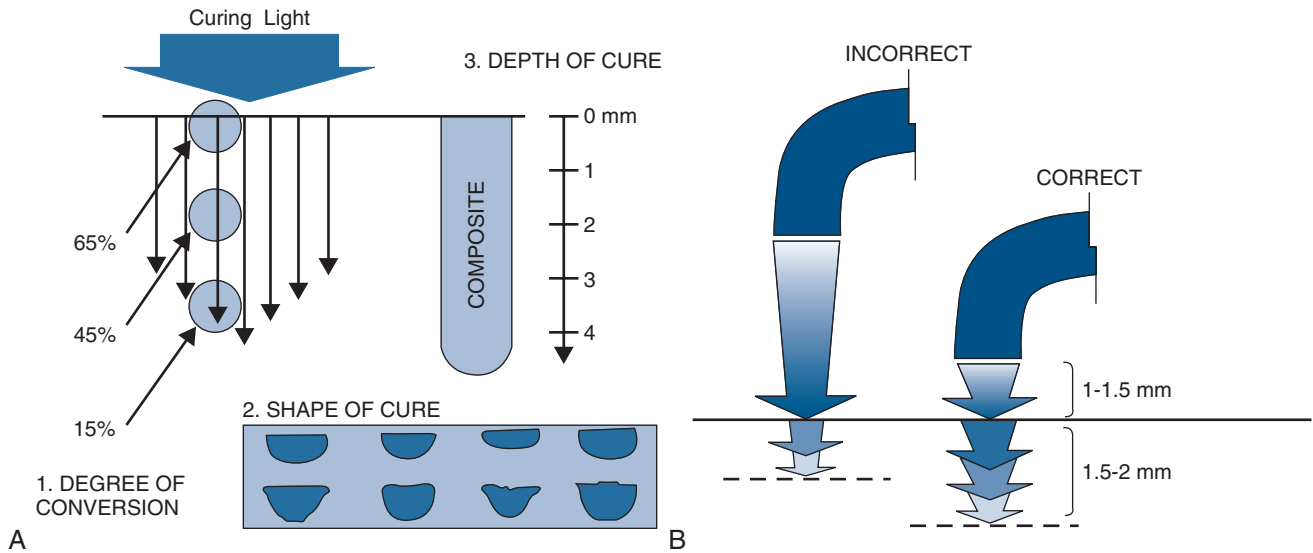


Online Fig. 18-75 Internal operation of a quartz-tungsten-halogen (QTH) visible-light-curing unit. **A**, Schematic of a typical pistol-grip handle attached to the power supply for the unit. **B**, A disassembled pistol grip of unit (Kerr Demetron) showing light pipe (left), shield to prevent operator from directly viewing light tip, filters in light path, light bulb and reflector, light socket, cooling fan (behind socket), trigger, circuit board, and wired connection to power supply. Note: Always reference the manufacturer's directions for use for the curing light and composite. (**B**, Courtesy of Kerr Corporation, Orange, CA.)

window. Smaller or larger curing unit tips cannot be tested effectively. Light energy entering into a fiberoptic bundle is diffused or concentrated depending on whether the curing unit tip is larger or smaller. Shifting from a standard 11-mm-diameter tip to a small 3-mm-diameter has the effect of increasing the light output eightfold. This increased output increases the chance that heat produced in the curing procedure will raise the temperature of the restoration and the surrounding dentin to much more dangerous levels. Increases in pulpal temperatures of more than 5°C to 8°C easily cause cell death.^{34,35}

Light emanating from the tip of a curing unit does not maintain its intensity but is scattered by molecules in the air on the path to the restoration. Ideally, the fiberoptic tip should be adjacent to the surface being cured, but this most likely would cause the tip to be contaminated by the material being cured. The intensity of light striking the composite is

inversely proportional to the distance from the tip of the fiberoptic bundle of the curing light to the composite surface. Ideally, the tip should be within 1 to 2 mm of the composite to be effective (Online Fig. 18-76). This is not possible in many dental procedures because the anatomy of a tooth or the distance into the preparation extensions creates geometric interference. Distances of 5 to 6 mm often are encountered. At distances beyond 6 mm for QTH lights, the output may be less than one third that at the tip. To permit closer approximation of the curing light to the composite, light-transmitting wedges have been promoted for interproximal curing, and light-focusing tips have become available for access into proximal boxes.¹⁷⁵ Smaller tips are useful to overcome this problem, but they require many more light-curing cycles to cover the same amount of cured area. Certain walls containing bonding systems to be cured within complex preparation extensions such as Class II restorations may not



Online Fig. 18-76 Light intensity influences on the polymerization zone. **A**, Varying light intensity with width and depth affects the degree of conversion of monomer to polymer, shape of cure, and depth of cure. **B**, Proximity of curing light to the surface affects the depth of penetration of light into the surface.

be oriented ideally to the curing light direction and still may be under-cured.

The composite itself also affects the light-curing process. Filler particles tend to scatter the light, and darker colorants tend to absorb the light. It is generally recommended that no more than 1.5- to 2-mm increments be light-cured at a time.^{176,177} Smaller filler particles (0.1–1 μm) interfere most with the light and maximize scattering. That particle size corresponds to the wavelength range for the photo-initiator used for curing.

Within a composite, the pattern of curing varies as a function of the radius of the curing tip and the depth of penetration into the material. The intensity of the tip output generally falls off from the center to the edges. Bulk curing of composite produces a bullet-shaped curing pattern; this may lead to inadequate curing in regions such as the proximal box line angles of Class II restorations. The degree of conversion (or degree of cure) is related to the intensity of light and duration of exposure. It decreases considerably with depth into a composite material. Restorative materials based on BIS-GMA-like restorative matrices generally can be converted only to 65% because of technical problems with steric hindrance of the reacting molecules; 65% would be considered a good degree of conversion. A curing light may produce only a 55% degree of cure at 1 mm into a composite and even less at greater depths. Clinically, it is impossible to distinguish the differences in the degree of cure. Only the start of uncured material can be detected. The boundary between somewhat cured and uncured material is called *depth of cure* and is often 5 mm for light Vita shades (A2 or A3) of material, in which the tip is close to the composite. In cases of poor access or darker shades, it is recommended that materials be placed and cured in increments of 1.5 to 2 mm. For the darkest shades, increments should be limited to 1 mm of thickness. Problems of light penetration are only slightly overcome by increasing curing times.

Light-curing typically required a minimum of 20 seconds for adequate curing under optimal conditions of access. This

time is shortened, however, by increasing the concentration of the photo-initiator in the composite system or increasing the intensity of the output. It has been estimated that for a standard restorative practice during the course of a normal year, 20 to 40 hours may be consumed solely with light-curing. Faster curing includes some cautions as well. High-intensity plasma-arc curing or laser lights can reduce curing times to 3 to 10 seconds, but generate much more unwanted heat as well. Bandpass filters can remove much of unwanted wavelengths of light and decrease some heating effects. LED systems work best, however, at generating well-controlled wavelengths with minimal heating effects. However, cautions for LEDs exist as well. Some composites use photo-initiators, which absorb wavelengths other than the LED output. At least one LED curing light provides an option for additional wavelength output to cover the range of variant photo-initiators.

To guarantee that adequate curing has occurred, it is common to postcure for one to two additional curing cycles. It is suspected that postcuring (curing again after completion of the recommended curing procedure) may slightly improve the surface layer properties such as wear resistance, but this has never been proved.

High-intensity lights do not produce the same type of polymer network during curing. Rapid polymerization may produce excessive polymerization stresses and weaken the bonding system layer against the tooth structure. The physics of polymerization is much more complex than has been considered.

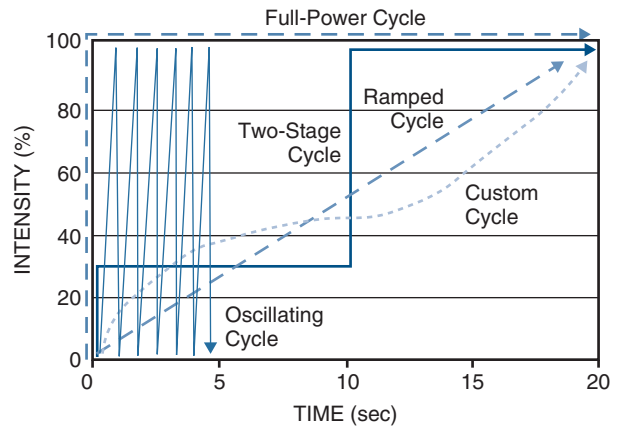
As noted earlier, acrylic resin monomers used in dentistry undergo polymerization in stages, namely, *activation*, *initiation*, *propagation*, and *termination*. Activation involves the production of free radicals. Initiation is the step in which free radicals react with monomer units to create the initial end of a polymer chain. Propagation is the addition of monomer to the growing chain. Termination is the conclusion of the process as a result of steric hindrance, lack of monomer, or other problems. Light-curing influences the initiation process. Increased light intensity increases the probability of effective activation

and the subsequent number of chains started. However, a minimum critical intensity below which light does not cause activation does exist. Increased light exposure time is not useful to push the degree of conversion to high levels deeper within a material. Activation and initiation that do occur happen quickly. Early propagation rates involve 100,000 to one million monomer reactions per second. Amounts of unreacted material remain a concern. If the degree of conversion is 65% in systems with di-functional or polyfunctional molecules, this includes monomer that has at least one site reacted to tie it into the polymer network and some monomer that is totally unreacted. The unreacted materials may diffuse out of the system. Current composites are complex mixtures that generally include two or more principal monomers, and these do not co-react equally. Evidence is increasing that TEGDMA constitutes most of the unreacted monomer in the system. This is apparently influenced by the activation step as well.

Rapid polymerization also affects the mechanical properties of the polymer network that is forming. As the first polymerization occurs, only some monomer is consumed, and the system still principally remains a viscous liquid. During conversion from monomer to polymer, the formation of new monomer-to-monomer bonds causes shrinkage, decreasing the net volume of the system. As long as the system is a liquid, it deforms quickly. As the degree of conversion approaches 10% to 20%, however, the network is extensive enough to create a gel. Beyond the gel point, polymerization shrinkage creates strain on the network and the attachment area to the bonding system. Built-in stresses are relieved ultimately but are considered deleterious at the time of curing because of potential effects on restoration marginal walls. To decrease or eliminate this problem, a range of altered curing cycles (staged curing) has been explored. Some evidence suggests that this approach to achieve “soft-start” polymerization works for certain composites cured by specific curing lights, but other evidence also is strong that this is not a universal response for all systems.

The original stepped curing system was possible with the Elipar Highlight (ESPE, Seefeld, Germany) in 1997. It produced a 100 mW/cm² output for 10 seconds, followed by an immediate jump to 600 mW/cm² output for 30 seconds. The presumption was that lower curing energy allowed the newly forming polymer network to stress-relax and eliminate strains before completion of the curing process. A wide range of soft-start polymerization approaches is possible (Online 18-77). Curing cycles may involve variable light intensities and variations in on-and-off periods during the cycle. In spite of recent interest in understanding these effects, all of the curing cycles are complicated by the problems mentioned earlier, including light tip sizes, tip orientations, material thickness, and material composition.

Alternatives to the wide range of challenges with light-curing systems are few. One approach is to consider LED technology to generate the appropriate wavelength and curing cycle. This eliminates many of the equipment problems associated with QTH devices. However, LED technology does not solve the manipulation and restoration problems in light-curing. Other polymerization mechanisms that do not include traditional acrylic monomers also are being considered. Whatever the final solution, it is crucial that light-curing in general practice be economical, simple to manage, and highly reliable.



Online Fig. 18-77 Examples of the variety of duty cycles (intensity versus time) available with different types of light-curing units.

Composition, Structure, and Properties

Composites originally were designed for restoration of Class III, IV, and V tooth preparations but now are used in modified forms for most other restorative dental uses. On the basis of their intended application, they can be used in all Classes (I–VI) of restorations, cements, bases, cores, veneers, or repair materials. A summary of the composition, structure, and properties of five composites is provided in Online Table 18-15 as examples of commercially available materials. As the overall filler content increases, the physical, chemical, and mechanical properties generally improve.

A physical property of historical concern has been the LCTE. Tooth structure expands and contracts at a linear rate of approximately 9 to 11 ppm/°C (see the section on materials properties). Unfilled acrylics (e.g., PMMA) have linear rates of 72 ppm/°C. The LCTE for composites (28–45 ppm/°C) may be almost twice as much as the value for amalgam (25 ppm/°C) and three to four times greater than that for the tooth structure. During extreme intraoral temperature changes, significant stresses may be generated at the tooth–restoration interfaces where composites are micromechanically bonded. If the interfacial bond fails, microleakage may produce unesthetic staining, pulpal sensitivity caused by dentinal fluid flow, pulpal irritation from diffusion of bacterial endotoxins, or predisposition toward recurrent caries. Thermal changes alone do not produce significant problems of thermal expansion. Polymeric and ceramic materials are insulators, have low thermal diffusivities, and change in temperature only at relatively slow rates. Intraoral temperature changes of 20°C to 30°C that involve only 20 to 30 seconds may be insufficient to produce any significant temperature change in either the tooth structure or the composite. For this reason, much of the thermal cycling information from laboratory experiments may be of little or no value in predicting the clinical performance of composite margins.

Well-cured composites are resistant to chemical change. Most compositions can be practically cured only to levels of 55% to 65% degree of conversion of the reactive monomer sites. During conversion of monomer to polymer, a composite undergoes polymerization shrinkage. In the early stages of conversion, only a few polymer chains exist, and they are not well connected (cross-linked). In the range of approximately 20% conversion, however, the polymer network is sufficient

Online Table 18-15 Comparison of Properties of Representative Composites*

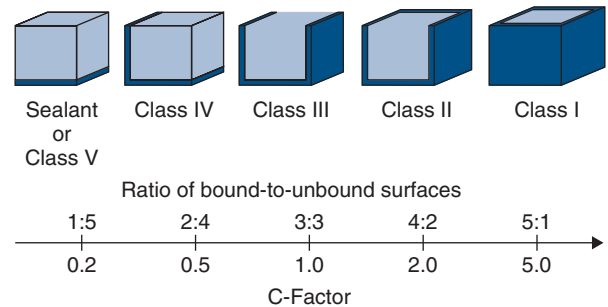
	Macrofill	Midifill	Microfill	Hybrid	Flowable	Packable	Nanofill
Material	Adaptic	Concise	Heliomolar	Herculite XRV	Æliteflo	SureFil	Filtek Supreme
Manufacturer	J&J	3M	Kulzer	Kerr	Bisco	Dentsply	3M ESPE
Filler level (weight %)	78	81	70	79	60	77	—
Filler level (volume %)	64	68	48	66	42	65	—
Depth of cure (mm)	—	—	—	6.1	5.6	5.5	—
Flexural modulus (GPa)	—	—	5.8	10.2	5.4	10.3	7.2
3-pt. flexure strength (MPa)	100	111	85	135	—	100	150
Compressive strength (MPa)	236	262	210	285	203	256	225
Diametral tensile strength (MPa)	—	—	36	45	34	34	35
Fracture toughness (MPa • m ^{1/2})	[Poor]	[Poor]	0.8	1.2	1.1	1.2	1.3
Diamond pyramid hardness (kg/mm ²)	—	—	70	68	—	96	85
In vitro wear (µm/100K cycles)	—	—	12	9	28	2	7

*Relative properties are shown in brackets. The values reported are from a variety of sources from 1963-2000, including manufacturer's product bulletins. Comparisons should be made only in terms of general application requirements and not in terms of any single property.

Data from Bayne SC, et al: A characterization of first-generation flowable composites, *J Am Dent Assoc* 129:567-577, 1998; Choi KK, et al: Properties of packable dental composites, *J Esthet Dent* 12:216-226, 2000; Leinfelder KF, et al: Packable composites: Overview and technical considerations, *J Esthet Dent* 11:234-249, 1999; Ruddell DE, et al: Mechanical properties and wear behavior of condensable composites [abstract 407], *J Dent Res* 78:156, 1999; Wilkerson MD, et al: Biaxial flexure strength and fracture toughness of flowable composites [abstract 779], *J Dent Res* 77:203, 1998.

to create a gel. At this point, the system changes from behaving like a liquid that can flow to a solid that has increasingly stronger mechanical properties. During the first 20% or so of chemical reaction, the accompanying polymerization shrinkage is accommodated by fluid changes in the dimension of the system. After the gel point, polymerization shrinkage produces internal stresses within the network and stresses along all the surfaces of the system. Bounded surfaces of enamel and dentin may undergo some local stress, which could reduce the strength of the recently formed bonding layer. Unbounded surfaces distort, when possible, to accommodate the stress.

In the 1980s, when composites were less highly filled, and bonding systems were not as reliable or strong, shrinkage stresses from composite curing could dislocate the newly bonded surfaces and created marginal openings. The consequences of this process were first analyzed by Feilzer and others and described in terms of the ratio (configuration factor) of surface area of fixed walls bounding a tooth preparation versus unbounded walls.^{178,179} Configuration factors for dental restorations typically range from 0.1 to 5 with higher values (>1.5) indicating more likelihood of high interfacial stresses (Online Fig. 18-78). Bulk-cured heterogeneous microfill systems in Class I situations were projected to generate preparation wall shrinkage stresses that exceeded 8 MPa. A key effect on actual stress is the complexity of a dental tooth preparation.¹⁸⁰ The effect of deformation of the tooth structure to accommodate potential stress is unknown. Light-cured composites develop higher stress than autocured analogues, and higher energy curing lights further exacerbate the situation.¹⁸¹⁻¹⁸⁴ More highly filled composites produce larger bulk polymerization stress.¹⁸⁵ Contraction stresses in thin films are much higher and decrease with increasing film thickness.¹⁸⁶⁻¹⁸⁹ Margin analysis in clinical situations has shown evidence of disruption, but parallel studies have not confirmed microleakage associated with this problem.^{190,191} Glass



Online Fig. 18-78 Configuration factors ("C-factors") associated with polymerization shrinkage for different situations using dental restorative materials. C-factors are the ratio of bound-to-unbound surface areas on restorations and are shown in the figure as calculated using average estimates of dimensions of tooth preparations. C-factors may be estimated as the ratio of the number of bound-to-unbound preparation surfaces, and those are reported as well, but do not produce the same numbers or order on the scale. (From Feilzer AJ, et al: Setting stress in composite resin in relation to configuration of the restoration, *J Dent Res* 66:1636-1639, 1987.)

ionomers set more slowly and seem to develop less interfacial stress.¹⁹²

Because of its simplicity, this theory has been an attractive explanation for potential clinical problems. The real importance of these effects for current clinical systems, however, may be much less. Many composites are highly filled, placed incrementally, and less well cured with visible light than are self-cured materials. Newer bonding systems are much better bonded. Some newer dentin bonding systems are designed thicker to be stress relieving. Typical wall stresses during curing may be only 1 to 2 MPa, well within acceptable ranges. The effects of wall stresses on postoperative sensitivity are unknown. Stresses within the cured composite and along the

walls seem to be relieved quickly in a few hours. That process is accelerated by the absorption of water.¹⁹³

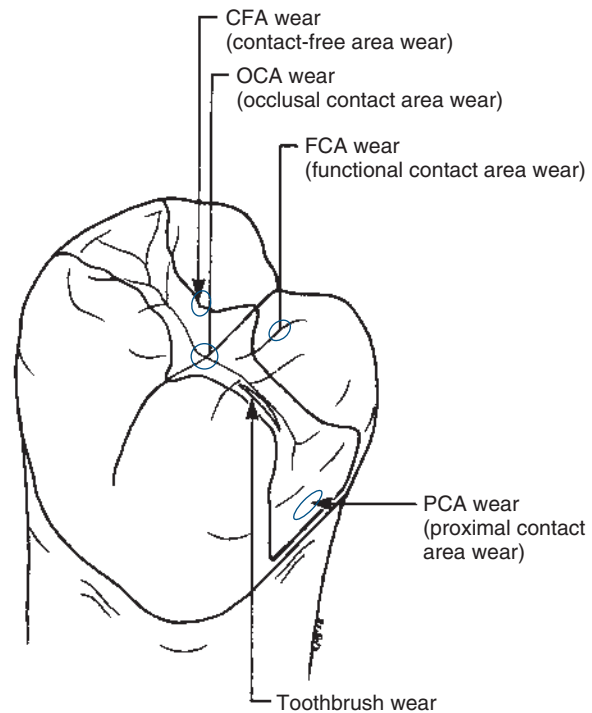
Interest in eliminating the shrinkage of composites has always been present. Early investigations centered on the use of ring-opening reactions with spiro-orthocarbonates to produce expansion that would counteract normal shrinkage.¹⁹⁴ These materials, however, were easily combined with existing composite monomers. More recently, oxirane and oxitane chemistry as a method of designing controlled-shrinkage composites, which undergo little curing shrinkage compared with traditional composites, has attracted strong interest.

Water absorption swells the polymer portion of the composite and promotes diffusion and desorption of any unbound monomer. Water and other small molecules can plasticize the composite and chemically degrade the matrix into monomer or other derivatives.¹⁹⁵ Beef or cholesterol esterase has been shown to produce chemical decomposition of polymer matrices into formaldehyde or low-molecular-weight monomer species.^{137,196,197} The consequences for the properties of the composite are obvious. The biologic consequences of small releases of these materials are unknown, although it has been hypothesized that unreacted leachable monomer components such as bisphenol-A could act as estrogenic agents in the body. Initial studies in this area concluded, however, that this is not likely to be a significant concern.¹⁹⁸⁻²⁰¹

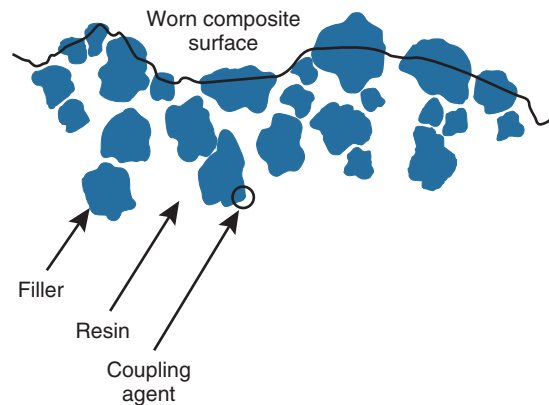
No clear relationship between clinical performance and any single mechanical property has been established. Most investigators agree, however, that stronger composites should resist intraoral occlusal stresses better in most situations. The general consensus is that filler contents should be maximized. The material's elastic modulus is also of concern. Recent evidence suggests that teeth deform more than previously suspected.⁴⁶ Composites with high elastic moduli may not be able to accommodate some changes in tooth shape that are associated with flexural forces. This limitation could result in debonding of the composite restoration from enamel or dentin. This situation is more critical for cervical restorations on facial surfaces where flexural stresses may produce large deformations (see Online Fig. 18-17). Flexible restorations (low elastic modulus) would be clinically more retentive because of improved accommodation to flexural forces. The opposite requirement would be true for large mesio-occlusal-distal restorations. Composites in those cases should be rigid and minimize tooth flexure of remaining cusps.

Wear resistance of composites on occlusal surfaces of posterior restorations has received considerable attention in clinical studies.²⁰²⁻²⁰⁷ At least five types (Online Fig. 18-79) of composite wear events are based on the location on the restoration surface: (1) wear by food (CFA wear), (2) impact by tooth contact in centric contacts (occlusal contact area wear), (3) sliding by tooth contact in function (functional contact area wear), (4) rubbing by tooth contact interproximally (proximal contact area wear), and (5) wear from oral prophylaxis methods (toothbrush or dentifrice abrasion). The relative contributions of these processes are poorly understood.

Several mechanisms of wear are hypothesized on the basis of clinical information for CFA wear on relatively small posterior occlusal restorations. Mechanisms of wear are associated with failure of composite components (Online Fig. 18-80). Microfracture theory proposes that high modulus filler particles are compressed onto the adjacent matrix during

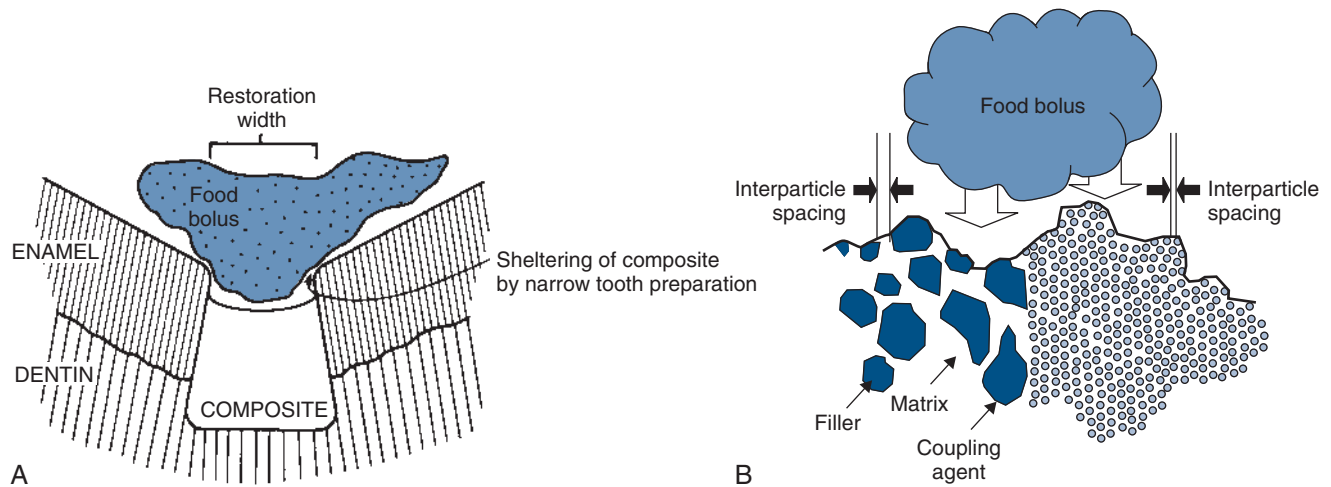


Online Fig. 18-79 Locations of different types of wear on posterior composite restorations.



Online Fig. 18-80 Schematic view of wear of composite restoration. (From Bayne SC, et al: Protection hypothesis for composite wear, Dent Mater 8:305-309, 1992.)

occlusal loading, and this creates microfractures in the weaker matrix.²⁰⁸ With the passage of time, these microfractures become connected, and the surface layers of the composite are exfoliated. Hydrolysis theory suggests that the silane bond between the resin matrix and the filler particle is hydrolytically unstable and becomes debonded.²⁰⁹ This bond failure allows surface filler particles to be lost. This mechanism has not been observed in normal acidic environments but does seem to occur when conditions become strongly basic.^{210,211} Chemical degradation theory proposes that materials from food and saliva are absorbed into the matrix, causing matrix degradation and sloughing from the surface.⁵⁹ Finally, protection theory proposes that the weak matrix is eroded between the particles.^{158,212}



Online Fig. 18-81 Protection theory of contact-free area (CFA) wear. **A**, Macroprotection of composite by sheltering effect of narrow tooth preparation. **B**, Microprotection of matrix resin from small abrasive particles in a food bolus is created by close interparticle spacing of filler particles. Interparticle spacing is reduced from midfill composites (left) to minifill composites (right). (Adapted from Bayne SC, et al: Protection hypothesis for composite wear, *Dent Mater* 8:305–309, 1992.)

If a posterior occlusal restoration is narrow enough, occlusal contact wear is significantly reduced or eliminated, and wear is almost entirely caused by food bolus contact (CFA wear) (Online Fig. 18-81, A). It now seems that CFA wear resistance is not related to composite mechanical strength but, rather, to filler spacing. Filler particles are much harder than the polymer matrix and resist wear well. If filler particles are closely spaced, they shelter the intervening matrix polymer. This is called *microprotection* (see Online Fig. 18-81, B). In microfill composites, the particles are extremely small, and the interparticle spacing is very small.¹⁵⁸ As a result, microfills, even with their low filler contents, show good CFA wear resistance. If their strengths are low, however, they do not resist direct tooth contact wear forces well. Composite restorations with relatively narrow tooth preparations minimize food bolus contact and provide sheltering of the restoration. This process is called *macroprotection* (see Online Fig. 18-81, A). The size of the anticipated restoration is a good indication for the discretionary use of posterior composite materials. If the tooth preparation is narrow, composites can be used with little concern about wear. If the tooth preparation is wide or is located in a molar tooth (which is most frequently involved in masticating the food bolus), the restoration is more susceptible to wear.

Large, extensive posterior composites that include total occlusal contact coverage are more prone to failure because of impact (occlusal contact area wear) and fatigue (functional contact area wear).^{162,213} If the opposing teeth contact only the composite restoration, undesirable composite wear usually occurs at those contacts. This process is restricted, however, if centric contacts remain on enamel elsewhere in the restored tooth.

Wear resistance of posterior composites has been evaluated extensively in longitudinal clinical studies at the University of North Carolina and the University of Alabama over 20 years.^{116,203,205,207,214–217} Results of this research have shown that microfill composites were the most wear-resistant formulations; most other commercially available restorative composites (midhybrids, minihybrids, and some packables) display

extremely low in vitro and in vivo wear rates. Clinical research on at least one packable composite showed extremely low wear rates over 5 years of investigation.

Numerous in vitro wear simulators have been investigated over more than 30 years to try to duplicate the complicated combination of intraoral wear events. Only one device (Leinfelder wear tester) has shown excellent correlation with a wide range of clinical results.²¹⁸ Several other devices are used routinely to measure in vitro wear (Krejci wear simulator, Ferracane wear simulator).^{219,220}

Toothbrush (and toothpaste) abrasion of composites is poorly understood. Direct evidence from anterior composites that this process occurs other than at very low rates is lacking. Still, intuitive thinking suggests that aggressive tooth brushing, particularly with powered toothbrushes, may produce significant abrasion. Studies on first-generation flowable composites show that they wear more than do sealants.²²¹

Clinical Considerations

Composites are monitored in clinical studies by using U.S. Public Health Service categories of interest: color matching, interfacial staining, secondary caries, anatomic form (wear), and marginal integrity.^{222,223} Color matching not only depends on proper initial color matching but also on the relative changes that occur with time. The restoration and the tooth structure are known to change in color with age. The assessment is made with the tooth structure properly hydrated. Temporary drying of the tooth structure makes it appear lighter and whiter in color because of the dehydration of enamel (see the discussion on optical properties in the section on materials properties). With time, chemical changes in the matrix polymer may cause the composite to appear more yellow. This process is accelerated by exposure to UV light, oxidation, and moisture. Anterior restorative materials with high matrix contents that are self-cured are more likely to undergo yellowing.²²⁴ Newer systems that are visible light-cured, contain higher filler contents, and are modified with UV absorbers and antioxidants are more resistant to color change.

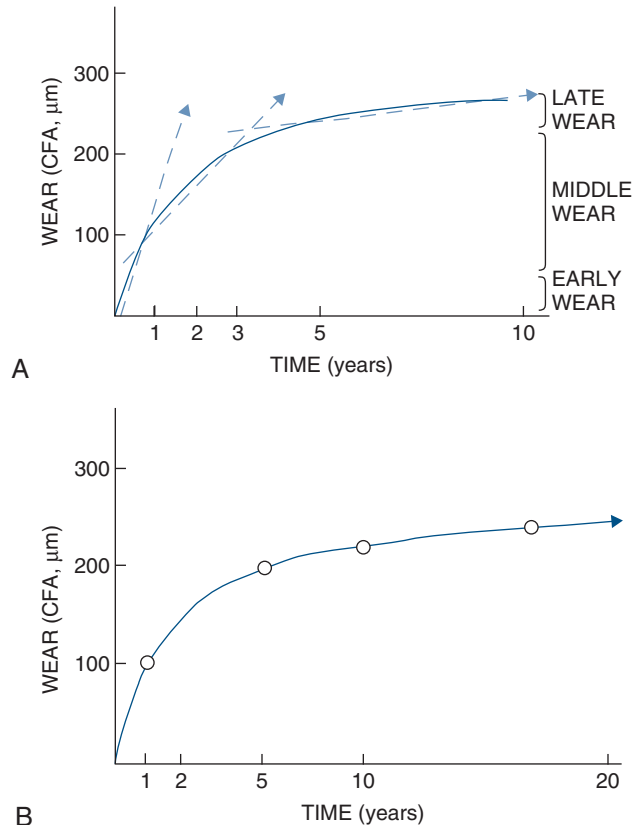
Even if a composite is relatively color stable, the tooth structure undergoes a change in appearance over time because of dentin darkening with aging. The aged tooth structure appears more opaque and is darker yellow in color. The clinical challenge is to match the restoration's rate and type of color change with those of the tooth structure. A color mismatch that appears after several years is difficult to avoid. Dentin is likely to change color most rapidly during middle age (35–60 years).

Bleaching of teeth has become extremely popular (in-office and home bleaching). This practice complicates the process of establishing and maintaining good color match of an anterior restoration to the adjacent tooth structure. If bleaching occurs as a treatment of fixed duration, restorative procedures should be postponed until after teeth have assumed a stable lighter shade. Continual bleaching or on-and-off bleaching (“date bleaching” or “weekend bleaching”) generally makes it impossible for the restoration shade to match the tooth color perfectly. Newer whitening toothpastes and continual bleaching may have some effects on restoration surfaces as well, but these are not well known.

Another important consideration for esthetics is a gradual transition in color and translucency between the restoration and the tooth structure. Beveling the enamel tends to blend any color difference associated with the margin over approximately 0.5 to 1 mm (depending on the preparation size and requirements for bevel width), rather than making the transition abrupt. This step is particularly beneficial for anterior restorations. It also produces more surface area for a well-bonded margin that does not leak. Marginal leakage leads to the accumulation of subsurface interfacial staining that is difficult or impossible to remove and creates a marked boundary for the appearance of the restoration. Restorations that have been properly acid-etched should be well bonded for years. The longevity of micromechanical enamel retention as well as the effects of fatigue stresses or other intraoral events are unknown. However, clinical studies lasting 14 years have indicated relatively good resistance to interfacial staining.

As long as the margins are well bonded and no marginal fractures occur, effective resistance to secondary caries can be expected. Although not well documented, most secondary caries seems to occur along the proximal or cervical margins, where enamel is thin, less well-oriented for bonding, difficult to access during the restorative procedure, and potentially subject to flexural stresses. Only rarely is secondary caries observed along the margins on the occlusal surfaces or the noncervical aspects of other surfaces.²²⁵ The incidence of caries varies, depending largely on the degree of technical excellence during composite placement. Clinical research studies indicate that for well-controlled insertion techniques, the incidence of secondary caries after 10 years is 3%.²²⁶ Under these circumstances, the primary reason for composite failure is poor esthetics or excessive wear. Cross-sectional studies of dental practices that did not conform strictly to recommended techniques indicate that caries levels of 25% to 30% have been observed after 10 years for composites placed during the 1970s and early 1980s.

The principal concern for posterior composites has been that occlusal wear could occur at a high rate and continue over long periods, exposing underlying dentin and leading to secondary caries or sensitivity. Excellent evidence from clinical research studies for small-width to medium-width



Online Fig. 18-82 Clinical wear curves for posterior composite restorations. **A**, Continually decreasing wear rate until the wear almost stops as a result of sheltering from occlusal preparation margins of small-to-moderate-sized posterior restorations. **B**, Pooled average of clinical wear for several types of UV-cured posterior composite restorations monitored over 17 years. (From Wilder AD, Jr, et al: *Seventeen-year clinical study of ultraviolet-cured posterior composite Class I and II restorations*, *J Esthet Dent* 11:135–142, 1999.)

restorations now indicates the rate of occlusal wear tends to decrease over time, with total wear approaching an average limiting value of approximately 250 μm over about 5 years (Online Fig. 18-82). Wear-resistant composites take longer to reach that level of wear. Evidence that composites wear to the point of exposing underlying dentin is minimal. After many years of clinical service, worn restorations can be repaired simply by rebonding a new surface onto the old composite to replace a worn or discolored surface.

Wear of posterior composite restorations with that for amalgams has been compared in references, but this comparison may be misleading. Occlusal amalgams do wear, but the wear is gradually compensated by continuing expansion of the restoration. The amalgam restoration seems to have the same occlusal contour. Although this expansion may be a functional advantage, the biologic effects of the wear of the amalgam are unknown.

Marginal integrity of composites is effective under most circumstances. Clinical appearance is affected by the nature of the margin. Butt-joint margins emphasize composite wear more than do beveled margins. Butt-joint margins of well-bonded restorations wear more slowly and create a meniscus appearance against enamel. As beveled composite margins

wear, however, thinner edges of material that are more prone to fracture are produced.

Bulk fracture of posterior composite restorations is rare. Although a rumor that microfill composites are more subject to fracture at occlusal contact areas has persisted, no published evidence of that fact exists, except in the case of a few restorations.²⁰³ Although bulk fracture may be the most prevalent failure mechanism in high-copper amalgam restorations, it is only rarely observed in intracoronal composite restorations.

Another clinical concern for all restorative material procedures has been the occurrence of postoperative sensitivity. Actual causes of this event are poorly researched but are hypothesized to be caused by (1) marginal diffusion of species that induce fluid flow within dentin or (2) dimensional changes of the restoration itself. Contraction resulting from polymerization shrinkage or expansion from water absorption, or a combination of both, can cause flexure of bonded cusps and produce pain. The incidence of postoperative sensitivity for posterior composite restorations is relatively low.²²⁷ In most cases, it occurs within the first 6 months to 1 year of the procedure and subsides within 6 months of initial onset. Only rarely must a posterior composite be removed to manage the problem.²²⁸

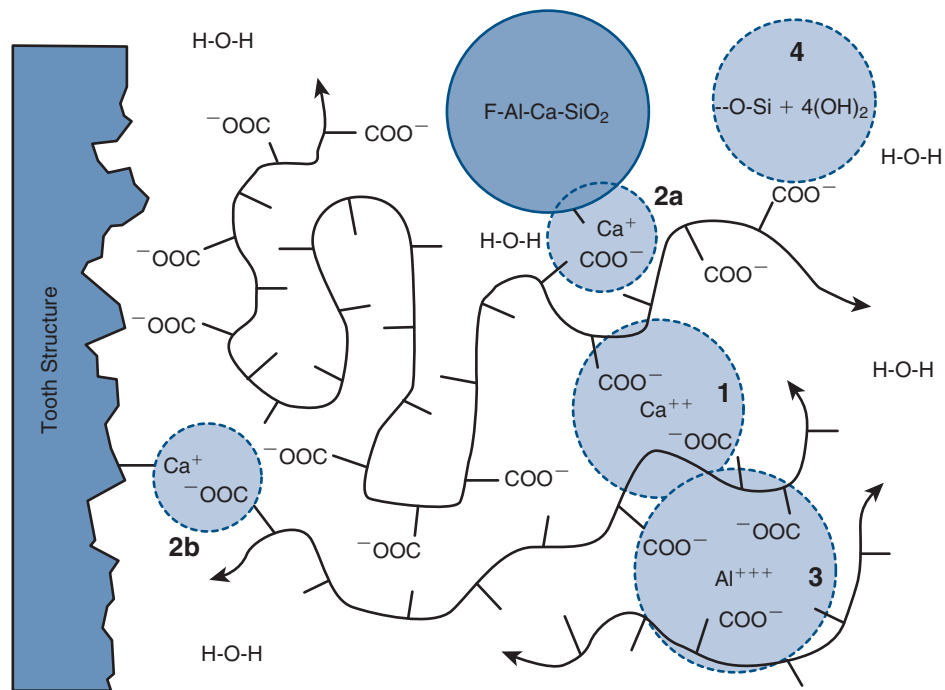
Problems of biocompatibility are limited for most composites with the dental pulp. Although the unpolymerized materials are potentially cytotoxic and may have been classified as carcinogenic, they are poorly soluble in water and are polymerized into a bound state before dissolution and diffusion can occur. Monomers that do not polymerize may diffuse slowly out of the restoration, but the concentration of released

monomer at any given time is so low that the materials do not seem to represent any practical risk. As noted with mercury migration from amalgam restorations, concentration and time are the key factors in assessing biohazards. These events, however, still need to be examined more closely. Evidence from long-term clinical studies of any clinical problems resulting in pulp death or soft tissue changes with the use of composite does not exist.

Glass Ionomers

Terminology and Classification

Glass ionomers are materials consisting of ion-cross-linked polymer matrices surrounding glass-reinforcing filler particles. The earliest glass ionomer materials for restorations were based on a solution of polyacrylic acid liquid that was mixed with a complex aluminosilicate powder containing calcium and fluoride. The acidic liquid solution (pH = 1) dissolves portions of the periphery of the silicate glass particle, releasing calcium, aluminum, fluoride, silicon, and other ions. Divalent calcium ions are chelated quickly by ionized carboxyl side groups on polyacrylic acid polymer chains, cross-linking the chains and producing an amorphous polymer gel. During the next 24 to 72 hours, the calcium ions are replaced by more slowly reacting aluminum ions to produce a more highly cross-linked matrix that is now mechanically stronger.²²⁹ It is now believed that during the maturation involving aluminum ion cross-linking, silicon ions and unbound water participate in producing an inorganic co-matrix, best described as a hydrated silicate (Online Fig. 18-83).²³⁰



Online Fig. 18-83 Schematic view of the setting and adhesion reactions for a variety of glass-ionomer compositions produced when ions are released from periphery of fluorine–aluminum–calcium–silicate (aluminosilicate glass) glass particles being dissolved by polyacrylic acid solutions. 1, Initial setting is caused by divalent calcium ions (Ca²⁺), which chelate polyacrylic acid carboxyls and cross-link adjacent polymer chains. 2, Pendant carboxyl groups on polymer chains also chelate surface ions on powder particles (2a) and tooth structure (2b) to produce further chemical bonding. 3, Trivalent aluminum ions (Al³⁺) gradually replace divalent Ca²⁺ during the first 24 to 72 hours of the reaction and form a new, tighter, cross-linked network of polymer chains that is much stronger. 4, Silicate ions react with available water and form a covalent silicate network slowly over 30 days. (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)

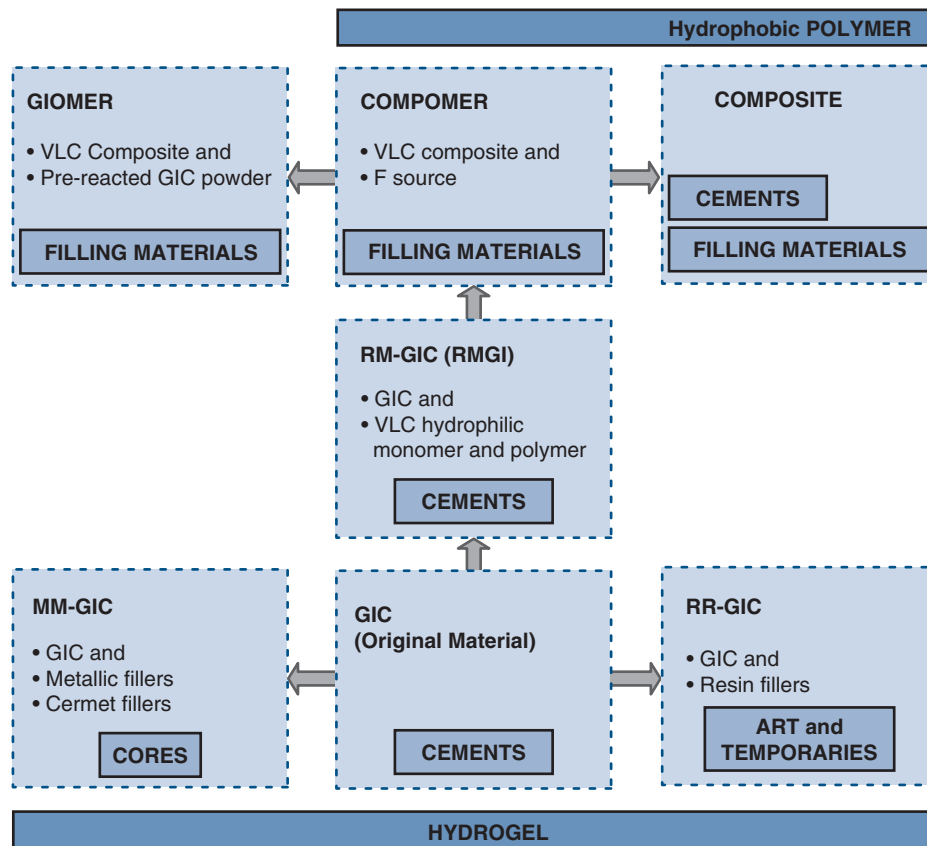
The same carboxylic acid side groups also are capable of chelating surface ions on the glass particles or calcium ions from the tooth structure. This process generates true chemical bonds at all internal and external interfaces when the reaction conditions are correct. Set materials have modest properties compared with composites but have relatively good adhesion and the ability to release fluoride ions from the matrix for incorporation into the neighboring tooth structure to suppress caries. The perceived advantages of adhesion and fluoride release have driven more than 30 years of intense research to improve glass ionomer products to the point of being competitive with other restorative material options.

Historical Development

The design of the original glass ionomer cements was a hybrid formulation of silicate and polycarboxylate cements. Glass ionomers used the aluminosilicate powder from silicates and the polyacrylic acid liquid of polycarboxylates. The earliest commercial product was named using the acronym for this hybrid formulation—ASPA (aluminosilicate polyacrylic acid).

Many liquid and powder modifications were soon incorporated to improve the physical, chemical, and mechanical properties. Despite these changes, however, early materials were very technique sensitive. Mixing, placement, and early intra-oral conditions were crucial to the properties achieved.^{231,232} Glass ionomers, which are hydrogels, are fundamentally hydrophilic, and dental composites are hydrophobic. The presence of water in glass ionomers makes it difficult to provide esthetics and mechanical strength as with dental composites. The varied history of modifications of the basic composition to create products with improved properties is traced in Online Figure 18-84.

The original polyacrylic acid in the liquid component was modified by co-polymerization with different amounts of maleic acid, itaconic acid, or tartaric acid to increase the stability of the liquid and modify its reactivity. Powder particles were reduced in size and modified by incorporating additional types of powder particles for reinforcement. Silver–tin particles (amalgam alloy particles) were admixed in some formulations to produce an amalgam substitute. This combination became known as the “miracle mixture” because it was



Online Fig. 18-84 Summary of the historical evolution of glass ionomer cements. The original cement (GIC) is hydrophilic because of the water content required to dissolve the polyacrylic acid chains and maintain the ion–cross-linked hydrogel. Hydrogels (*bottom middle*) are neither as strong nor as esthetic as dental composites (*upper right*). Early experiments focused on replacing some of the fluoroaluminosilicate filler with metal or cement particles. These metal-modified glass ionomers (MM-GIC) were not esthetically pleasing but have been used as cores. Replacing part of the hydrogel with water-soluble, light-curing monomers and polymer phases generated resin-modified glass ionomer (RM-GIC, or RMGI). Complete replacement of the matrix with typical composite chemistry but inclusion of the fluoride-releasing matrix phases or glass produced compomers (composites capable of releasing fluorine ions). Modification of compomers by blending in pre-cured glass ionomer phases as particles produced giomers. Original glass ionomer “as is” or modified with small additions of polymer resin or more fluorine-enriched glasses generated resin-reinforced glass ionomers (RR-GIC, or RRG), which have been extremely popular as atraumatic restorative treatment (ART) and temporary materials. Fuji IX (GC Corporation) is a noteworthy representative of this category. (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)

initially introduced during the early 1980s at the time when the mercury controversy was increasing dentists' questions about the safety of amalgams.²³³ The properties of the miracle mixture were far inferior to those of amalgam, however, and it was therefore not well received as a restorative material. In part, the problem with the admixture was that the matrix would not adhere strongly to the silver–tin alloy particles.

To circumvent this difficulty, it was substituted by silver–palladium (Ag–Pd), which generates a passivating oxide film of palladium oxide that is chemically reactive by chelation with polyacrylic acid. These mixtures, termed *ceramic–metal (cermet) mixtures* (see [Online Fig. 18-84](#)), were much stronger than unmodified glass ionomer cements but had poor esthetics and could not be highly modified, as otherwise they would not set as well. These materials are used mostly as cores.

In the face of limited success with these modifications, glass ionomer compositions were promoted for less demanding applications such as liners, bases, cements, cores, and root canal filling materials, rather than as restorative materials. During the 1980s, the use of glass ionomers for such applications increased. Glass ionomers were plagued, however, by technique sensitivities owing to mixing requirements, potential problems with postoperative sensitivity, and the need for moisture protection to prevent surface degradation before the secondary setting reaction was completed. With careful attention to procedural details, glass ionomers have proven to be clinically successful in many applications.²³²

In restorative filling applications, glass ionomers have never been as esthetic or strong as composites. Glass ionomers are hydrogels, and their water reduces light scattering and decreases mechanical strength. One path for redesign has been to limit or eliminate the actual hydrogel content.

In the early 1990s, reformulated ionomer-based materials replaced part of the original glass ionomer formulation with alternative filler particles or matrix setting reactions to make them more composite-like (see [Online Fig. 18-84](#)).²³⁴ These materials are categorized as hybrid or resin-modified glass ionomers (RMGIs). These are usually light-cured, are less technique sensitive, and may be finished at the time of placement. Although more composite-like, they still may include acid-base reactions and display some chemical behavior of traditional glass ionomer materials. Because RMGIs are significantly stronger than traditional glass ionomers, they are recommended for Class V restorations and can be used for Class I and II restorations in primary teeth.

With continued evolution of glass ionomers, polyacid-modified resin composites or compomers were created.^{177,235-238} The earliest term for these systems was *isosit* (combining the terms *ionomer* and *composite*), but it was trademarked by a single manufacturer. The industry, however, adopted the alternative combination term *compomer*. Although the term *compomer* implies that the material possesses a combination of the characteristics of composites and glass ionomers, these materials are essentially polymer-based composites that have been slightly modified to permit fluoride release from the glass or special matrix phases. The mechanical properties are superior to the properties of traditional and RMGIs and, in some cases, rival those of contemporary polymer-based composites.

Since about 1990, a special filling material has been fabricated from glass ionomers for use in the atraumatic restorative treatment (ART) technique. In locations such as the rural

regions of developing countries, where routine treatment is not possible, untrained dental personnel can use ART to halt or lessen the progression of frank carious lesions until the patient can access dental facilities.²³⁹ An ART restoration is based on a self-cured version of a conventional glass ionomer that is a mixture of powder and liquid and is capable of a relatively high fluoride release. A frank lesion can be partially excavated without using dental instruments. An ART restoration is mixed by rubbing the powder and liquid materials together between the tips of the thumb and forefinger and is then inserted into the tooth excavation. Biting onto the restoration, the patient creates some gross anatomy and occlusal adjustment. Since the development of ART, evidence has accumulated that these materials are useful in numerous dental situations. One application is as a permanent restorative material for deciduous teeth instead of amalgam, composite, or other options. ART restorations seem to survive with only minor management for several years.

Yet another type of glass ionomer is called *giomer* (see [Online Fig. 18-84](#)). In an attempt to retain some traditional properties of glass ionomers, giomers include pre-cured and pulverized particles of glass ionomer as an additional dispersed phase within a compomer. Early clinical trials seem to indicate that they are not truly competitive with composites as permanent filling materials in posterior locations.

Composition, Structure, and Properties

Examples of a traditional glass ionomer, RMGI, and compomer are listed in [Online Table 18-16](#) along with certain key properties.

Clinical Considerations

The mainstay arguments for the use of glass ionomers are chemical adhesion and fluoride release. Despite intuitive belief in these benefits, little clinical evidence indicates that glass ionomers produce better restorations compared with composites. Adhesion of conventional glass ionomers (not RMGIs or compomers) to enamel, dentin, or both produces only macroshear bond strengths of 6 to 12 MPa. By comparison, dentin bonding agents now can produce bond strengths of 22 to 35 MPa. Although glass ionomers are aqueous systems and wet the tooth structure well, they tend to have relatively high viscosity and do not adapt readily to micromechanical spaces. Glass ionomer adhesion is achieved partly by mechanical retention and partly by chemical chelation. Although chemical bonding for dental systems has always been fascinating, the bond density per unit area is greater for mechanical bonding than for chemical bonding. In most cases, good mechanical bonding is much more important than chemical bonding. The potential of glass ionomers for chemical bonding is only an advantage in situations in which it is difficult or impossible to produce effective micromechanical retention.

Historically, fluoride-containing silicate cement restorations had almost no associated secondary caries, despite the significant marginal disintegration and solubility of the restoration itself. Similar success has never been shown for glass ionomers. Two factors influence the effects of fluoride ion release. First, the levels of fluoride ion release are relatively low. The release is proportional to the concentration available to diffuse from the matrix or residual silicate particles through

Online Table 18-16 Comparison of Compositions, Structures, and Properties of Typical Examples of Three Glass Ionomers

		Conventional Glass Ionomer (GI)	Resin-Modified Glass Ionomer (RMGI)	Polyacid-modified Resin Composite
Abbreviation		GI	RMGI	RMGI
Commercial name		Fuji II	Vitremer	Dyract
Manufacturer		GC	3M ESPE	Dentsply
Applications		Liner, base, cement	Cement, restorative	Restorative
Acid-base setting reaction		Yes	Yes	No
Polymerization setting reaction		No	Yes	Yes
Properties				
VLC depth of cure (mm)		NA	2.7	4.7
Water absorption ($\mu\text{g}/\text{mm}^3$)	7d	236	—	—
	180d	—	174	26
Radiopacity (mm of Al)		2.5	1.8	3
Fluoride release ($\mu\text{g}/\text{cm}^2$)	7d	25.9	21.2	7.8
	22d	9.3	8.8	7.8
Flexural modulus (GPa)	Dry	12.9	9.6	7.6
	Wet	5.5	—	7.5
3-pt. flexure strength (MPa)	Dry	20	68	96
	Wet	4	—	—

Al, aluminum; GPa, gigapascal; MPa, megapascal; NA, not applicable; VLC, visible light-cured.

Data from McCabe JF: Resin-modified glass-ionomers, *Biomaterials* 19:521–527, 1998; Meyer JM, et al: Compomers: Between glass-ionomer cements and composites, *Biomaterials* 19:529–539, 1998; and Smith DC: Development of glass-ionomer cement systems, *Biomaterials* 19:467–478, 1998.

to the restoration surface. Generally, fluoride ion release is relatively high during the first few days after the reaction, but that rate of release decreases rapidly to low levels as fluoride concentration is depleted in the matrix (Online Fig. 18-85). A critical level of fluoride release over time never has been defined clinically. Second, and more important, the absence of significant secondary caries with glass ionomers is not evidence of a fluoride ion effect. For technically well-placed posterior composites, the incidence of secondary caries can be less than 3% at 10 years, even in the absence of fluoride release. No clinical evidence has been collected to indicate that glass-ionomer restorative materials can produce comparable or better results. Esthetic problems with many glass ionomers result in replacement or repair in much less than 10 years. Fluoride release from restorations may not be a major advantage if other factors do not favor long-term service.

Nonetheless, fluoride release from restorative materials such as glass ionomers may have therapeutic effects that have yet to be shown. Glass ionomer restorations seem well suited for situations involving high caries risks. These include patients known to be more caries susceptible, patients with reduced or no saliva flow, and patients with oral diseases that accelerate the pathogenic activities associated with caries. When bonding composite to gingival areas with little or no enamel, a glass ionomer liner extended just short of the margins has been suggested as a way to reduce caries risks if microleakage occurs.

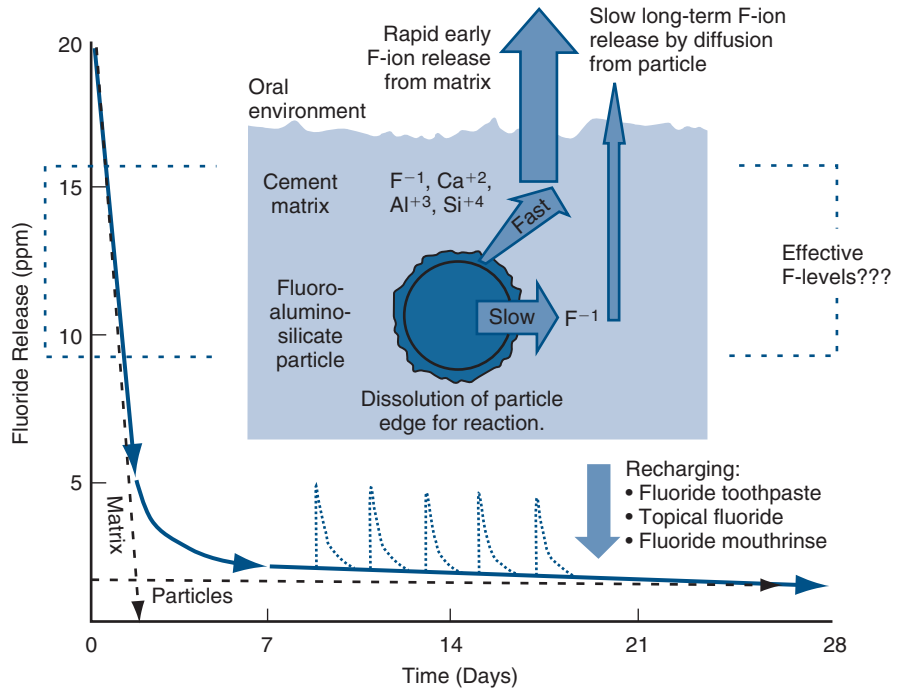
Fluoride release from glass ionomers and other similar compositions is diffusion limited and affected by the concentrations in the matrix, the glass filler particles, and the surrounding environment (see Online Fig. 18-85). For glass

ionomers, the initial high burst of fluoride ion release is caused by the high concentration of fluoride ions that remain in the matrix immediately after the setting reaction concludes. During the initial part of the reaction, acid dissolution of outside edges of powder particles releases a large amount of fluoride into the matrix. These fluoride ions diffuse quickly out of the matrix at external surfaces. The ions from the matrix are replaced only very slowly by fluoride ions diffusing from the particles. The actual long-term release rate for fluoride ions is much lower (see Online Fig. 18-84).

Whenever glass ionomers are exposed to unusually high external levels of fluoride ions from other sources such as topical fluorides, fluoride rinses, or fluoride-containing dentifrices, the concentration gradient temporarily is reversed and fluoride diffuses into the glass ionomers. This process is called *recharging*. At first, it was claimed to provide high levels of fluoride for continual release. Yet, as fast as recharging occurs, discharging occurs; this is illustrated schematically in Online Figure 18-85. It is unlikely that this event significantly improves the effectiveness of glass ionomers for the prevention of secondary caries compared with other restorative materials.

Biocompatibility of traditional glass ionomer cements has been a clinical concern. At the time of initial mixing, sensitivity and pulpal irritation could potentially be caused. As the reaction for glass ionomer proceeds, the pH increases from initial values near 1 to a range of 4 to 5. As the setting reaction nears completion, the final pH value reaches 6.7 to 7. Because the acid groups are attached to polymer molecules that have limited diffusibility, any potential pulpal effects from low initial pH are limited to areas immediately adjacent to the material. If the RDT is less than 0.5 mm, it may be necessary

Online Fig. 18-85 Summary of release of fluoride ions (F^-) from fluoride-releasing materials such as glass ionomer cement. Inset shows that glass-ionomer cement releases a large amount of F^- into the matrix during the setting reaction, which is responsible for the initially high release rates during the first day or so. Thereafter, the only source of F^- is the residual fluoroaluminosilicate particles, and diffusion from them is slow but rapid from the matrix. The net release of fluoride tends to be low (0.2–2 ppm) over long periods. External sources may generate F^- (e.g., toothpaste, mouthrinse, or topical fluoride) that diffuses into the matrix owing to the concentration gradient temporarily present, but these are released quickly back into the oral environment (as shown in the figure), and F^- release decreases back to the original level. (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)



to protect the dentinal surfaces from direct contact with unset glass ionomer materials by using a calcium hydroxide liner. When fluid-filled dentinal tubules are in direct contact with setting cement, two problems occur: (1) High ionic concentrations in the unset glass ionomer cause dentinal fluid to diffuse rapidly outward into the cement. This phenomenon produces a minor fluid movement sensed by pressure receptors near the pulpal odontoblasts and causes pulpal sensitivity or pain. (2) At the same time, unset components such as hydrogen ions may move into tubules and toward the pulp. Tubule fluid contents typically buffer the ions when the RDT is adequate and prevent chemical irritation of the pulp. The key to successful use of these materials is strict attention to specific techniques. The risks for postoperative sensitivity with RMGIs and compomers are much lower.

To increase mechanical strength, glass ionomer materials intended for use as restorations are mixed at higher powder-to-liquid (or filler-to-matrix) levels than similar ones used for luting. The reduced matrix content decreases the risk of postoperative sensitivity or pulpal problems. In addition, tooth preparations may be lined with calcium hydroxide to provide a barrier to the diffusion of unset glass ionomer components while the material is curing.

Indirect Restorative Biomaterials

Traditional stages of fabricating dental restorations by indirect restorative techniques involve impressions, dies, wax patterns, investing, casting or molding, finishing and polishing, and cementing. Computer-aided design/computer-assisted manufacturing (CAD/CAM) approaches are possible as well and are discussed later. Because of the multiple stages of these techniques, errors that enter into the procedures at any point tend to be compounded and carried into the next stage. It is

important to adhere strictly to the procedural details throughout the techniques, or the final restoration will not fit.

Impression Material Terminology and Classification

Impression materials are used to record the surface topography and detail of hard and soft tissues and produce a mold for making a replica (cast) of those structures. Nine types of impression materials have been used historically in dentistry. Their generic compositions, common names, and key clinical properties are summarized in Online Table 18-17.

Plaster, impression compound, and ZOE are rigid solids incapable of being removed directly from undercut areas of hard or soft tissues. They have limited use for dentulous patients. Alginate (irreversible hydrocolloid) and reversible hydrocolloid (agar-agar) are elastic and have the advantage of wetting the intraoral surfaces well but have limited dimensional stability because they include 85% water in their composition. Polysulfide (rubber base, Thiokol rubber), silicone (condensation silicone, conventional silicone), polyether, and polyvinyl siloxane (PVS; vinyl polysiloxane, addition silicone, addition polydimethyl siloxane) are nonaqueous polymer-based rubber impression materials that have good elasticity (see Online Table 18-17). They are listed in the order of development. PVS is the most widely used.

Composition, Structure, and Properties

To be totally effective, an impression material must be fluid before it sets, hydrophilic to wet intraoral surfaces, highly elastic to prevent permanent distortion during removal, sterilizable, dimensionally stable, and compatible with the cast material and must undergo complete conversion to an elastic solid. To meet these mechanical requirements, the most

Online Table 18-17 Classification of Dental Impression Materials

Type (and Synonyms)	Mechanical Behavior	Setting Reactions	Special Versions
Impression plaster	Rigid	Chemical (irreversible)	—
Impression compound	Rigid	Physical (reversible)	—
ZOE	Rigid	Chemical (irreversible)	—
Alginate	Flexible	Chemical (irreversible)	—
Agar-agar	Flexible	Physical (reversible)	—
Polysulfide (rubber base, Thiokol rubber)	Flexible	Chemical (irreversible)	—
Silicone (conventional or condensation silicone)	Flexible	Chemical (irreversible)	—
Polyether	Flexible	Chemical (irreversible)	—
Polyvinyl siloxane (vinyl polysiloxane, additional silicone)	Flexible	Chemical (irreversible)	Hydrophilic

ZOE, zinc oxide–eugenol.

common formulation for an impression material is a mixture of nonreactive filler with a flexible polymer matrix.

Elastomeric polymer matrices are produced by polymerizing fluid monomer or oligomer mixtures by stepwise polymerization or by chain-reaction polymerization. Polysulfide, condensation silicones, and polyether impression materials involve stepwise polymerization. Stepwise reactions are relatively slow and do not go to completion for several hours. Approximately 65% to 85% conversion occurs within 6 to 8 minutes during initial setting before a dental impression is removed from the mouth. As long as the impression is in the mouth, the shrinkage is confined to noncritical areas because the intraoral surfaces restrain the impression material. After removal, the impression experiences more shrinkage as the polymerization continues. Although these materials are elastic, the elastic recovery is visco-elastic and requires 20 to 30 minutes to reach a point of accurately returning to the intraoral dimensions being duplicated. During this pause for elastic recovery, continued polymerization can distort the impression size and shape. To minimize these effects, high levels of fillers are incorporated in the matrix. Filler levels vary between 15 and 60 wt% and are chosen on the basis of compatibility with the matrix material and expense.

Portions of the impression that must record fine details of the tooth structure are normally impressed with the least-filled formulations (light-bodied material) to achieve maximal flow and adaptation to intraoral structure before curing. The bulk of the impression is the highly filled material (heavy-bodied material), however, which minimizes shrinkage contributions and greatly reduces inaccuracy. During setting, PVS undergoes a chain-reaction polymerization (which is also an addition reaction), that is fast, goes almost to completion, and does not generate condensation byproducts. This characteristic provides a major advantage for these materials compared with other elastic impression materials. When the impression is removed, it is dimensionally stable, and the casts that are fabricated from the impression can be produced at any time. In the case of the other rubber elastic impression materials, the impression should be poured immediately after pausing 20 to 30 minutes for visco-elastic recovery.

PVS materials commonly use exotic curing systems that are based on chloroplatinic acid (a platinum catalyst). During the reaction, the acid decomposes and generates small amounts

of hydrogen gas as a byproduct. Early versions of PVS were plagued by gas bubble formation that ruined casts poured in the impressions unless 24 to 48 hours were permitted for out-gassing. Newer materials contain hydrogen scavengers that react with, and tie up, the hydrogen byproducts.

Another more recent modification to many commercial PVS impression materials is the addition of surfactant to increase the hydrophilic nature of the material. Although this seems to have a favorable effect on the ease with which these new “hydrophilic” siloxane materials can be poured up with gypsum products, no conclusive evidence exists to indicate that these newer materials wet tooth structure better than unmodified (no surfactant added) siloxane materials.²⁴⁰⁻²⁴²

Clinical Considerations

The most significant clinical consideration when using an elastic impression material is the rate of removal of the initially set impression. All polymer-based materials are strain-rate sensitive. If they are stressed quickly, they behave as though they are stronger and more elastic than if stressed slowly. Elastic impression materials should be removed from the intraoral surfaces with a relatively rapid motion. The objective is to minimize the time that the impression is distorted. This approach prevents conversion of mechanical energy into plastic deformation, rather than elastic deformation. Teasing or slowly deforming an impression produces unwanted plastic deformation and introduces inaccuracies into the final impression and the resulting cast.

The properties of impression materials influence not only the clinical techniques but also the preparation of casts and dies. Hydrophobic impressions are not wet well by water-based cast and die materials. Wetting agents are used to avert air entrapment in detailed areas under these conditions. A final mechanical property of the impression material dictates ease of cast removal. The stiffness of impressions (e.g., polyether material) can cause breakage of thin “teeth” of the cast. The impression must remain accurate while being disinfected.

Cast Metal Restorations

Creation of a cast metal restoration involves a chain of procedures from waxing a pattern of the intended final restoration

on a die, investing the pattern to create a mold space for casting, casting the restoration, finishing and polishing the casting, and cementing the restoration intraorally. Because of the complexity of this sequence, properties desirable for a casting alloy are governed as much by technique limitations as by the final intraoral service considerations. These properties are addressed in the following paragraphs.

In recent years, technology allowing dentists to make optical impression has become available. The accuracy of optical impressions for single restorations and three-unit fixed partial dentures is excellent. It must be stressed that all the requirements for making an acceptable clinical impression (dry field, successful gingival displacement) are also imperative for acceptable optical impressions. Existing systems for optical impressions are currently expensive and, from a practical viewpoint, offer far more benefits to the dental laboratory than to the dentist because the laboratory no longer is required to perform time-consuming model and die procedures. The optical impression is sent digitally to a central laboratory that machine-fabricates the models and dies and then forwards these components to the dental laboratory.

Terminology

Cast metal alloys may be used to form the entire restoration or may be designed as a substructure and veneered with porcelain to create a tooth-colored restoration. Cast metal alloys that are veneered with porcelain may be described generically as porcelain-bonded-to-metal, ceramic-bonded-to-metal, or PFM restorations. For successful porcelain application, the metal alloy must have a relatively high melting point to tolerate the high porcelain firing temperatures without sagging or melting. The melting temperature of restorations that are all metal (without porcelain) can be any temperature that can be conveniently processed.

Classification

Corrosion resistance is an essential characteristic of dental casting alloys. These alloys are categorized in terms of (1) their mechanism of corrosion resistance and (2) the main elements in the composition affecting the corrosion resistance (see the next section). Corrosion resistance is achieved with either immune or passivating alloy systems. For dentistry, immune systems are divided into gold systems and gold substitute systems. Passivating systems are divided into nickel–chromium (Ni–Cr), cobalt–chromium (Co–Cr), iron–chromium (Fe–Cr), and titanium (Ti) systems.

Many of the terms relating to corrosion resistance have special meanings. Noble metal alloys are very resistant to corrosion and electrochemical corrosion. These systems are based on gold, platinum, palladium, rhodium, iridium, ruthenium, or osmium. Precious metal alloys contain metals of high economic value and, as a group, traditionally include all of the noble metals and silver. Low-gold alloys contain only 3 to 50 wt% gold or other noble metal elements. If less than half (75 wt%) of the atoms in a gold alloy are corrosion resistant (gold [Au], platinum [Pt], or palladium [Pd]), the overall corrosion resistance decreases dramatically. Low-gold alloys are attempts at producing lower cost alloys that still retain some of the qualities of premium-priced, gold-based alloys. The actual quantity of gold may be deceptively low. Gold substitute alloys

are precious metal alloys that do not contain gold. The best examples are silver–palladium (Ag–Pd) systems and other palladium alloys.

Base metal alloys are based on active metallic elements that corrode but develop corrosion resistance via surface oxidation, which produces a thin, tightly adherent film that inhibits further corrosion. Alloys are formulated with 18% to 28% by weight chromium (Cr) that produces films of chromium oxide (Cr_2O_3) that passivate the surface. The films are brittle and may be ruptured, but re-form immediately if sufficient chromium remains locally in the composition. Oxidation of other elements such as nickel (Ni) and cobalt (Co) also produces superficial oxides, but chromium oxide is principally responsible for the corrosion resistance. Titanium (Ti) (and Ti-6Al-4V) alloy is widely used in dentistry for implant systems because it passivates by forming titanium dioxide (TiO_2), is biocompatible, and permits osseointegration with bone.

Composition, Structure, and Properties of Gold Castings

Cast restorations are constructed traditionally from gold alloys because of their potentially excellent corrosion resistance. In the nineteenth century, gold coins were used as the source of alloy for casting restorations. Standardization of casting materials occurred in the 1930s. Dental gold casting alloys were defined in terms of their relative noble metal concentration, physical properties (fusion temperature), and mechanical properties (hardness, elongation, and yield point). The original ADA classification system defined types A, B, and C gold alloys.²⁴³ This specification was revised and extended to include four types (I, II, III, IV) of alloys. Types I, II, and III corresponded to the original types A, B, and C, whereas type IV included higher strength alloys.²⁴⁴ These four alloy types contain approximately 83%, 78%, 78%, and 75% noble metal elements, of which gold is the principal one. Type I and II alloys are not capable of being heat treated, whereas type III and IV alloys are. Type I compositions are intended for small inlays that do not involve significant occlusal loads. Type II alloys are intended for inlays and onlays. Type III alloys are intended for onlays and crowns. Type IV alloys are intended for crowns, bridges, and removable partial dentures.

The major elemental components of gold casting alloys for several commercial products are listed in [Online Table 18-18](#). Gold is primarily responsible for producing corrosion resistance, but it also is relatively soft and requires the addition of other elements to solution-harden the alloy. Copper is the primary element that increases the hardness of the alloy. Copper also tends to make the color less yellow and more orange. Silver is added to offset the color contributions of copper. Palladium is added to increase the hardness of the alloy and has a strong whitening effect. Palladium and platinum tend to increase the melting range for the alloy. Finally, zinc is added as a processing aid to scavenge oxygen at the surface of a melt and prevent oxidation and loss of other key elements during the casting procedure.

In recent years, the relatively high cost of gold has prompted the increased use of low-gold, gold substitute, and base metal alloys for dental castings.²⁴⁵ Cast partial dentures are almost exclusively made of base metal alloys. Many full crowns and fixed bridges are made of palladium-based gold substitute

Online Table 18-18 Objectives for Alloying the Components of Gold Casting Alloys

Alloying Element (chemical symbol)	Major Contribution to Casting Alloy	Density (g/cm ³)	Melting Point (°C)	Corrosion Behavior
Gold (Au)	Corrosion resistance	19.28	1063	Immune
Copper (Cu)	Solution hardening	8.93	1083	Active
Silver (Ag)	Counteract orange color of copper	10.50	961	Active
Palladium (Pd)	Increase hardness; elevate melting range	12.02	1552	Immune
Platinum (Pt)	Elevate melting range	21.45	1769	Immune
Zinc (Zn)	Scavenge oxygen during processing	7.14	420	Active

alloys, but the mechanical properties of these materials make them difficult to be fabricated into inlays and onlays. Gradual improvement in the materials has made the low-gold alloys acceptable for selective use for these applications. Many products containing approximately 50 wt% of gold are available that exhibit acceptable tarnish resistance and adequate properties if extensive marginal burnishing is not required.

Key properties for casting alloys are provided in [Online Table 18-19](#). A low melting range is desirable for simplified heating and casting procedures. Moderately high density is advantageous because most dental alloys are normally cast by centrifugal force casting machines. High density helps force the alloy quickly into the intricate details of the pattern within the casting mold before cooling solidifies the material. Gold-based alloys are much better in this regard than most other alloys. Finally, a low coefficient of thermal expansion helps reduce the shrinkage that occurs from the solidus temperature down to room temperature. Because cooling produces shrinkage, some expansion must occur somewhere else in the technique sequence to compensate for dimensional changes on cooling. Alloys with low coefficients of thermal contraction and that possess low melting temperatures can be controlled more easily.

The primary chemical property of concern is corrosion resistance. To achieve this quality, it is desirable that the entire alloy be a single-phase composition. Two-phase compositions are prone to local galvanic (structure-selective) corrosion. Type I, II, and III compositions are single-phase alloys. Type IV compositions may include two phases. There is a mechanical advantage with a second phase because of a hardening effect, but that benefit must be weighed against the loss of some corrosion resistance. Contamination or improper casting of gold-based alloys can produce unwanted phases that compromise the mechanical properties and the corrosion resistance.

The primary mechanical properties of interest for the final cast restoration are a high modulus of elasticity (stiffness) and a high elastic limit (hardness) to resist deformation in service. High values are not desirable properties, however, during the fabrication of the restoration. Laboratory procedures such as finishing, polishing, and burnishing are more complicated if the restoration has a high resistance to plastic deformation (high hardness). During these processes, it is important for the casting metal near the margins to be adapted closely to the die (but without damaging the die), by minimal mechanical deformation (burnishing). Marginal gaps that exceed 0.1 mm should not be burnished; the casting should be remade. Alloys

with a high percentage elongation and a low yield point (low hardness) facilitate burnishing. After these procedures are completed, it is advisable to increase the overall hardness to achieve high levels for clinical service. This goal can be accomplished with type III and IV ADA gold alloys, which are heat treatable. The heat treatment produces disorder–order or spinodal hardening processes.

Cast alloys should not produce toxic reaction products or release toxic elements from their surfaces. Immune and passive alloys seem to have excellent biologic properties. Some casting alloys are active, however, and generate soluble corrosion products. Although the restorations look unchanged, toxic soluble products can be released.

Clinical Considerations

The three principal clinical considerations for long-term success of cast restorations are close fit, corrosion resistance, and retention. Sturdevant et al and Morris showed that gold-based alloys exhibit excellent corrosion resistance for at least 10 years.^{246,247} If the cemented restorations have a close fit (within 20 μm), and the tooth preparations are adequately designed, the conventional dental cements resist degradation and provide excellent retention and service for 20 to 40 years.

Retention and service life of cast restorations are produced by a combination of factors, such as the taper of the tooth preparation, stress distribution design of the tooth preparation to protect the remaining tooth structure against fracture, cement type, surface roughness on the internal aspects of the restoration, and potential micromechanical or chemical bonding of cement with the restoration and the tooth structure. Under most circumstances, the restoration surface for gold-based alloys is not well suited to cement adhesion. The gold alloy surfaces are not wet well with cements and do not have the potential to be chemically bonded by existing formulations. If the internal surfaces are sandblasted, sufficient micromechanical irregularities are produced to permit excellent luting. Tin or other metal plating also can be used as a surface modification that is chemically reactive toward some cements.

In some cases, such as with Maryland bridges, the retention of the casting depends on well-developed micromechanical spaces along the bonded surfaces of enamel and the casting. The retentive surface of the casting is accomplished by choosing a two-phase dental casting alloy. The metal surface to be bonded is relieved by chemical or electrolytic etching of one phase in preference to the other. The relieved surface is

Online Table 18-19 Properties of Typical Gold Casting Alloys*

Representative Alloy (Supplier)	Pentron I (Pentron)	Modulay (Jelenko)	Firmalay (Jelenko)	Sterngold 100 (Sterngold)
COMPOSITION (WEIGHT %)				
Gold (Au)	84	77	74.5	60
Copper (Cu)	Balance	Balance	Balance	Balance
Silver (Ag)	12	14	11	19
Platinum (Pt)	—	—	—	—
Palladium (Pd)	1	1	3.5	4
Zinc (Zn)	<1	<1	<1	<1
CLASSIFICATION				
Gold content	High gold	High gold	High gold	High gold
ADA type	I	II	III	IV
PHYSICAL PROPERTIES				
Color	Gold	Gold	Gold	Gold
LCTE (ppm/°C)	[14–18]	[14–18]	[14–18]	[14–18]
Density (g/cm ³)	16.6	15.9	15.5	13.9
CHEMICAL PROPERTIES				
Corrosion resistance	[Excellent]	[Excellent]	[Excellent]	[Excellent]
Tarnish resistance	[Good]	[Good]	[Good]	[Good]
MECHANICAL PROPERTIES				
Modulus (MPa)	—	—	—	—
Elongation (%)	0–22	0–38	19–39	4–25
Hardness (BHN, soft/hard)	68/—	101/—	110/165	150/257
Compressive strength (MPa)	—	—	—	—
Tensile strength (MPa)	—	—	—	—
BIOLOGIC PROPERTIES				
Biocompatibility	[Acceptable]	[Acceptable]	[Acceptable]	[Acceptable]

*Relative properties are shown in brackets.

ADA, American Dental Association; BHN, Brinell hardness number; LCTE, linear coefficient of thermal expansion; MPa, megapascal.

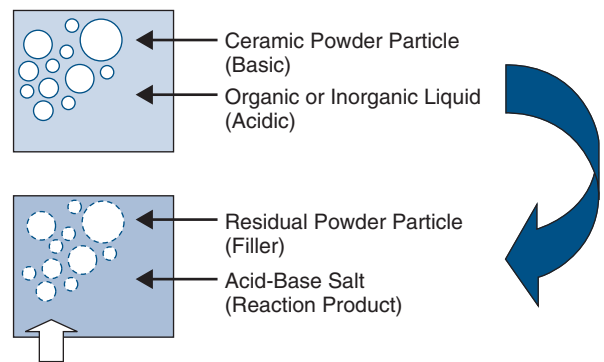
micromechanically interlocked with composite cement onto the etched tooth structure.

Dental Cements

Traditional ceramic dental cements are based on reactions between acidic liquids and basic powders to produce reaction product salts that form a solid matrix surrounding residual powder particles (Online Fig. 18-86). Microscopically, these cements are classic examples of filler and matrix microstructures. Newer cements are formulated as modified versions of materials originally developed as composite restorative materials. In all cements, the properties of interest are governed by the extent to which the matrix is minimized in the final material.

Terminology and Classification

Traditional ceramic dental cements and polymer-based dental cements are listed in Online Table 18-20, along with identification of the major powder and liquid components and the



Powder reinforces set cement matrix

Online Fig. 18-86 Schematic representation of dental cement components and microstructures. An acid-functional liquid is mixed with a basic powder. Reaction of the periphery of the powder consumes the acid groups of the liquid, producing a reaction product matrix that surrounds residual powder particles. The microstructure is a classic composite-like one with residual powder particles reinforcing the weaker matrix. (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)

Online Table 18-20 Summary of Dental Cement Classifications, Abbreviations, Reactants, and Reaction Products

Classification	Abbreviation	Liquid Components	Powder Components	Reaction Product Matrix
TRADITIONAL CERAMIC DENTAL CEMENTS				
Unmodified ZOE	ZOE	Eugenol	ZnO	Crystalline zinc eugenolate
Resin-reinforced ZOE	R-ZOE	Eugenol	ZnO, polymer, resin	Crystalline zinc eugenolate
EBA-modified ZOE	ZOE-EBA	Eugenol, EBA	ZnO, Al ₂ O ₃ , polymer	Crystalline zinc eugenolate, crystalline zinc ethoxybenzoate
Zinc phosphate	ZP	H ₃ PO ₄ , H ₂ O	ZnO	Crystalline tertiary zinc phosphate
Silicate	SC	H ₃ PO ₄ , H ₂ O	F-Al-Silicate glass	Amorphous silicophosphate
Zinc silicophosphate	ZSP	H ₃ PO ₄ , H ₂ O	F-Al-Silicate glass, ZnO	Amorphous silicophosphate, crystalline tertiary zinc phosphate
POLYMER-BASED DENTAL CEMENTS				
Polycarboxylate	PC	PAA, H ₂ O	ZnO	Amorphous zinc-polyacrylate gel
Conventional GI	GI	PAA, H ₂ O	F-Al-Silicate glass	Amorphous aluminopolyacrylate gel
Resin-modified GI	RMGI	PAA, H ₂ O, water-soluble monomers	F-Al-Silicate glass	Amorphous aluminopolyacrylate gel, cross-linked polymer
Compomer	CM	Monomers	F-Al-Silicate glass	Amorphous cross-linked polymer, aluminopolyacrylate gel
Composite (or resin)	CP	Monomers	Silicate glass	Amorphous cross-linked polymer

EBA, ethoxybenzoic acid; *GI*, glass ionomer; *PAA*, polyacrylic acid; *ZOE*, zinc oxide–eugenol.

reaction products. ZOE, reinforced ZOE, ZOE-EBA, silicate, and zinc silicophosphate traditional ceramic cements are no longer routinely used in permanent cement restorations. Zinc phosphate and polycarboxylate were used until about 1990 but now have been extensively replaced by RMGI, compomer, and composite cements.²⁴⁸⁻²⁵⁰ Zinc phosphate cement originally was developed more than 100 years ago and was extremely popular during most of the twentieth century. For that reason, it is often referred to as the “gold standard” for all dental cements despite the fact that its laboratory properties are generally inferior to those of most other currently used cements. The powder component is 90% zinc oxide powder with 10% magnesium oxide added. The liquid is 50% phosphoric acid in water and is buffered with aluminum and zinc salts to control the pH. Components are mixed typically 2:1 (powder-to-liquid by weight) on a chilled glass slab using controlled additions of powder to the liquid. These precautions are necessary to reduce reaction speed, alter the pH in a controlled manner, dissipate heat from the exothermic reaction, and provide sufficient working time. During setting, phosphoric acid ions react with zinc ions to produce a successive series of hydrated zinc phosphate salts. Ultimately, this results in tertiary zinc phosphate crystals that form a crystalline matrix around residual polycrystalline zinc oxide particles. The intercrystalline spaces within the matrix permit diffusion or leakage of very small molecules but still provide a reasonable seal. Zinc phosphate tends to be weaker and more brittle than polymer-based dental cements that have amorphous matrices.

Polycarboxylate cement was developed in the 1960s by Smith in an effort to circumvent potential pulpal problems associated with the low pH of traditional cements (e.g., zinc phosphate cement) and biocompatibility problems related to the mobility of small acidic ions. By choosing an

acid-functional polymer as a substitute for phosphoric acid in forming the matrix, it also was possible to produce cements that could adhere via chelation to dental surfaces. The original acid-functional polymer was polyacrylic acid. More recent commercial products include two or more monomers in the polymer. It is technically more correct to refer to the final polymer as a polyalkenoate. Cements based on solutions of these polymers (i.e., polycarboxylate or glass ionomer cements) may be called *polyalkenoic cements*.

Glass ionomer cements are hybrids of silicate and polycarboxylate cements designed to combine the optical and fluoride-releasing properties of silicate particles with the chemically adhesive and more biocompatible characteristics of the polyacrylic acid matrix compared with the extremely acidic matrix of silicate cement. RMGI cements have the liquid and powder components modified to provide visible light-curing reactions in addition to traditional glass ionomer setting reactions. RMGIs have been extremely popular since the 1990s and are found in about 75% of all cement use.⁹⁸

Composite cements (or resin cements or composite resin cements) have the same general components as composite restorative materials but generally have slightly lower concentrations of filler particles. These materials are reserved almost exclusively for use with all-ceramic restorations (discussed later), although they are suitable for use with all indirect restorative materials. These materials have the best laboratory properties of all cements but require more complicated clinical procedures and generally include bonding systems for dentin, enamel, and the restoration. Some newer resin cements have been described as “self-adhesive.” These cements have components similar to those used in self-etching dentin primers and thus have the potential to bond directly to clean dentin without separate binding procedures.

Although dental cements are most often used for luting indirect restorations, they also may be used as bases. As luting agents, the most important clinical requirements are flow, wetting, and film thickness. To enhance flow, the materials are mixed at relatively low powder-to-liquid ratios. To guarantee that a thin film can be produced, dispersed phase particles of 5 μm or less in diameter should be used. The actual film thickness that is achieved ranges from 50 to 100 μm and depends on (1) the viscosity of the mixture and (2) the availability of space for displacement of the cement (as discussed in the next section). Although low powder-to-liquid ratios produce low viscosities for luting agents, cements used for bases should be mechanically stronger and are mixed with the maximum powder content manageable.

Composition, Structure, and Properties

The final properties of dental cements depend on the powder-to-liquid ratios used during mixing. Higher powder-to-liquid ratios not only increase the mechanical strength but also increase the viscosity and reduce wetting and flow. The final matrices of the set cement are indicated in Online Table 18-20. A brief summary of dental cement properties is provided in Online Table 18-21. The principal goals for cementation are retention and sealing. No laboratory tests or pseudoclinical tests of cements have ever been correlated with clinical performance. A unique short-term clinical research study was performed in the 1970s at the University of Michigan by Silvey and Myers, in which zinc phosphate, reinforced ZOE, and polycarboxylate cements were compared for the retention of crowns and bridges over 7 years.²⁵¹ Practically no difference was seen in failure rates (zinc phosphate = 2%, reinforced ZOE = 8%, polycarboxylate = 5%), and no differences were statistically significant. Much longer studies are needed to assess real performance.

The mechanisms of failure of these materials are not well understood. Because most cements tend to be brittle, it is presumed that fatigue loading initiates cracks at the internal defects, propagates the cracks into a network, and causes cement loss or permits microleakage at the margins. This is accompanied by sensitivity or secondary caries. Cemented crowns and bridges principally transport occlusal stress within the restoration and onto the margins, rather than transferring it onto the underlying coronal tooth structure. The effects of high stresses at various points on margins is further amplified by poor or inadequate resistance and retention forms of the preparation.

Clinical Considerations

Zinc phosphate cements have the potential during setting to release components from the acid-rich matrix into dentin and irritate the pulp. When using zinc phosphate cement, dentin is routinely protected with varnish or a dentin sealer. Other cements that can chemically bond to dentin must, however, be allowed to come into direct contact with that surface. Varnishes or sealers should not be used to coat dentin if a polycarboxylate or conventional glass ionomer cement is to be used for chemical adhesion. When bonding composite or ceramic restorations, dentin should not be varnished or sealed, but instead the entire preparation should be treated with a bonding system.

Cement displacement is a key factor for successfully cementing restorations. The process is a hydraulic (liquid in motion) one, dependent on rapid flow and escape of excess cement between the restoration and the tooth preparation during cementation. The seating of the restoration must be completed within a few seconds while the cement is sufficiently fluid. One way to increase the potential of maximum seating is to make channels large enough (larger if they are longer) to

Online Table 18-21 Characteristic Properties of Categories of Luting Dental Cements*

	R-ZOE	EBA	ZP	PC	GI	RMGI	COMP
WORKING CHARACTERISTICS							
P/L ratio	[Low]	[Low]	[Low]	[Low]	[Low]	1.2–1.6	—
Film thickness (μm, ADA flow test)	32	—	18	21	24	—	10–60
Setting-time range (min)	6–8	—	5–7	2–3	3–5	2–3	—
PHYSICAL PROPERTIES							
LCTE (ppm/°C)	[Low]	[Low]	[Low]	—	—	[Low]	50
Thermal conductivity	[Low]	[Low]	[Low]	[Low]	[Low]	[Low]	[Low]
CHEMICAL PROPERTIES							
Solubility/disintegration (% , ADA test)	0.08	0.05	0.06	0.60	1.25	—	0.01
MECHANICAL PROPERTIES							
Compressive strength (MPa)	48	65	160	70	120	148–180	170–190
Diametral tensile strength (MPa)	4	7	10	10	12	30–35	30–35
BIOLOGIC PROPERTIES							
Pulpal response	[Mild]	[Mild]	[Moderate]	[Moderate]	[Mild]	[Mild]	—

*Relative values are shown in brackets. These values are representative of a wide range of possible values.

ADA, American Dental Association; LCTE, linear coefficient of thermal expansion; MPa, megapascal; P/L, powder-to-liquid. (See Online Table 18-20, for abbreviations for cement.)

permit the rapid escape of cement that otherwise would be entrapped. For metal castings, the channels could be created internally in the wax pattern or cut in the casting, extending gingivally from the occlusal (pulpal wall) aspect of the preparation (casting) to a point approximately 0.5 mm short of the restoration margins. Inlay and onlay preparations have short enough external walls so that the castings do not usually require escape channels, but crowns may require them if considerable axial length is present. Channels allow seating with 330 N load (75 lb), the recognized possible masticatory pressure achievable in the molar region. To produce cement flow further, loading (forces placed on the restoration being seated) must be applied rapidly, at sufficiently high levels, and steadily maintained until the cement has initially set. The final result ideally is a restoration so well-seated that its preparation-side surface is in intimate contact with the tooth preparation, particularly along the margins, resulting in a cement film thickness no greater than 50 μm .

Machined Restorations

Until 1988, indirect ceramic dental restorations were fabricated exclusively by casting or sintering techniques. Neither casting nor sintering is capable of consistently producing pore-free restorations. Cooling shrinkage distortions and residual stresses can initiate fractures at residual pores in ceramics. Pore-free restorations can be produced by machining blocks of commercially fabricated pore-free ceramic or composite.

Terminology and Classification

The two principal machining approaches for dental restorations are copy-milling and computer-aided design/computer-aided manufacturing (CAD/CAM) milling. Examples of commercial systems are provided in [Online Table 18-22](#). Copy-milling uses a replica (e.g., wax, plastic, stone, or metal) of the desired form as a guide for a milling machine. The surface of the replica is traced by turning the pattern and touching the pattern's surface with a finger stylus. The positions of the pattern and stylus are used to adjust the positions of a block of machinable material and a milling tool cutting the block. This procedure is represented schematically in [Online Figure 18-87](#).

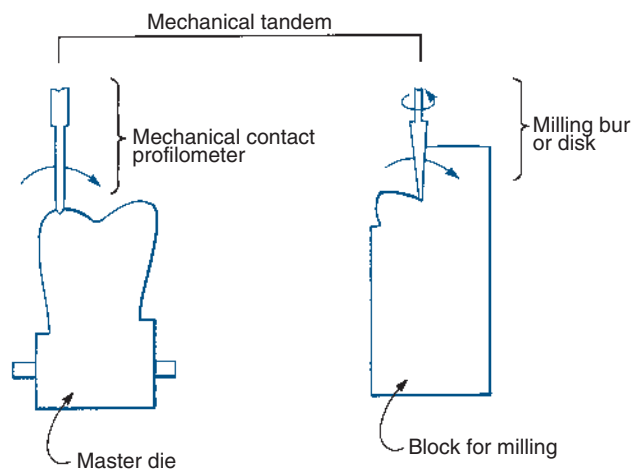
A wide variety of material types can be used in conjunction with copy-milling systems, including materials difficult to process using other methods. Titanium, which has a high melting temperature and could undergo excessive oxidation, is difficult to cast. It can be copy-milled easily and inexpensively, however. Composite and ceramic materials are being used for copy-milling. The choice of material depends in large part on the type of margin, mechanical strength, and toughness required for the restoration. Virtually any geometry and size can be copy-milled as long as direct access of the finger guide and cutting tool to the surfaces involved is available.

CAD/CAM milling uses digital information about the tooth preparation (computerized surface digitization), or a pattern of the restoration to provide a CAD on a video monitor for inspection and modification. The image is the reference for designing a restoration. When the three-dimensional image for the restoration design is accepted, the computer translates the image into a set of instructions to guide a milling tool

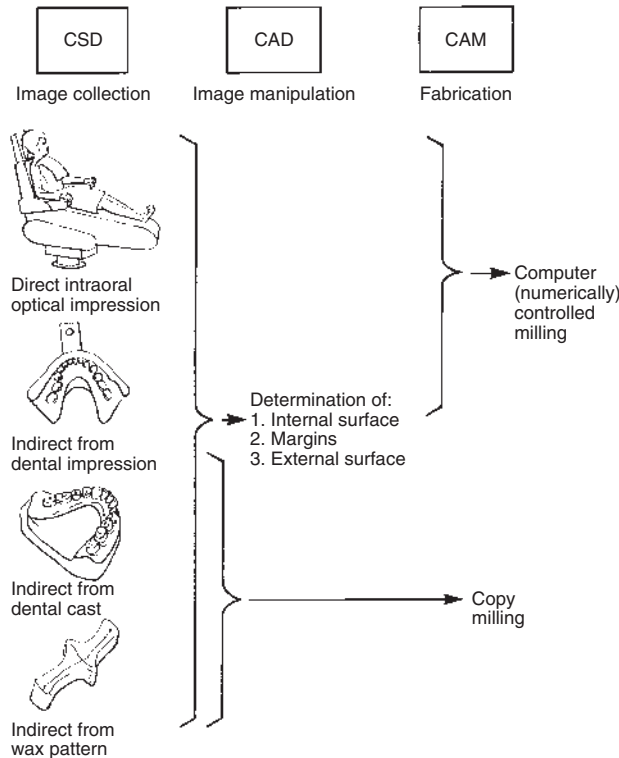
Online Table 18-22 Examples of CAD/CAM and Copy-Milling Systems in Dentistry

System	Developer/Manufacturer
Automill	Allident, Liechtenstein
Avanza 100	Ceramic Dental, Sweden
Bego Medifabricating	Bego Medical, Germany
Cad-esthetics	Decim Norden, Sweden
Cadim	Advance, Japan
Celay	Mikrona Technology, Switzerland
Ce.novation	Inocermic, Germany
Cercon	Dentsply/DeguDent, United States/Germany
Cerec 1/2/3/InLab	Siemens/Sirona, Germany
Cicero	Elephant Dental, The Netherlands
DCS Precident	DCS Dental, Switzerland
DECSY	Digital Process, Japan
Dental CAD/CAM GN1	GC, Japan
Digident	Girrbach Dental, Germany
E4D	D4D Technologies, Richardson, Texas
Etkon	Etkon, Germany
Kavo-Everest	Kavo, Germany
Lava	3M ESPE, United States/Germany
Premium Dental System	I-mes, Germany
Pro 50	Cynovad, Canada
Procera	Nobel Biocare, Sweden
Wol-ceram	Wol-dent, Germany
XAWEX Production System	I-mes, Germany

CAD/CAM, computer-aided design/computer-aided manufacturing.
 Data from Hickel R, et al: CAD/CAM-Fillings of the future? *Int Dent J* 47:247-258, 1997; Preston JD, Duret F: CAD/CAM in dentistry, *Oral Health* 87:17-27, 1997; Willer J, et al: Computer-assisted milling of dental restorations using a new CAD/CAM data acquisition system, *J Prosthet Dent* 80:346-353, 1998.



Online Fig. 18-87 Schematic representation of copy-milling.



Online Fig. 18-88 Schematic summary of computer-aided design/computer-aided manufacturing (CAD/CAM) and copy-milling operations.

(CAM) in cutting the restoration from a block of material (Online Fig. 18-88).

Stages of Fabrication

Numerous approaches to CAD/CAM for restorative dentistry have evolved, but all systems ideally involve five basic stages: (1) computerized surface digitization, (2) CAD, (3) CAM, (4) computer-aided esthetics, and (5) computer-aided finishing.^{226,252} The last two stages are very difficult and have not yet been included in commercial systems. Various computerized surface digitization techniques have been explored (photogrammetry, Moiré, laser scanning, computed tomography, magnetic resonance imaging, ultrasound, contact profilometry). Laser (optical) techniques and contact digitization are the most promising approaches from the point of view of cost and accuracy.

The Ceramic Reconstruction System (CEREC-1; Siemens, Munich, Germany) was the first commercially available CAD/CAM system used in dentistry. An intraoral video camera images the tooth preparation and the adjacent tooth surfaces. Elevations of the imaged surfaces are calculated by Moiré fringe displacement. Features of the tooth preparation are used to define the limits of the restoration. External surfaces of the restoration are estimated as distances to adjacent tooth structure in the computer view. Occlusal surfaces are designed from a pre-existing shape library and information about the occlusion. CEREC-3 displays an extremely high level of sophistication and can fabricate inlays, onlays, crowns, and veneers. It can be operated chairside but also is being used with remote milling units in dental laboratories for

two-appointment procedures. All other current CAD/CAM systems are employed in dental laboratories to fabricate a wide range of ceramic restorations (see Online Table 18-22).²⁵³⁻²⁵⁵

Composition, Structure, and Properties of Machined Materials

Restorations can be machined from metals, ceramics, or composites. Ceramics generally are preferred because of their superior esthetics and biocompatibility. The machinable ceramics used generally have been some form of modified feldspathic porcelain or special fluoroaluminosilicate glass-ceramics with excellent fracture and wear resistance. In addition, partially sintered high-strength ceramic compositions of alumina, spinel, and zirconia can be machined for use as copings. The porcelain and glass-ceramic materials being machined are pore-free and generally have crystalline and noncrystalline phases. A two-phase composition permits differential etching of internal restoration walls for micromechanical retention using bonding agents, luting cements, or both. Currently, differential etching is not possible with mainly alumina and zirconia all-ceramic materials. Those materials are limited to interfacial retention created by sandblasting. Online Table 18-23 summarizes the typical properties of examples of machinable ceramic materials in clinical use.²⁵⁶⁻²⁵⁸ Online Figure 18-89 shows an example of the phases, revealed by etching for bonding of a machinable glass-ceramic material.

Bonding of ceramic CAD/CAM restorations is a critical step in achieving good long-term results. Ceramic restorations are bonded to tooth structure by (1) etching enamel to increase the bondable surface area; (2) etching, priming, and applying the bonding agent to dentin (when appropriate); (3) etching (by hydrofluoric acid) and then priming (silanating) the restoration; and (4) cementing the restoration with composite cement. This situation is schematically summarized in Online Figure 18-90.

CAD/CAM systems for fabricating restorations currently are not designed to produce esthetics comparable with the characterization possible in a dental laboratory. Most CAD/CAM systems use uniform color (monolithic) materials for the entire restoration. Despite the fact that increased shades of ceramic and composite are becoming available for use with CAD/CAM and copy-milling systems, the final esthetics depend on a combination of color match to adjacent tooth structure and light scattering from adjacent tooth structure into the restoration. Small restorations display color governed more by scattered light and are highly esthetic. Larger restorations appear to be duller and less esthetic. Although this latter occurrence cannot be totally remedied, some color variation can be introduced by cutting troughs into the internal (tooth side) surface of CAD/CAM restorations. The troughs are filled with varying shades of composite. This technique produces an optical effect of different dentin colors and enhances the overall esthetic appearance. Another approach is to machine a high-strength coping onto which veneering porcelain and glazes are applied.

Composition, Structure, and Properties of Composite Cements

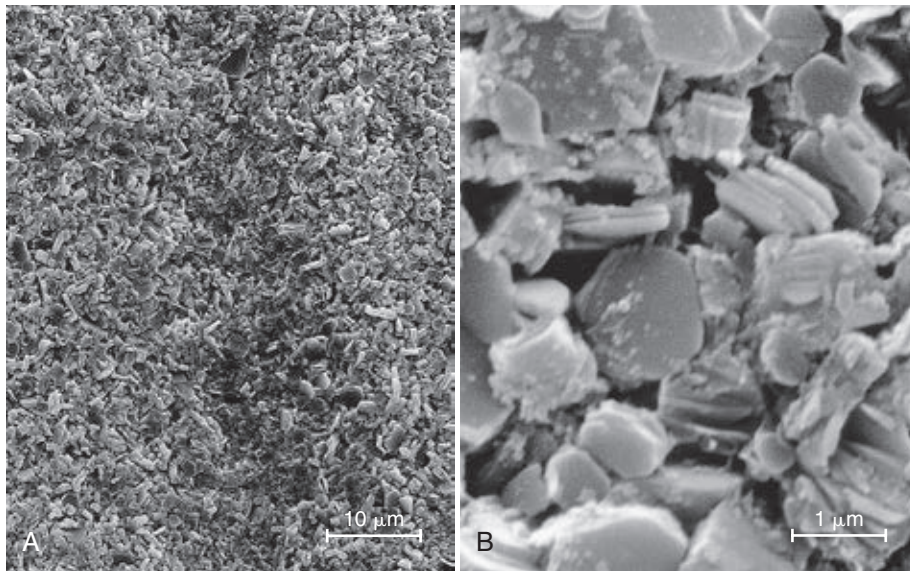
Although the dimensional accuracy and fit of machined restorations continues to improve, a weak link with CAD/CAM

Online Table 18-23 Mechanical Properties of Machinable Ceramic Materials in Clinical Use with CAD/CAM and Copy-Milling Systems

MATERIAL	Vita Mark II	MZ100	ProCad	InCeram Alumina	Lava
MANUFACTURER	Vita Zahnfabrik	3M ESPE	Ivoclar	Vita Zahnfabrik	3M ESPE
MATERIAL TYPE	Feldspathic porcelain	Composite	Leucite-reinforced porcelain	Glass-infiltrated alumina	Zirconia
HARDNESS (GPA)	6.9	—	6.8	9.8	10
FLEXURAL MODULUS (GPA)	73	14	78	286	210
3-PT FLEXURE STRENGTH (MPA)	122	150	160	446	1625
FRACTURE TOUGHNESS (MPA • M ^{1/2})	1.3	1.4	1.4	4.6	9.6

CAD/CAM, computer-aided design/computer-aided manufacturing; GPs, gigapascal; MPA, megapascal.

Data from Grossman DG: Structure and physical properties of Dicor/MGC glass-ceramic. In: *Proceedings of the International Symposium on Computer Restorations*, Chicago, 1991, Quintessence; Seghi RR, Sorensen JA: Relative flexural strength of six new ceramic materials, *Int J Prosthodont* 8:239–246, 1995; Seghi RR, et al: Relative fracture toughness and hardness of new dental ceramics, *J Prosthet Dent* 74:145–150, 1995; Thompson JY, et al: Mechanical properties of a new mica-based machinable glass ceramic for CAD/CAM restorations, *J Prosthet Dent* 76:619–623, 1996.



Online Fig. 18-89 Ammonium bifluoride acid-etched machinable glass-ceramic inlay (Dicor MGC; Dentsply International, York, PA) in preparation for cementation. Approximately 65% of glass-ceramic is fluoromica crystals embedded in an amorphous matrix. The matrix at its surface is partially dissolved by etching. **A**, Etching partially reveals crystals that are 1 to 5 µm in size. **B**, Higher magnification view of fluoromica crystals that provide micromechanical interlocking for bonding. (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI.)

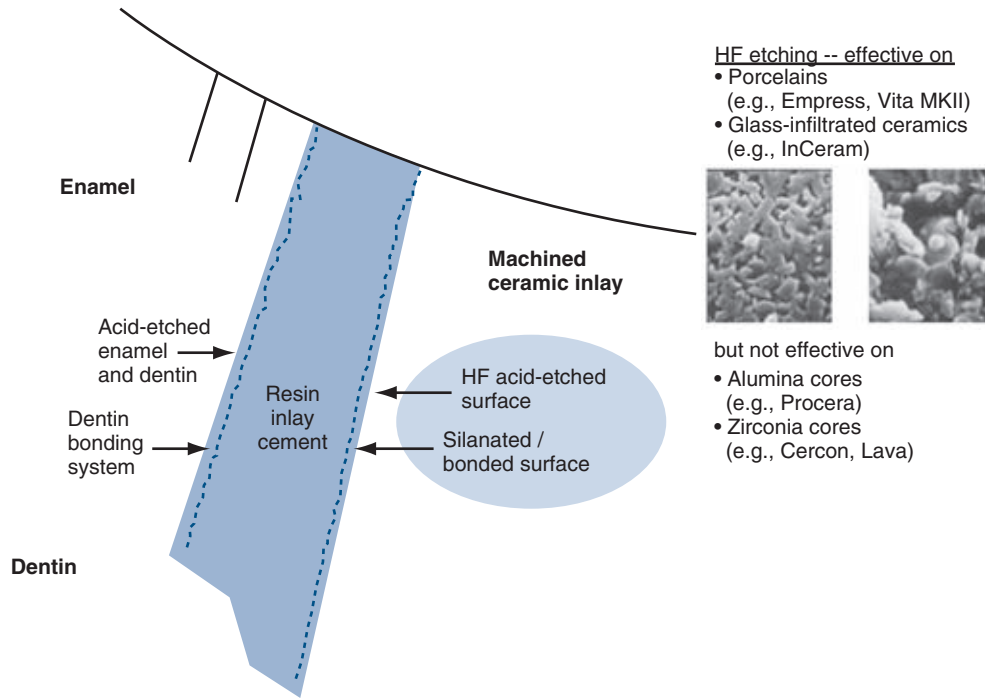
and copy milling systems is the cement gap along occlusal surfaces that may be wider than desired. Normal food abrasion produces cement loss and ditching. Wear of this type permits stain accumulation in marginal gaps and leaves exposed enamel and ceramic margins. Minimizing this gap depends on the computer digitization, design, and manufacturing steps being sufficiently accurate.

CAD/CAM restorations are routinely cemented with moderately filled composites (homogeneous microfills, minifill hybrids) or compomers. The composite or compomer cements are not as mechanically strong as composite restorative materials, but they do provide the best abrasion resistance because of the microprotection effect of closely spaced filler particles. Zinc phosphate and glass ionomer cements are not recommended for use with milled ceramic restorations.²⁵⁹

Clinical considerations

The clinical longevity of these restorations is difficult to project because only relatively short-term clinical research information is available.^{204,260-262} Review of the earliest restorations of this type indicates that although cement margins may wear slightly, the restorations themselves survive equally as well as amalgam or composite restorations of the same type. Evidence of postoperative sensitivity or secondary caries does not exist.

The major advantages of milled ceramics are their excellent flexural strength and the ability to bond remaining tooth structures rigidly together. Occasional restoration fractures have been reported, but in most cases, they are associated with restoration designs that are too thin and subject to stress concentration during flexure or fatigue fracture. It is still



Online Fig. 18-90 Schematic summary of attaching ceramic computer-aided design/computer-aided manufacturing (CAD/CAM) inlays to tooth structure. Enamel is etched for retention of bonding agents. Inlays are etched (with hydrofluoric acid) and primed (silanated), when possible, to produce microretention or can be sandblasted. The restoration is cemented with resin (composite) cement. (Courtesy of S.C. Bayne, School of Dentistry, University of Michigan, Ann Arbor, MI; and J.Y. Thompson, College of Dental Medicine, Nova Southeastern University, Fort Lauderdale, FL)

important to use adequate thickness in the restoration design to resist flexure. Additionally, restorations from these systems are repairable because they are etchable. Small defects can be restored using bonded composites. There should be no reason to replace the restoration completely unless it has undergone bulk fracture.

Safety and Efficacy

The availability of biomaterials of high quality and dependability is due, in large part, to the existence of standards for the safety and efficacy of such products. Few clinicians are aware of, or understand, the intricate system of voluntary and mandatory controls currently in place to accomplish this purpose. Safety is a concern with regard to biomaterial effects not only on patients but also on office personnel.

Standards Programs

The numerous organizations involved in standards programs and their acronyms are listed in [Online Box 18-2](#). Standards programs can be divided broadly into dental professional organizations, larger interest groups that include all professional organizations, and government agencies. These hierarchies exist within the United States and throughout the world. [Online Figure 18-91](#) shows the inter-relations among these groups. In the following discussion, individual group activities are addressed. Most professional organizations attempt to coordinate their standards with other organizations so that a rational system of tests is involved in evaluating similar events. Professional organizations develop voluntary standards that are often the basis for governmental regulatory standards whenever governments become involved. In many cases, the

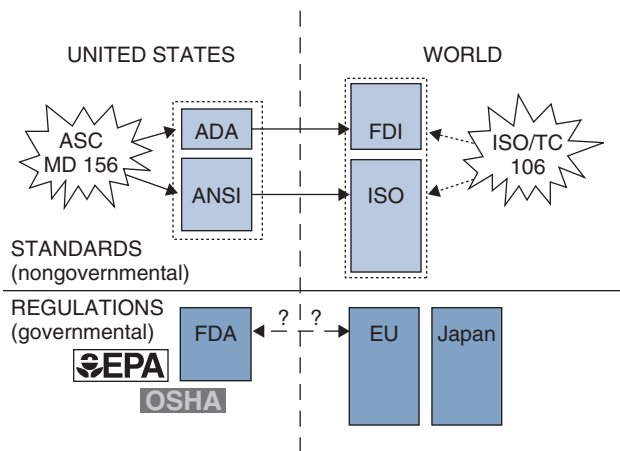
Online Box 18-2 Acronyms for National and International Groups Interested in Dental Standards

ADA	American Dental Association
ANSI	American National Standards Institute
ASC MD156	Accredited Standards Committee, Medical Devices
ASTM	American Society for Testing and Materials
FDA	U.S. Food and Drug Administration
FDI	Federation Dentaire Internationale
ISO	International Organization for Standards
ISO TC 106	ISO Technical Committee
NDA	National Dental Association

good faith standards and self-regulation of industry obviate the need for government involvement.

American Dental Association

For over 80 years the ADA (www.ada.org) has been a reliable source of information on the safety and effectiveness of dental products (therapeutics, materials, instruments and equipment.) by means of its Seal of Acceptance Program (www.ada.org/seal) ([Online Fig. 18-92](#)). From its inception in 1930, the Seal was awarded to both consumer and professional dental products that were able to satisfy the rigorous ADA criteria for safety and effectiveness. In 2004, professional dental products were removed from the Seal Program and have been subsequently evaluated in the, ADA Professional Product Review Program (www.ada.org/ppr). The objectives and formats of the two programs differ. Only the Seal Program awards the ADA Seal, whereas the PPR provides information on how products



Online Fig. 18-91 Summary of key standards (voluntary) and regulations (mandatory). Dental professional standards communicate with standards organizations via liaison groups (the ADA with the ANSI via ASC MD156; the FDI with the ISO via ISO/TC 106). A few countries have regulatory groups.



Online Fig. 18-92 The American Dental Association (ADA) Seal of Acceptance for consumer products. (Courtesy of American Dental Association Council on Scientific Affairs, Chicago, IL.)

compare when they are put through a series of tests, the type of information dental professionals are more interested in.

The ADA's Council on Scientific Affairs, which administers the Seal Program, conducts objective, scientific evaluations of laboratory and clinical studies on the safety and effectiveness of over-the-counter oral health products, and awards the Seal to those that meet its criteria. Since the Council also evaluates claims of effectiveness made on labeling and in advertising, you can be assured that all effectiveness claims that are made for Seal products have been verified.

American National Standards Institute

The American National Standards Institute (ANSI) (www.ansi.org) is a clearinghouse for national standards. The Accredited Standards Committee (ASC) MD156 is a liaison group between the ADA and the ANSI. It is an independent committee of both organizations sponsored by the ADA and accredited by the ANSI for dentistry in the United States. The ADA standards that are developed are submitted to the ANSI for approval as national standards.

Food and Drug Administration

Since 1976, the FDA (www.fda.gov) has been charged with regulating dental devices (including materials). In this role,

they classify individual materials as Class I, II, or III. Class I materials are simply required to be produced under conditions of good manufacturing practices to ensure reproducibility and continuing safety. Class II materials are required to present evidence of meeting standards as well, such as the International Standards Organization (ISO) standards for acceptance or certification. Class III materials are required additionally to submit evidence of safety and efficacy using biocompatibility and clinical data to show satisfactory performance in tissue culture tests, implantation tests, or usage tests. Tests for the relative safety of biomaterials (biocompatibility) are described as part of ISO 7405:1997. Biocompatibility tests are continuing to evolve in light of new or more sophisticated understandings of the science of biocompatibility.

American Society for Testing and Materials

The American Society for Testing and Materials (ASTM) (www.astm.org) is a nongovernmental group involved widely in the development of standards for test methods for use in industry. More recently, it has become interested in standards for dentistry (dental materials and devices) and the development of appropriate terminology, nomenclature, and test methods. The ASTM's F-4 subcommittee has developed specifications for surgical implants; the F-8 subcommittee governs sports devices such as mouth guards; and the D-2 subcommittee is concerned with rubber products such as rubber gloves.

Federation Dentaire Internationale

The worldwide voluntary federation of national dental organizations is known as the Federation Dentaire Internationale (FDI) (www.fdiworldental.org).

International Standards Organization

An ISO (www.iso.org), or International Organization for Standards, exists for the purpose of developing international standards for all activities, not only dentistry. ISO is a non-treaty organization. The ANSI is the U.S. member of the ISO. The FDI maintains a permanent liaison with the ISO through its ISO/TC106-Dentistry group. To the extent that each group coordinates its activities with each other, the ADA's role has been a major one in initiating standards for a range of current standards organizations.

Safety for Dental Professionals

Although numerous organizations and standards regulate the safety of biomaterials with regard to the patient, quite different ones are concerned with the health of dental professionals. In many situations, the scope and regulations of different groups overlap and are inconsistent.

Occupational Safety and Health Administration

The Occupational Safety and Health Administration (OSHA) is the U.S. federal agency charged with responsibility for maintaining safety in the workplace. It differs from the organizations discussed previously in that the OSHA has the legal

authority to enforce compliance. During 1970, the United States adopted a wide range of OSHA regulations, with the goal of reducing the potential for illness or injury to employees from chemical exposures. Many of these regulations were enforced only sparingly during the 1980s and usually only for large businesses. Since 1992, enforcement of these standards for dental offices and dental laboratories has been stricter. The OSHA has issued regulations involving a wide range of issues, including hazard communications, blood-borne pathogens, office water lines, and waste disposal.

Hazard communications include public posting of OSHA regulations, office record keeping, office emergency planning, office employee training, and office planning for workers' compensation. These processes involve seven categories of responsibilities described in the following paragraphs. The ADA provides dental professionals with detailed information in this regard.

FIRST CATEGORY OF RESPONSIBILITY

To ensure that all employees are aware of the processes required to guarantee the safety and health of the employees, an OSHA poster must be always displayed within the office (at one or more sites) so as to be seen by all personnel. This location is most often a kitchen, apparel changing location, or employee lounge area. The poster is titled *Job Health and Safety Protection*.

SECOND CATEGORY OF RESPONSIBILITY

For many years, large businesses and laboratories have had to meet OSHA requirements involving hazardous chemicals to protect the health of their employees. The enforcement of these requirements has been extended more recently to cover dental offices. Although modifications of office routines are required, dentistry can benefit from the prior experience of industry in refining the application of these safety principles. Hazardous chemical materials are managed routinely by proper labeling and storage and by certifying that all office personnel are fully informed of possible risks and the necessary precautions in those regards. The requirement for hazardous chemical labeling is waived for FDA-regulated items such as most products in dental offices. The information about the nature of the chemical hazard and its management is, however, still a responsibility of the office. This information is published on material safety data sheets (MSDSs) and is available from individual manufacturers. Manufacturers have the primary responsibility to determine whether an MSDS is required and to supply that information. Commercial chemicals generally are packaged with MSDSs. Dental products often cannot conveniently include the MSDS, however, because the sheet is too big for the package in which materials are sold. Only some dental products include MSDSs, and absent MSDS information must be collected after the fact. Most personnel in a dental office are not familiar with key information they need about materials to be able to make an informed judgment about relative risks or hazards. The best approach is to inventory everything in the office (by company or supplier) and check a published list for the presence or absence of an MSDS.

MSDS information must be available for access by any employee at all times they are within the work environment. MSDS information is now available readily on the Internet both on manufacturer and on OSHA home pages. This

information can be referenced through digital records or via access to free comprehensive MSDS databases (www.msds.com). Paper MSDS sheets are not required but are still the most convenient for many small operations. Paper sheets should be stored in a central location with clear labeling or identification of the site. Most sheets are three-hole punched for convenient insertion into an MSDS notebook. A common recommendation is to label the notebook "MSDS" on the spine and on the front. The notebook should be of a color that is distinct from any other notebooks or books that might be in the same area. All MSDSs should be organized within the notebook in a logical fashion for locating easily.

MSDSs are typically a 2-to-4-page summary of the material's name, chemical reactivity, potential risks in storage or biologic contact, methods of managing emergencies, and summaries of key biologic information. A sample MSDS is shown in [Online Figure 18-93](#), with categoric sections indicated. Despite the good intentions of this MSDS system, in case of an office emergency involving biomaterials, it is highly recommended that the regional U.S. Poison Control Center (800-222-1222) be immediately contacted for instructions for treatment.

THIRD CATEGORY OF RESPONSIBILITY

The information, once collected, must be communicated to all employees on a regular basis. In the same notebook with the MSDSs, records should be kept on procedures and times for annual employee hazard communications training. This record should include information about nonroutine tasks, such as cleaning the dental unit suction reservoirs; training new employees; training service personnel for the office (e.g., janitorial personnel); and taking inventory of new materials, equipment, or devices that might require updating the MSDSs. This process is rigorously defined, and the appropriate details can be obtained from the OSHA and the ADA. Some of the details are emphasized in the following sections.

FOURTH CATEGORY OF RESPONSIBILITY

For safety in the general office environment and during servicing, sterilization, and maintenance of equipment and instruments, it is mandatory that precautionary measures (e.g., ventilation), personal protective equipment (e.g., protective gloves, apron, and goggles), and emergency equipment (e.g., eyewash fountain, fire extinguisher, mercury spill kit, first aid kit, and resuscitator mask) be available and appropriately used. These precautions should be reviewed at least annually. Review of the emergency equipment should be checked at least monthly. A complete review of emergency preparedness for a small office for health and safety generally can be conducted in 10 to 15 minutes. This review requires only a small amount of time and minimizes employee and patient risks. All the procedures are described fully on the OSHA Web site (www.osha.gov) under "Compliance Assistance."

FIFTH CATEGORY OF RESPONSIBILITY

Any incidents that require medical attention or involve loss of work should be documented. A range of forms is needed to (1) maintain permanent records of incidents, follow-ups, and new preventive measures; (2) summarize incidents and dates for periodic review; and (3) file workers' compensation reports.

Text continued on p. e92.

Material Safety Data Sheet acc. to ISO/DIS 11014

Printing date 08/24/2010

Reviewed on 08/23/2010

1 Identification of substance:

· **Product details:**

· **Trade name:** **Gluma Comfort Bond + Desensitizer**

· **Application of the substance / the preparation** Dental bonding material

· **Manufacturer/Supplier:**

Heraeus Kulzer GmbH
Grüner Weg 11, D-63450 Hanau

Tel.: 0800 4372522

· **Information department:**

Dr. Hoffmann
Tel.: +49 6081 959-313
Fax: +49 6081 959-223
email: marcus.hoffmann@heraeus.com

· **Emergency information:**

Call "Poisoning Emergency Center Berlin": + 49 30 30686 790 (24 hours, support in English and German language)

2 Hazards identification

· **Hazard description:**



Xn Harmful

· **Information pertaining to particular dangers for man and environment**

The product has to be labelled due to the calculation procedure of the "General Classification guideline for preparations of the EU" in the latest valid version.

R 10 Flammable.

R 20/22 Harmful by inhalation and if swallowed.

R 37/38 Irritating to respiratory system and skin.

R 41 Risk of serious damage to eyes.

R 42/43 May cause sensitization by inhalation and skin contact.

· **Classification system**

The classification was made according to the latest editions of the EU-lists, and expanded upon from company and literature data.

· **NFPA ratings for USA (scale 0-4)**



Health = 2

Fire = 3

Reactivity = 0

· **HMIS-Ratings (Scale 0-4)**



Health = *2

Fire = 3

Reactivity = 0

3 Composition/Data on components:

· **Chemical characterization**

· **Description:** Composition based on methacrylates

· **Dangerous components:**

64-17-5	ethanol	F; R 11	25-50%
868-77-9	2-hydroxyethyl methacrylate	Xi; R 36/38-43	10-25%

(Contd. on page 2)

USA

Online Fig. 18-93 Example of a material safety data sheet (MSDS) for a popular dentin sealer (GLUMA Comfort Bond + Desensitizer), containing information on the material's ingredients and identity, physical and chemical characteristics, fire and explosion hazards, reactivity, environmental precautions, suggested first aid, precautions for safe management and use, shipping and handling regulations, and health hazards. Note: the form shown here is in U.S. format. (Courtesy of Heraeus Kulzer, South Bend, IN.)

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Trade name: Gluma Comfort Bond + Desensitizer

(Contd. of page 1)

	Poly(methacrylic-oligo-acrylic acid)	Xi; R 36	5-10%
70293-55-9	4-methacryloxyethyltrimellitic acid anhydride	Xn, Xi; R 22-36/38-43	0-5%
111-30-8	glutaral	T, C, N; R 23/25-34-42/43-50	0-5%

· **Additional information** For the wording of the listed risk phrases refer to section 16.

4 First aid measures

- **General information**
Symptoms of poisoning may even occur after several hours; therefore medical observation for at least 48 hours after the accident.
- **After inhalation** Supply fresh air; consult doctor in case of complaints.
- **After skin contact** Immediately wash with water and soap and rinse thoroughly.
- **After eye contact**
Rinse opened eye for several minutes under running water. Then consult a doctor.
- **After swallowing**
Immediately call a doctor.
Composition based on methacrylates

5 Fire fighting measures

- **Suitable extinguishing agents**
CO₂, extinguishing powder or water spray. Fight larger fires with water spray or alcohol resistant foam.
- **For safety reasons unsuitable extinguishing agents** Water with full jet.
- **Special hazards caused by the material, its products of combustion or resulting gases:**
Can form explosive gas-air mixtures.
Formation of toxic gases is possible during heating or in case of fire.
- **Protective equipment:** Mount respiratory protective device.
- **Additional information** -

6 Accidental release measures

- **Person-related safety precautions:** Wear protective equipment. Keep unprotected persons away.
- **Measures for environmental protection:** No special measures required.
- **Measures for cleaning/collecting:**
Absorb with liquid binding material (diatomite, universal binders, for small amounts tissues).
Dispose contaminated material as waste according to item 13.
Send for recovery or disposal in suitable receptacles.
- **Additional information:**
See Section 13 for disposal information.
See Section 8 for information on personal protection equipment.
-

7 Handling and storage

- **Handling**
 - **Information for safe handling:**
Keep receptacles tightly sealed.
Ensure good ventilation/exhaustion at the workplace.
Prevent formation of aerosols.
 - **Information about protection against explosions and fires:**
Keep ignition sources away - Do not smoke.
Protect against electrostatic charges.

(Contd. on page 3)

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Trade name: Gluma Comfort Bond + Desensitizer

(Contd. of page 2)

· **Storage**

- **Requirements to be met by storerooms and receptacles:** No special requirements.
- **Information about storage in one common storage facility:** Not required.
- **Further information about storage conditions:** Keep cool, if possible (not above 25 °C).

8 Exposure controls and personal protection

- **Additional information about design of technical systems:** No further data; see item 7.

- **Components with limit values that require monitoring at the workplace:**

64-17-5 ethanol

PEL ()	1900 mg/m ³ , 1000 ppm
REL ()	1900 mg/m ³ , 1000 ppm
TLV ()	1880 mg/m ³ , 1000 ppm

111-30-8 glutaral

REL ()	Short-term value: C 0.8 mg/m ³ , C 0.2 ppm
TLV ()	Short-term value: C 0.2 mg/m ³ , C 0.05 ppm
SEN	

- **Additional information:** The lists that were valid during the creation were used as basis.

· **Personal protective equipment**

· **General protective and hygienic measures**

- Keep away from foodstuffs, beverages and feed.
- Immediately remove all soiled and contaminated clothing
- Wash hands before breaks and at the end of work.
- Do not inhale gases / fumes / aerosols.
- Avoid contact with the eyes and skin.

· **Breathing equipment:**

Not necessary with efficient local exhaust. If exposition to vapours is possible, use breathing protective mask (filter A).

· **Protection of hands:**

If skin contact cannot be avoided, protective gloves are recommended to avoid possible sensitization.

Solvent resistant gloves

The glove material has to be impermeable and resistant to the product/ the substance/ the preparation.

Selection of the glove material on consideration of the penetration times, rates of diffusion and the degradation

· **Material of gloves**

The selection of the suitable gloves does not only depend on the material, but also on further marks of quality and varies from manufacturer to manufacturer. As the product is a preparation of several substances, the resistance of the glove material can not be calculated in advance and has therefore to be checked prior to the application.

· **Penetration time of glove material**

The exact break through time has to be found out by the manufacturer of the protective gloves and has to be observed.

· **For the permanent contact of a maximum of 15 minutes gloves made of the following materials are suitable:**

Butyl rubber, BR

· **Eye protection:** Tightly sealed goggles.

· **Body protection:** Light weight protective clothing

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(Contd. on page 4)

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Trade name: Gluma Comfort Bond + Desensitizer

(Contd. of page 3)

9 Physical and chemical properties:

· General Information

- **Form:** Fluid
- **Color:** Yellowish
- **Odor:** Characteristic

· Change in condition

- **Melting point/Melting range:** undetermined
- **Boiling point/Boiling range:** 78°C (172°F)

· **Flash point:** 24°C (75°F)

· **Ignition temperature:** 425.0°C (797°F)

· **Auto igniting:** Product is not selfigniting.

· **Danger of explosion:** Product is not explosive. However, formation of explosive air/vapor mixtures are possible.

· Explosion limits:

- **Lower:** 3.5 Vol %
- **Upper:** 15.0 Vol %

· **Vapor pressure at 20°C (68°F):** 57 hPa (43 mm Hg)

· **Density:** Not determined

· Solubility in / Miscibility with

· **Water:** Not miscible or difficult to mix

· Solvent content:

· **Water:** 10.0 %

10 Stability and reactivity

- **Dangerous reactions** No dangerous reactions known
- **Dangerous products of decomposition:** none

11 Toxicological information

· Acute toxicity:

· Primary irritant effect:

- **on the skin:** Irritant to skin and mucous membranes.
- **on the eye:** Strong irritant with the danger of severe eye injury.

· Sensitization:

- Sensitization possible through inhalation.
- Sensitization possible through skin contact.

· Additional toxicological information:

Harmful
Irritant

12 Ecological information:

· General notes:

Do not allow product to reach ground water, water course or sewage system, even in small quantities.

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Trade name: Gluma Comfort Bond + Desensitizer

Danger to drinking water if even extremely small quantities leak into the ground.

(Contd. of page 4)

13 Disposal considerations

- **Product:**
 - **Recommendation**
Must not be disposed of together with household garbage. Do not allow product to reach sewage system.
- **Uncleaned packagings:**
 - **Recommendation:** Disposal must be made according to official regulations.

14 Transport information

· **DOT regulations:**



- **Hazard class:** 3
- **Identification number:** UN1170
- **Packing group:** III
- **Proper shipping name (technical name):** ETHANOL SOLUTION
- **Label:** 3

· **Land transport ADR/RID (cross-border)**



- **ADR/RID class:** 3 (F1) Flammable liquids
- **Danger code (Kemler):** 30
- **UN-Number:** 1170
- **Packaging group:** III
- **Label:** 3
- **Description of goods:** 1170 ETHANOL SOLUTION (ETHYL ALCOHOL SOLUTION)

· **Maritime transport IMDG:**



- **IMDG Class:** 3
- **UN Number:** 1170
- **Label:** 3
- **Packaging group:** III
- **EMS Number:** F-E,S-D
- **Marine pollutant:** No

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Trade name: Gluma Comfort Bond + Desensitizer

(Contd. of page 5)

· **Propper shipping name:** ETHANOL SOLUTION (ETHYL ALCOHOL SOLUTION)

· **Air transport ICAO-TI and IATA-DGR:**



· **ICAO/IATA Class:** 3
 · **UN/ID Number:** 1170
 · **Label:** 3
 · **Packaging group:** III
 · **Propper shipping name:** ETHANOL, solution

· **Transport/Additional information:** -

15 Regulations

· **SARA Section 355 (extremely hazardous substances)**

None of the ingredients is listed.

· **SARA Section 313 (specific toxic chemical listings)**

None of the ingredients is listed.

· **Prop 65 - Chemicals known to cause cancer**

None of the ingredients is listed.

· **Cancerogenity categories**

· **EPA (Environmental Protection Agency)**

None of the ingredients is listed.

· **IARC (International Agency for Research on Cancer)**

None of the ingredients is listed.

· **NTP (National Toxicology Program)**

None of the ingredients is listed.

· **TLV (Threshold Limit Value established by ACGIH)**

64-17-5	ethanol	A4
111-30-8	glutaral	A4

· **NIOSH-Ca (National Institute for Occupational Safety and Health)**

None of the ingredients is listed.

· **OSHA-Ca (Occupational Safety & Health Administration)**

None of the ingredients is listed.

· **Markings according to EU guidelines:**

The product has been classified and marked in accordance with EU Directives / Ordinance on Hazardous Materials

· **Code letter and hazard designation of product:**

Xn Harmful

· **Hazard-determining components of labelling:**

2-hydroxyethyl methacrylate
 glutaral
 4-methacryloxyethyltrimellitic acid anhydride

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Trade name: Gluma Comfort Bond + Desensitizer

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· **Risk phrases:**

- 10 Flammable.
- 20/22 Harmful by inhalation and if swallowed.
- 37/38 Irritating to respiratory system and skin.
- 41 Risk of serious damage to eyes.
- 42/43 May cause sensitization by inhalation and skin contact.

· **Safety phrases:**

- 7/9 Keep container tightly closed and in a well-ventilated place.
- 23 Do not breathe fumes
- 24 Avoid contact with skin.
- 26 In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
- 37/39 Wear suitable gloves and eyeface protection.
- 45 In case of accident or if you feel unwell, seek medical advice immediately.

16 Other information:

These data are based on our present knowledge. However, they shall not constitute a guarantee for any specific product features and shall not establish a legally valid contractual relationship.

· **Relevant R-phrases**

- 11 Highly flammable.
- 22 Harmful if swallowed.
- 23/25 Toxic by inhalation and if swallowed.
- 34 Causes burns.
- 36 Irritating to eyes.
- 36/38 Irritating to eyes and skin.
- 42/43 May cause sensitization by inhalation and skin contact.
- 43 May cause sensitization by skin contact.
- 50 Very toxic to aquatic organisms.

· **Department issuing MSDS:** Safety department

· **Contact:**

Dr. Thiele Tel.: (+49) 6181 35-3012
email: ruediger.thiele@heraeus.com

· * **Data compared to the previous version altered.**

USA

Online Fig. 18-93, cont'd

SIXTH CATEGORY OF RESPONSIBILITY

In addition to OSHA's initial concern with hazard communications, more recent emphases have been placed on universal precautions against exposure to blood-borne pathogens and waste disposal for dental offices. Infection control practices for blood-borne pathogens have become much more sophisticated because of concern about the increase in hepatitis virus and human immunodeficiency virus (HIV) transmissions.

Waste disposal currently is not regulated by the OSHA. It involves the collection, transport, and management operations. Within the dental office, the collection systems must be more sophisticated than in many businesses because of infection control regulations. Trash must be separated on the basis of being (1) biohazard waste (hazardous), (2) chemical waste (hazardous), or (3) regular (nonhazardous) waste.

Nonhazardous waste can be placed in sanitary landfills. The other materials must be incinerated or buried in continuously managed waste disposal sites.

Currently, most communities focus only on medical waste. Containers, such as dentin bonding agent vials or precapsulated amalgam capsules, although considered chemical waste, currently can be disposed as nonhazardous waste, but those regulations may change. Waste transport may occur within a building or from the building to an approved disposal facility or site. The owner of the office generating the waste is responsible for guaranteeing appropriate and safe transport for disposal. Numerous careless or unscrupulous transporters and managers of waste disposal, however, are inadequately informed or unconvinced about the care that needs to be exercised. The dental office personnel have some

responsibility to ensure the reliability of individuals providing these services.

SEVENTH CATEGORY OF RESPONSIBILITY

Finally, employee training and education programs must be conducted at least annually with respect to hazards, management of blood-borne pathogens, and waste disposal. All new employees must be trained immediately. Records must be kept of the training procedures and training times. All individual records should be kept in the MSDS notebook or in personnel records.

To remain up to date and aware of potential hazards concerning biomaterials the currently available materials and their properties should be constantly reviewed.

Environmental Protection Agency

All byproducts of dental procedures end up as solid, liquid, or gaseous wastes, and their disposal can be regulated by the Environmental Protection Agency (EPA) (www.epa.gov). At the present time, most waste disposal is regulated by local authorities.

Hazardous gases or vapors such as nitrous oxide should be vented directly to the outside air or should be collected from the air using scrubbing devices to protect intraoffice individuals and to prevent inadvertent contamination of other local air systems. Liquid wastes emptied into the sewer or drainage systems have some potential to contaminate the waste treatment plant or groundwater supplies. It is becoming increasingly important to separate hazardous liquids such as waste solvents for controlled disposal. Small amounts of water-based chemicals can be diluted and flushed into the sewer system. Water-immiscible materials, however, are best disposed of in alternative ways. Waste disposal of blood and body fluids into sanitary sewers is a commonly accepted practice. Solid wastes include the trash from an office and the effluent disposed into the sewer system. Collected amalgam scrap should be recycled (see the section on mercury management and [Online Box 18-1](#)). Amalgam scrap in wastewater is an important issue, and separating devices are required in many regions to separate suspended solids (see the section on amalgam waste management). Chairside and plumbing line filters are available for this purpose. The regulations across the United States have not yet been made uniform.

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Infection Control

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Exposure Risks and Effect of Infections on Dentistry

Pervasive increases in serious transmissible diseases over the last few decades have created global concern and have affected the treatment approach of all American health care practitioners. Every health care specialty that involves contact with mucosa, blood, or blood-contaminated body fluids is now regulated. The goal is to ensure compliance with standard precautions and other methods to minimize infection risks.¹

Although the objective of operative dentistry has been to provide the highest standard of care, a prevailing concern has been to minimize the patient's anxiety with regard to treatment. Providing a supportive, informal, relaxed, and non-threatening operatory environment has been one emphasis. Although that concern has not waned, emphasis now has expanded to ensuring and showing to patients that they are well protected from risks of infectious disease. Universal use of treatment gloves, masks, protective eyewear, overgarments, plastic barriers to protect equipment, proper disinfectants, and instrument sterilization provides a professional health care atmosphere that conveys conscientious protection and treatment according to sound principles of infection control in keeping with current regulations (Online Fig. 19-1).

Environment of the Dental Operatory

To comprehend the problem of microbial contamination that confronts dentistry, it is necessary to examine the dental treatment environment. Because it was poorly understood in the past, personnel went unprotected from unseen exposures. For most of the twentieth century, general dentistry was routinely practiced without barriers to protect eyes, nose, mouth, and hands as shown in Online Figure 19-2. Not until 1991 were dental personnel required to wear gloves, masks, gowns, and protective eyewear while treating patients. Microbial exposures in the dental operatory include air-borne contamination

(see Online Fig. 19-2) and direct and indirect contamination of surfaces.

Air-Borne Contamination

A high-speed handpiece is capable of creating air-borne contaminants from bacterial residents in the dental unit water spray system and from microbial contaminants from saliva, tissues, blood, plaque, and fine debris cut from carious teeth (see Online Fig. 19-2). With respect to size, these air-borne contaminants exist in the form of spatter, mists, and aerosols. Aerosols consist of invisible particles ranging from 5 mm to approximately 50 mm that can remain suspended in the air and breathed for hours.² Aerosols and larger particles may carry agents of any respiratory infection carried by the patient. No scientific evidence indicates, however, that fine aerosols have transmitted the blood-borne infection caused by hepatitis B virus (HBV).^{3,4} Transmission of human immunodeficiency virus (HIV) by aerosols is even less likely, as evidenced by the extremely low transmissibility of HIV in dental procedures and in the homes of infected persons.⁵⁻⁸ Mists that become visible in a beam of light consist of droplets estimated to approach or exceed 50 mm. Heavy mists tend to settle gradually from the air after 5 to 15 minutes.⁹ Aerosols and mists produced by the cough of a patient with unrecognized active pulmonary or pharyngeal tuberculosis are likely to transmit the infection.¹⁰ Spatter consists of particles generally larger than 50 mm and even visible splashes. Spatter has a distinct trajectory, usually falling within 3 feet (ft) of the patient's mouth, having the potential for coating the face and outer garments of the attending personnel.⁹ Spatter or splashing of mucosa is considered a potential route of infection for dental personnel by blood-borne pathogens.^{7,11}

Barrier protection of personnel using masks, protective eyewear, gloves, and gowns is now a standard requirement for dental procedures. A pretreatment mouthrinse, rubber dam, and high-velocity air evacuation also can reduce microbial exposure.^{9,11} To help reduce exposure to air-borne particles capable of transmitting respiratory infections, adequate air circulation should be maintained, and masks should be kept in place until air exchange in the room has occurred or until personnel leave the operatory.¹⁰

The publisher and authors wish to acknowledge the contributions of James J. Crawford to this chapter in previous editions of this textbook.



Online Fig. 19-1 Personal protective equipment worn to comply with OSHA’s Bloodborne Disease Standard. (From Bird DL, Robinson DS: *Modern dental assisting*, ed 10, St. Louis, Saunders, 2012.)

Direct Contamination

Direct contamination occurs during direct contact with bodily fluids, and this is a major exposure concern for dental personnel.

Indirect Contamination

With saliva-contaminated hands, the hygienist, the dentist, and the assistant could repeatedly contact or handle unprotected operatory surfaces during treatments. The invisible trail of saliva left on such contaminated surfaces often defies either awareness or effective cleanup. Soiled surfaces that are poorly cleaned provide another source of gross environmental contamination and thus potential contamination of personnel and patients. Cross-contamination of patients by such contaminated surfaces was documented in a clinical office radiology setting.^{12,13}

Another study used water-soluble red-fluorescent poster paint (plain water-soluble fluorescent-red tempera in water) as a visible substitute for saliva to elevate awareness and facilitate problem solving in infection control. In this study, a hygienist was photographed treating a manikin fitted with dentures coated with red paint (Online Fig. 19-3).^{14,15} The results showed how extensively the dental operatory surfaces were smeared; how time consuming, expensive, and difficult it was to clean the contaminated surfaces; and how difficult it was to identify, clean, and disinfect objects covered with actual films of invisible saliva. Red poster paint is still used in dramatic training exercises, workshops, and poster displays to show or evaluate contamination control in dental operatories.

Bacterial contamination of dental operatory surfaces was investigated in 10 private dental offices after the surfaces were cleaned and disinfected.¹⁴ Sampling confirmed widespread residual contamination with oral bacteria. Contamination was not controlled by conscientious following of cleaning and disinfecting procedures. Items or areas still contaminated after cleaning included handpieces; unprotected lamp handles; air-water syringe handles; control switches on the patient’s chair; tubes, jars, and canisters of treatment materials; seat edges and rests of the dentist’s and assistant’s chairs; faucet knobs;



Online Fig. 19-2 Dentistry as it may have been practiced in the past. Rotary instrumentation can expose personnel to heavy spatter of more than 50- μ m particles and mists. Aerosol particles of less than 5 μ m remain suspended and can reach the alveoli if not stopped by a barrier. Air purification is a growing concern. (Courtesy of Laminair Corporation, Palm Beach Gardens, FL.)



Online Fig. 19-3 Distribution of saliva spatter during a dental hygiene procedure. The hygienist needs to wear a long-sleeved overgarment, mask, protective eyewear, and gloves.

cabinet, drawer, and operatory tray handles; room light switches; and operatory telephones. Telephone handles at the receptionists' desks also became heavily contaminated with bacteria from saliva. Before handpiece sterilization requirements, contaminated handpieces and other equipment were cleaned only by wiping with disinfectant before reuse. (When nondental offices that were never disinfected were sampled as controls, phone handles and other similar surfaces were devoid of bacteria from saliva.) Amalgam mixing equipment, light-curing units, and camera equipment also are subject to heavy contamination by soiled hands. Maintaining no contamination of these items and areas is a priority objective today. Controlling contamination of equipment and personnel is essential to protecting patients and personnel in this operatory zone of potential heavy contamination. Barrier protection of personnel and equipment, instrument sterilization, and methods of avoiding direct contact with various surfaces are necessary.^{9,11,14}

Cross-Infections

Most information on cross-infection and infection control concepts has been derived from data collected in hospitals. Evidence of oral or systemic cross-infections in dentistry is more difficult to obtain because patients may have contracted infections elsewhere, before or after having a dental treatment. Infected patients usually are unaware of the source of their infection and go elsewhere for diagnosis and treatment of nonoral infections. Infection outbreaks usually are detected in patients or personnel only when they occur in clusters recognized by other health care providers or are detected by epidemiologic studies and investigative surveys of personnel.

Patient Vulnerability

Although infection risks for dental patients have not been as well investigated as risks of hospital patients, they seem to be low. Nine cluster cases of dentist-to-patient transmission of hepatitis B virus (HBV) and one cluster case of HIV have been documented since 1971. Since 1986, when infection control practices became widespread, no cluster cases of HBV transmission related to dentistry have been reported.^{8,16-18}

Personnel Vulnerability

When dental personnel experience exposure to saliva, blood, and possible injury from sharp instrumentation while treating patients, they are more vulnerable to infections if they have not had the proper immunizations or used the proper protective barriers. It is unfortunate that the need for proper control of exposures and infections was not realized before the occurrence of the blood-borne HBV infection, which poses a serious threat to all dental personnel (see the section on [the impact of HBV](#)).¹⁹ HIV has not taken a similar or worse toll, primarily because of the implementation of adequate infection control principles and surveillance. Transmission of occupational disease from the patient to the dental health care worker is low.¹⁷ Dental personnel who have treated infectious patients on a daily basis for years in hospital dental services have found infection control methods to be highly effective.²⁰ Infection control has helped dramatically reduce the risks and concerns of personnel in private dental offices and has instilled

confidence in a safe environment for patients as well as personnel.

Epidemiologic information about HBV, hepatitis C virus (HCV), HIV, and other relevant infections is important. Examining the impact of these serious diseases provides the impetus to use and improve effective methods of infection control. It also may prevent complacency about the risks from current and emerging diseases. The vulnerability of dental personnel that exists before the institution of infection control standards is the best indicator of the potential for infection transmission in dentistry. Findings related to HBV and HIV illustrate this point.

Impact of Hepatitis B Virus

HBV was the first infectious disease to gain attention as a risk for health care personnel who come in contact with blood and other bodily fluids. From 1982 to 1986, various blood sample studies in the United States showed that 14% to 28% of general dentists, 13% of dental assistants, and 17% of dental hygienists had evidence of past infection with HBV.¹⁹⁻²³ If only 20% of the approximately 120,000 dentists in the United States had been infected by 1982, 24,000 dentists would have been infected with HBV. With the 2% mortality rate that characterizes HBV, 480 of these infected would have died within 20 to 30 years after initial infection. A vaccine has dramatically curtailed HBV infection among dental personnel who have been effectively immunized. Infection control procedures remain a major concern, however, to prevent cross-infection among patients.¹¹

Impact of Human Immunodeficiency Virus and Acquired Immune Deficiency Syndrome

In view of the high HBV infection rate among dental personnel, epidemiologists anticipated that acquired immune deficiency syndrome (AIDS) would decimate the workforce population in dentistry. By the mid-1980s, HIV had infected approximately one million persons in the United States, most of whom were high-risk persons in metropolitan areas. By 1988, of more than 1000 dentists surveyed in high-risk areas who practiced with unprotected hands, only one was found to be infected, and this person claimed no other exposure risks. As of December 2006, no dentists for whom negative HIV blood tests were established at the time of job-related exposure have acquired job-related HIV infection.^{1,24-26}

Public alarm was intense when a Florida dentist with clinical AIDS transmitted his unique strain of HIV to six patients in his large dental practice.^{27,28} No other instance of clinician-to-patient transmission of HIV has been documented in dentistry. That isolated instance of HIV transmission contrasts dramatically with the transmissibility of HBV. Twenty reports have documented that more than 300 patients treated by HBV-infected health care workers acquired the virus. Nine of the reports in the United States listed more than 140 patients infected with HBV by dental practitioners that caused several deaths.^{18,29} Evidence indicates that the Florida cluster of HIV infections and most treatment-related HBV infections from infected clinicians to patients could have been prevented by conscientious use of infection control procedures.^{17,24} The

Florida outbreak was nonetheless tragic for the individuals and families involved. The ensuing public demand for mandatory testing of all health care personnel was reduced to voluntary testing, and states were required to enforce U.S. Public Health Service guidelines for infection control in all health care facilities.³⁰ Public concern continues to focus unprecedented attention on the standards of infection control used in all health care professions, particularly in dentistry.^{6,30-33}

Despite the deficit in patient infection data and the misplaced concern regarding the transmissibility of HIV infection in dentistry, the Florida cluster of HIV infections and Occupational Safety and Health Administration (OSHA) regulations have provided, within a brief time span, a strong impetus to strengthen and control aseptic standards in all health care disciplines.³⁴ Dental students, auxiliary personnel, and patients all are the final beneficiaries of the dramatic changes that have occurred. Infection control is now accepted as a standard of care by dentists.^{35,36}

Federal and State Regulations to Reduce Exposure Risks from Pathogens in Blood and Other Sources of Infection

The term *infection control program* has a long tradition in hospital usage. Infection control programs such as those recommended by the Centers for Disease Control and Prevention (CDC) and the American Dental Association (ADA) are designed to protect both patients and personnel.^{37,38}

The federal Occupational Safety and Health Administration (OSHA) uses a different term, *exposure control plan*, for the required office programs designed to protect workers against risks of exposure to infection. Other agencies' guidelines and requirements that pertain to areas of infection control not covered by the OSHA are discussed in the next section. State occupational safety and health agencies are now enforcing regulations finalized by the federal OSHA, whose *Final Rule* (or *The Standard*) on occupational exposure to blood-borne pathogens was published in December 1991.³⁴

The OSHA rule derives from the original *Occupational Safety and Health Act* passed by the U.S. Congress in 1970.³⁹ This Act identified employers' obligations to protect employees from occupational risks. The Act has been the basis for all subsequent federal safety and health regulations. According to the Act, each employer must furnish employees with a place and conditions of employment free from recognized hazards that presently cause, or are likely to cause, death or serious harm to employees as specified in the "General Duty Clause" of the OSHA regulations. The Act created the OSHA in the U.S. Department of Labor. In the late 1980s, labor unions petitioned the OSHA in federal courts to extend chemical hazards protection standards to employees in the health care professions. Shortly thereafter, concerns about the transmission of HIV to health care workers stimulated the unions to take similar action to obtain the OSHA regulation with regard to exposure to blood and bodily fluids among health care personnel.

The Act covers two regulated programs of compliance: (1) the *OSHA Hazard Communications Program*, which deals with risks from environmental and chemical hazards in the

workplace, and (2) the *OSHA Bloodborne Pathogens Program*, which addresses control of "occupational exposure to blood and other potentially infectious materials."^{34,40} The OSHA Hazard Communications Program, which also must be implemented in every dental office, applies mainly to chemicals.⁴⁰

All aspects of the OSHA Bloodborne Pathogens program, which aims to protect employees, were required in every dental office by July 6, 1992.³⁴ *Federal Law 42*, passed by Congress in 1991, required state public health departments to apply similar standards or follow the CDC guidelines of infection control among all dental care personnel to ensure the protection of patients.³⁰ Under federal and state laws, "employers (including dentists operating nonincorporated offices) must comply with infection control regulations."

Preparing a Written Occupational Safety and Health Administration Office Exposure Control Plan: Summary Exposure Control Plan

A written exposure control plan must be accessible to all the employees who face exposure risks. The plan must be reviewed and updated at least annually and whenever alterations in procedures create new occupational exposures. Dental students do not come directly under OSHA regulations unless they are employees of the school with duties that involve exposure to blood-borne pathogens. In compliance with federal and state policies, school accreditation requirements, and university policies, however, all dental schools have an infection control manual of standard operating procedures that applies to students. These policies usually are based on the school's OSHA exposure control plan for faculty and staff. As future employers or employees, dental students will have to become acquainted with OSHA's exposure control plan.

The OSHA exposure control plan uses terms that require definition. *Exposure* is defined in the OSHA regulation as "specific eye, mouth, other mucous membrane, nonintact skin, or parenteral contact with blood or other potentially infectious materials (OPIM) that results from performance of an employee's duties."⁴¹ Only in dentistry is saliva considered a potentially infectious material because oral manipulations and dental treatments routinely cause saliva to become contaminated with the patient's blood. In dental practice, all patients must be treated with standard precautions to reduce the risk of disease transmission.

Means of compliance are expressed in the OSHA terminology for environmental safety engineers. *Work practice controls* and *engineering controls* are terms that describe precautions (e.g., careful handling of sharp instruments and not putting hands into sharps containers) and use of devices to reduce contamination risks (e.g., using high-volume suction, rubber dam, and protective sharps containers). *Personal protective equipment (PPE)* is the term used for barriers such as gloves, gowns, or masks. *Housekeeping* is a term that relates to the cleanup of treatment-soiled operatory equipment, instruments, counters, and floors and to the management of used gowns and waste. Housekeeping also relates to cautions for servicing contaminated equipment and using only mechanical means to clean contaminated broken glass.

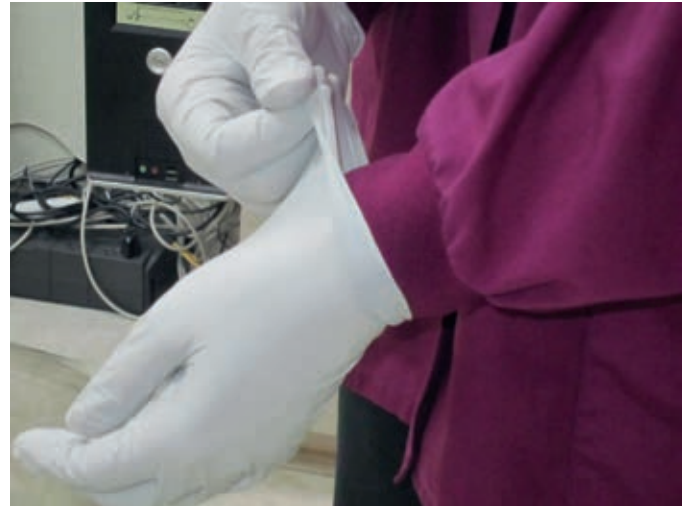
Dentists should obtain and read a copy of the *Final OSHA Rule on Bloodborne Pathogens* to be apprised of complete and



Online Fig. 19-4 In current dental practice, personal protective equipment (PPE) provides barriers against spatter and aerosols during patient treatments. (From Bird DL, Robinson DS: *Modern dental assisting, ed 10, St. Louis, Saunders, 2012.*)

exact regulatory details.³⁴ A summary of the current OSHA regulations specifying what employers must furnish, directions employers must provide, and compliance required of employees is as follows:

1. Employers must provide HBV immunization to employees, without charge, within 10 days of employment. The employer also must provide a copy of the OSHA regulations on blood-borne pathogens (from which this information is taken) to the health care professional responsible for providing HBV vaccination.
2. Employers must mandate that standard precautions be observed to prevent contact with blood and other potentially infectious materials. Saliva is considered a blood-contaminated bodily fluid in relation to dental treatments.^{1,6,7,11,31}
3. Employers must implement engineering controls to reduce the production of contaminated spatter, mists, and aerosols. Examples are use of a rubber dam, high-volume suction, rubber prophyl cup instead of brushes, scaling instruments for patients with respiratory infections instead of cavitron, and hard-wall containers to avoid contact with disposable and reusable sharps.⁴²⁻⁴⁴
4. Employers must implement work practice control precautions to minimize splashing, spatter, or contact of bare hands with contaminated surfaces. Telephones, switches, door handles, or faucet handles should never come in contact with soiled gloves. The subsequent items below (#5–#18) also are work practice control regulations.
5. Employers must provide facilities and instruction for washing hands after removing gloves and for washing other skin immediately or as soon as feasible after contact with blood or potentially infectious materials (Online Fig. 19-4, 19-5, and 19-6). If hands are not visibly soiled, cleaning them with alcohol gels is acceptable. The eye or mucosa should be flushed immediately or as soon as feasible after any contact with blood or potentially infectious materials.



Online Fig. 19-5 To remove a contaminated glove, pinch the palm side of the outer cuff surface with the gloved fingers of the other hand. Pull off the glove, inverting it. Both gloves can be removed simultaneously in this manner. Alternatively, after removing one, insert bare fingers under the cuff to grasp and pull off the remaining glove. Discard gloves safely.



Online Fig. 19-6 To wash hands after removing treatment gloves, operate the pump as shown with the clean underside of a wrist. Also, operate faucet handles the same way to avoid contamination or use foot controls. Never touch the handles with contaminated gloves.

6. Employers must prescribe safe handling of needles and other sharp items. Needles must not be bent or cut. When necessary, needles may be resheathed with mechanical aids or other one-handed techniques.
7. Employers must prescribe disposal of single-use needles, wires, carpules, and sharps as close to the place of use as possible, as soon as feasible, in hard-walled, leak-proof containers that are closable, from which needles cannot be easily spilled. Containers must be red in color or bear a biohazard label and must be kept upright and closed when moved. Teeth must not be discarded into trash but can be given to the patient or discarded in sharps containers.
8. Contaminated reusable sharp instruments must not be stored or processed in a manner that requires

- employees to reach into containers to retrieve them. A basket or cassette should be used to place instruments into, and retrieve them from, soaking pans and ultrasonic cleaners. Biohazard-labeled or red-colored pans that are leak-proof and puncture-resistant should be used.
9. Employers must prohibit staff from eating, drinking, handling contact lenses, and application (but not wearing) of facial cosmetics in contaminated environments such as operatories and cleanup areas. Storage of food and drinks in refrigerators or other spaces where blood or infectious materials are stored should be banned.
 10. Blood and contaminated specimens (e.g., impressions that have not been well cleaned and well disinfected, teeth, biopsy specimens, blood specimens, and culture specimens) to be shipped, transported, or stored should be placed in suitable closed containers that prevent leakage. An adequately strong plastic bag can be used for impressions. The surface of all containers must be clean or enclosed in another clean, red, or biohazard-labeled container.
 11. At no cost to employees, employers must provide them with necessary PPE and clear directions for use of appropriate universal barrier protection in treating all patients and for all other contact with blood or other infectious materials (see [Online Figs. 19-1 and 2-4](#)). PPE must not allow blood or other potentially infectious material to pass through to contaminate personal clothing, skin, or mucous membranes. Employers must provide protective gloves, or hypoallergenic gloves, as needed; appropriate protective body clothing such as gowns, the type and characteristics of which “depend upon the task and degree of exposure anticipated”;³⁴ protective eyewear, chin-length face shields, goggles, or glasses with solid protective side shields; masks; pocket resuscitation masks for cardiopulmonary resuscitation; and surgical caps or shoe covers to be worn when required for surgery or whenever heavy contamination can be reasonably anticipated.
 12. Employers should ensure that employees correctly use and discard PPE or prepare it properly for reuse. Adequate facilities should be provided to discard gowns or laundry in the location where they are used. *A face shield is not a substitute for a mask.*
 13. As soon as feasible after treatments, staff should attend to housekeeping requirements, including cleanup of floors, countertops, sinks, and other environmental equipment that are subject to contamination. Housekeeping requirements include the changing of protective covers after each appointment; alternatively, contaminated surfaces and operator equipment items that cannot be covered should be thoroughly cleaned and disinfected; discarded; or removed and sterilized. (See the sections on [operator asepsis](#), and [procedures, materials, and devices for cleaning instruments before sterilization](#) for details.)
 14. Employers must provide a written schedule for cleaning and decontaminating equipment, work surfaces, and contaminated floors. For contaminated spills, an appropriate method of cleaning and the application of disinfecting methods should be prescribed. Broken glassware that may be contaminated must be cleaned with mechanical means and never with gloved hands.
 15. Contaminated equipment that requires service first must be decontaminated, or a biohazard label must be used to indicate contaminated parts.
 16. Contaminated sharps are regulated waste and should be discarded in hard-walled containers. With regard to OSHA requirements in dentistry, regulated waste also means (1) liquid or semi-liquid blood or other potentially infectious materials, (2) contaminated items that would release blood or other potentially infectious materials in a liquid or semi-liquid state if compressed, and (3) items that are caked with blood or other potentially infectious materials and are capable of releasing these materials during handling. Such regulated waste should be disposed of properly in biohazard-labeled or red-colored closable bags or other labeled containers that prevent leakage. Containers contaminated on the outside must be placed in a secondary container. The secondary container also must be closable, prevent leakage, and be red-colored or biohazard-labeled. Containers or bags must be closed when moved. If outsides of reusable containers are likely to become contaminated, they must be inspected, decontaminated, and cleaned on a regularly scheduled basis and as soon as feasible if they become visibly contaminated. Cabinets or other storage areas on the premises in which blood-contaminated waste is stored must be identified by a biohazard label.
 17. Reusable contaminated sharp instruments should be placed in a basket in a hard-walled container for transportation to the cleanup area. Personnel must not reach into containers of contaminated sharps.
 18. Employers must provide laundering of protective garments used for standard precautions at no cost to employees. Contaminated laundry should be handled as little as possible without sorting or rinsing. All soiled linens should be bagged where they are used in a color-coded bag clearly indicating requirement of universal precautions.

Emergency and Exposure Incident Plan

An emergency and exposure incident plan must be developed for employees. A separate plan is needed for students if they use different medical care resources or methods for reporting exposure incidents. A program coordinator who will be the contact person when emergencies arise should be identified. That individual also may become the trainer for office personnel. The OSHA has mandated an exposure incident plan that emphasizes documentation of incidents and their follow-up. During training sessions, personnel must be instructed on what needs to be done in an emergency, but documenting a plan of medical emergency care is an equally important aspect of employee protection. Five requirements of an incident plan should be addressed:

1. Exposures to mucosa may not be associated with an injury, or an exposure incident may involve minor or severe injury (e.g., from a cutting instrument). Rapid

and thorough cleaning of a wound or washing a splashed eye or mouth as quickly as possible is the most important first step to minimize infection risks. Blood tends to collect on the surface of puncture wounds created by solid pointed instruments, so washing puncture wounds is just as important. Specific staff members to provide any help, direction, or transportation needed to obtain medical care must be identified. A brief written plan for accessing rapid medical attention should be formulated. This content should constitute the first part of the exposure incident plan. Sufficient time will still be available for a designated responsible individual to contact the patient and transmit medical records and other information to the attending physician, as presented next.

2. The written permission of the patient who is the source of exposure must be obtained to copy and convey his or her medical history to the attending physician or to obtain other medical records regarding the patient. Knowledge of risk behavior, blood test results, or other pertinent information usually can be conveyed verbally in confidence, however, without permission in case of exposure. Local laws must be consulted. Some states only prescribe communication of the name, address, and phone number of the patient and the name and phone number of the patient's physician to the attending physician of the exposed individual. The examining physician will contact the patient's physician, who will then deal with testing the patient.
3. As directed by OSHA regulations, employers must provide a copy of the exposure incident plan and explain it to the employees. Employers must document the route and circumstances of the exposure, identifying the source patient when possible. Employers must provide and pay for exposure incident evaluation and follow-up evaluations for an exposed employee, or these may be paid for by workers' compensation.
4. If other local regulations do not exist, employers also must (a) identify and contact the source patient if possible; (b) obtain the source individual's permission to be tested, unless he or she already is known to be infected; (c) have the source individual's blood tested by a health care professional, as soon as feasible, for evidence of current HIV or HBV infection (e.g., if blood is available, some states permit testing without permission in exposure instances); (d) provide results to the exposed employee in confidence (state laws often require counseling of the source patient and the exposed individual for HIV testing); (e) test the employee's blood, with his or her permission, as soon as feasible; (f) hold any available sample of the employee's blood for 90 days if consent is not given for HIV testing to provide for any change of mind; and (g) provide post-exposure prophylaxis to the employee, when medically indicated, according to recommendations of the U.S. Public Health Service.
5. The attending physician must be provided with a copy of OSHA regulations (from which this information is taken), documented information regarding the incident, results of the source individual's tests, and the employee's immunization records and any other relevant medical records.
6. A written report from the attending physician must be obtained by the employer and provided to the employee within 15 days of the completion of evaluation, stating that the employee has been informed of the results, possible infection consequences, and any further evaluation or treatment needed that relates to the exposure incident. Unrelated diagnoses or findings remain confidential.

Training of Personnel Required by Occupational Safety and Health Administration

Occupational safety guidelines require that new office personnel who will have contact with blood and blood-contaminated body fluids receive initial training in infection control. Retraining is required annually and whenever the exposure control protocol changes.³⁴ Training of personnel must contain the following elements, as listed in the OSHA standard:

1. An accessible copy of the regulatory text of this standard and an explanation of its contents
2. A general explanation of the epidemiology and symptoms of blood-borne diseases
3. An explanation of the modes of transmission of blood-borne pathogens
4. An explanation of the employer's exposure control plan and the means by which employees can obtain a copy of the written plan
5. An explanation of the appropriate methods for recognizing tasks and other activities that may involve exposure to blood and other potentially infectious materials
6. An explanation of the use and limitations of methods that would prevent or reduce exposure, including appropriate engineering controls, work practices, and PPE
7. Information on the types, proper use, location, removal, handling, decontamination, and disposal of PPE
8. An explanation of the basis for selection of PPE
9. Information on the HBV vaccine, including information on its efficacy, safety, method of administration, benefits of being vaccinated, and that the vaccine and vaccination will be offered free of charge
10. Information on the appropriate actions to take and persons to contact in an emergency involving blood or other potentially infectious materials
11. An explanation of the procedure to follow if an exposure incident occurs, including the method of reporting the incident and the medical follow-up that would be made available
12. Information on the postexposure evaluation and follow-up that the employer is required to provide for the employee after an exposure incident
13. An explanation of the signs and labels or color coding required by the OSHA standard
14. An opportunity for interactive questions and answers with the individual conducting the training session³⁴
15. Additional specific information must be provided regarding the details and cleanup schedules for employees' operatory and facilities.

Occupational Safety and Health Administration—Required Records

Job classification and immunization and medical records of personnel must be kept for 30 years by the office or a designated physician for OSHA inspection or disposed of, according to requirements. Training records must be kept for 3 years from the date of training. Exposure incidents must be tabulated and posted according to OSHA requirements. Details are provided in the regulations.³⁴ An interpretation of these regulations for dentistry has since been published.⁴⁵ Some variations from these and other OSHA regulations may be specified later for dentistry as a result of petitions made by the ADA. The dentist should consult current information.

Regulations of Other Agencies

State public health services and dental licensing boards complete the spectrum of infection control regulatory agencies. Most agencies specify the infection control guidelines of the ADA and the CDC of the U.S. Public Health Service, but focus more on tasks and procedures necessary for patient protection in dentistry.^{5,11,46-48}

Regulations Regarding Infected Health Care Personnel

Concerns about the possible transmission of AIDS from infected health care personnel to patients has led the U.S. Public Health Service to recommend additional precautions. All health care personnel who perform invasive, exposure-prone treatments are urged to obtain testing for HBV and HIV infections voluntarily.³²

Exposure-prone procedures include simultaneous use of the operator's fingers and sharp instrumentation in a highly confined or poorly visualized anatomic site such as the mouth, where tissues are cut or bleeding can occur. Clinical personnel are considered infected when they test positive for antibodies against HIV or for hepatitis B surface antigen (HBsAg) and hepatitis Be antigen (HBeAg). Infected health care personnel are advised not to perform exposure-prone procedures unless they have sought counsel from an expert review panel and have been advised under what circumstances they may continue to perform these procedures, depending on the experience and skill of the clinician involved. As defined by the CDC, a review panel may consist of the worker's physician, an infectious disease specialist with expertise in the epidemiology of HIV and HBV transmission, another health care professional with expertise in the type of procedures performed, and a local public health official.³²

Occupational Safety and Health Administration—Required

Acquired Immune Deficiency Syndrome and Human Immunodeficiency Virus Infection

AIDS is the last stage of a debilitating, eventually fatal human disease. AIDS may develop in 1.5 to 11 or more years after an initial infection with HIV.^{37,49} HIV is a relatively fragile

ribonucleic acid (RNA) retrovirus, which is easily destroyed in the dry state in 1 to 2 minutes by most disinfectants.^{6,7,37,50}

Human Immunodeficiency Virus: Epidemiology and Transmission

Since its recognition in 1981, as of the end of 2006, HIV had infected 1.1 million people in the United States, with 21% going undiagnosed.^{8,33,51,52} HIV is transmitted mainly through blood, blood-contaminated bodily fluids such as semen, and vaginal fluids. High-risk behaviors or situations that define high-risk groups include having multiple sex partners of the same or opposite sex; having a sexual partner who is at high risk or infected; intravenous drug abuse; treatment for hemophilia; blood transfusion received before spring 1985; and infants of an infected mother.^{33,53-55} Casual, nonsexual contact, including social kissing and sharing towels or food among family members in a household with an AIDS patient, has not been shown to transmit the infection.

Progression of Human Immunodeficiency Virus Infection into Acquired Immune Deficiency Syndrome

After a prolonged quiescent state of 1.5 to possibly 11 years after infection, HIV begins to destroy cells that control the normal immunity of the body against infections and tumors. At that time, the body becomes more and more vulnerable to many common viruses and microbes found in the normal environment. Commonly harmless parasites and fungi are able to cause severe and often fatal conditions such as pneumonia and cerebral infections.^{37,49}

On entering the blood or tissues, HIV can attach only to certain docking sites that it finds projecting from the surfaces of certain white blood cells. Helper lymphocytes crucial to the normal functioning of the immune system are covered with these sites. Immunologists have labeled these cells *T helper lymphocytes* because the thymus has an important role in preparing them to function. The surface attachment sites are termed *category designation four (CD4) glycoprotein antigens*. When it becomes attached, virus RNA can enter and infect the lymphocyte.⁵⁶

The cells commonly infected, termed *T4 (CD4) helper lymphocytes*, are crucial to normal cellular and antibody functions that protect humans against many bacteria-infected, fungi-infected, and virus-infected cells and tumors or cancers. Other cells such as macrophages, neurologic glial cells, colon or rectal cells, and possibly some connective tissue cells also have the CD4 glycoprotein surface sites to which HIV can attach itself. Colon cells (e.g., in the case of male homosexual intercourse) may serve as infection sites. It is unknown whether the mucosal cells of other body cavities may serve as initial infection sites as well. Various susceptible cells and perhaps the cells in bone marrow may serve as reservoirs of the virus in a prolonged latent or quiescent incubation stage when HIV sometimes cannot be detected in blood.⁵⁶

HIV is termed an *RNA retrovirus*, which needs complementary DNA formed within the nucleus of a host cell (termed *provirus form*) to reproduce the HIV. As HIV gains entry into the lymphocytes, reverse transcription of viral RNA begins, resulting in the formation of double-stranded viral DNA in

the infected cells. When inserted into the cell's genetic structure (genome), this DNA becomes the provirus of HIV. The DNA of HIV may divide and reproduce along with the cell's nuclear DNA for years. Antibody tests are now available to detect the provirus DNA fragments that regulate the production of various parts of the HIV structure (i.e., core proteins, *gag*; viral envelope, *env*; reverse transcriptase, *pol*).^{53,56}

After remaining latent during the prolonged incubation period in infected helper lymphocyte cells, HIV begins to replicate. The lymphocytes die, releasing the virus into blood, and the numbers of essential helper lymphocytes are drastically reduced. When helper cell counts decrease to less than 200/mm³ in blood, many different opportunistic infections and tumors appear. Conditions are such that it becomes increasingly difficult to treat the patient until fatal *Pneumocystis* infection of the lungs occurs, or until HIV or other infection of the brain causes death.⁴⁹ Levels of virus in blood usually increase at this time but are still low compared with the huge viral concentrations reached in the blood of patients with HBV.⁵³ At our institution, patients with T4 helper cell counts of 200/mm³ or less benefit from the protective facilities, nursing care, and treatment expertise offered by the hospital dental service clinicians.

Symptoms and Oral Manifestations

Within 3 months of infection, temporary flu-like symptoms—pharyngitis, myalgia, fatigue, fever, or diarrhea—may occur when antibodies to HIV become detectable. Following the prolonged incubation of the virus for approximately 1.5 to 11 years, any of several early signs of AIDS that signal the progressive failure of the immune system may be observed by the dentist.^{37,57} During examination, the dentist can easily detect one or two cervical lymph nodes, especially below the mandible, that persist for more than 3 months. The nodes may be attached and painless, or they may be movable, painful, and infected. Undifferentiated non-Hodgkin's lymphoma may arise in lymph nodes or may appear in the mandible, central nervous system, eyes, bone marrow, and other vital organs.³⁷

Persistent oral candidiasis is often seen with easily dislodged, white, curd-like patches scattered over the tongue. In AIDS, such infection may not respond easily to treatment and often recurs, developing into atrophic candidiasis or cheilitis at the angles of the lips. Painful herpes stomatitis also is common. Untreated herpes or candidiasis may progress to esophagitis or laryngitis, impairing speech.³⁷

Red, brownish-to-purple blotches that persist on the oral mucosa and skin typify sarcoma of the capillaries, termed *Kaposi's sarcoma*. Oral lesions often develop into tumors that may require surgery and radiation therapy. Kaposi's sarcoma often is found on the oral tissues of homosexual men. Human papillomavirus (HPV) can cause oral warts that appear flat or cauliflower-like.³⁷ Persistent, severe, recurrent gingivitis and periodontitis that bring patients to dental care are common findings typical of AIDS. The gingivitis may persist despite effective plaque control.⁵⁸

Early systemic signs of illness progressing to AIDS are marked by weight loss of 50 lb within a few months and chronic fever or night sweats that persist for 3 months or more.^{37,49} Early detection and medical treatment of HIV infection is beneficial to most patients. Current treatments are summarized in the annual *Journal of the American Dental*

Association supplement update, *Facts about AIDS for the Dentist*.³⁷

Serology of Human Immunodeficiency Virus Infection

HIV infection is detected with blood tests (enzyme-linked immunosorbent assay [ELISA], Western blot test, and fluorescent antibody test) that detect antibodies formed against the virus. Tests for anti-HIV antibodies are often positive within 3 months after infection. Most are positive by 6 months; in 1% of cases, it takes 12 months to obtain a positive test. A second positive test is necessary to confirm positive serologies. Serologic tests for the virus and provirus DNA also have been developed. Tests for T4/T8 (or CD4/CD8) lymphocyte ratios are used to identify the progress of the HIV infection. One criterion for starting zidovudine therapy is a T4 helper cell count less than 500/mm³ of blood.³⁷

Human Immunodeficiency Virus Risks for Clinical Personnel

Of all American health care workers injured by needles and sharp instruments used to treat HIV-infected persons, only 0.3% or less have become infected with HIV. This statistic contrasts with 30% of workers who become infected with HBV after parenteral exposure to infected blood.⁶ As of December 2006, among all U.S. health care personnel, documented occupation-related HIV infections total 57, of which none was reported among dental personnel.^{1,8,16,17,59} An additional 139 HIV infections are considered possible occupational transmissions, including 6 in dental personnel.^{1,25}

As was pointed out at the beginning of this chapter, dental personnel have been spared, almost miraculously, being infected with HIV. Thousands of unprotected dentists who unknowingly treated HIV-infected patients must have been exposed to HIV as the epidemic mounted during the 1980s before gloves and other barriers came into common use. Only six dentists who claim no other exposure risks seem to have acquired HIV infection by occupational exposure.^{1,6,8,16,17,25} Testing at the time of exposure for evidence of prior HIV infection was not commonly performed in dentistry until the 1990s. Because none of the infected dentists had such baseline blood tests, their HIV infections cannot be linked firmly to the time and circumstance of clinical exposure.

HIV infection was reported to have developed in a nurse and a technician who were splattered with HIV-infected blood. Other medical personnel have been reported to have acquired HIV infections related to spatter of infected blood on their nonintact skin. The serologic status of HIV in these persons was apparently not known when they were exposed.^{6,8,16,17} Personnel are required to protect their eyes, mucosa, skin, and hands from spatter and direct contact with blood and blood-contaminated bodily fluids during dental treatments of all patients.⁴⁵ Precautions also must be taken to minimize risks of injuries with sharp instrumentation.

Patients seriously ill with AIDS who are seen in a hospital setting also may harbor transmissible respiratory infections such as tuberculosis and cytomegalovirus (CMV) infection.^{60,61} As indicated in the section on the epidemiology of other infection risks, transmission of drug-resistant tuberculosis from immunocompromised patients is a growing

concern. Personnel without adequate barrier protection should avoid exposure to coughing, saliva spatter, and heavy aerosols from HIV-infected persons with signs of respiratory infection. This applies especially to pregnant women because recent infection with CMV can be detrimental to the fetus. CMV is also a blood-borne pathogen.

Human Immunodeficiency Virus risks for Dental Patients

With proper use of infection control measures in dental practice, the risk for a dental patient of contracting HIV from office personnel or from other patients is extremely low. HIV has not been transmitted to dental patients from infected clinical personnel anywhere in the United States, with the exception of one unique outbreak.^{17,24,27} In a circumstance that has been unique as of 2011, six patients were found to be infected with the same strain of HIV present in a Florida dentist who had treated them.^{17,24,27} These patients had no apparent source of exposure other than the dentist who, in spite of having AIDS symptoms, continued to treat patients. This dentist's use of adequate infection control measures was questionable. It is quite likely that some kind of clinician-to-patient transmission had occurred in this case. At this time, no other instances of transmission of HIV from infected dentists or physicians to patients have been reported. One or more alleged HIV cross-infections between patients, attributed to contaminated dental equipment, are under investigation.¹⁶

Human Immunodeficiency Virus Data Related to Infection Control

Data that provide a better understanding of disease agents, their survival qualities, and clinical transmission potentials help clinicians institute effective infection control. The following HIV data are reassuring and help explain the amazingly low occupational risk of HIV infection for dental personnel:^{26,37}

1. In contrast to HBV, very low levels of HIV usually have been found in the blood of infected persons. This is especially true of asymptomatic persons, who are the most difficult to recognize and would be most likely to be treated in private clinics.^{31,62}
2. HIV was detected in only 28 of 50 samples of blood from infected persons. In saliva from infected persons, HIV was detectable in only 1 of 83 samples.³ Counts of virus per milliliter of blood fluctuate but may increase as the number of antibodies to the HIV core protein decline.^{53,62}
3. CDC investigators have found 99% of HIV to be inactive in approximately 90 minutes in dried infected blood.³¹ Longer survival data on larger numbers of HIV grown in laboratory cell cultures have created misleading information about the survival of HIV in dried infected blood. In blood that remains wet, however, the virus may survive for 2 or more days.⁶³ Caution is required when handling containers of used needles in which virus-infected blood may remain wet.
4. HIV is killed by all methods of sterilization. When used properly, all disinfectants, except some quaternary ammonium compounds, are said to inactivate HIV in less than 2 minutes.^{31,37,64}
5. HIV has been transmitted through blood-contaminated fluids that have been heavily spattered or splashed on persons.²⁷ Aerosols such as those produced during dental treatments have not been found to transmit HBV or HIV infection.^{31,65}
6. Barriers have proved successful in protecting dental personnel in hospital dentistry and in all other dental clinics against HIV; at our institution, for more than 10 years, they have been providing effective prevention of even more easily transmissible viral infections.

A more recent concern for immunocompromised individuals and for dental personnel is airborne transmission of multidrug-resistant *Mycobacterium tuberculosis*.^{10,46,60}

Viral Hepatitis: Agents, Epidemiology, and Infection

In the 8 years after AIDS was recognized, 38,000 persons were identified to have developed the disease. During that same period, an estimated 38,400 persons died from HBV, related cirrhosis, or liver carcinoma.^{33,66,67} Infective inflammation of the liver, termed *hepatitis*, can be caused by infection from various hepatitis viruses labeled A to G. The type of infection is diagnosed specifically by serologic testing. Hepatitis types A, B, and C are roughly equally divided among cases of viral hepatitis detected in population surveys, with hepatitis A virus (HAV) being the most prevalent. HBV, HCV, and HDV are blood-borne infections. HAV and HEV are fecal-borne infections.^{67,68} A new blood-borne virus, HGV, has been detected in a group of high-risk hospitalized dental patients with liver disease associated with other viral agents or conditions.⁶⁹ The importance of HGV and its contribution to liver disease are unclear.

HBV is found in 1 in 100 to 500 persons in the general population (estimated 1.2 million people with chronic infection in the U.S.), including dental patients. The incidence has peaked in areas associated with high rates of intravenous drug abuse and closely follows the incidence of HIV infection.^{7,42,51,70} According to the CDC, 1 in 55 persons (1.8%) in the U.S. population may carry HCV, with an estimated 3.2 million people with chronic HCV infection.^{51,68,71,72} HCV accounts for one third of liver transplantations and more than 8000 deaths per year.⁷¹

Viral Hepatitis Infection: Symptoms, and Clinical Findings

HBV must enter the circulating blood to reach the liver, where the viral DNA causes infected hepatic cells to reproduce the virus. Symptoms usually appear after 2 to 4 months of incubation. Extensive liver damage and illness occur rapidly in approximately 2 of 10 infected persons. Symptoms and signs include nausea, vomiting, chronic fatigue, mental depression, fever, joint pain, darkened urine, jaundice, elevated liver enzymes, and possibly diarrhea or rash. Mortality is 2% or less but tends to be 2% or greater in individuals older than 30 years of age.^{29,38} CMV and Epstein-Barr virus (EBV) infections also may produce jaundice and elevated liver enzymes.

Only 2 of 10 individuals infected with HBV show symptoms. The other 8 individuals are usually unaware of their infection. For this reason, it is impossible to detect most HBV-infected individuals from medical history. Whether or not the infected individuals are symptomatic, they can transmit HBV. Usually, within 1 year, 9 of the 10 individuals develop immunity to HBV and are no longer infectious. Of the 10 infected individuals, 1 remains infected and infectious, often for the remainder of life. Acute cirrhosis may be fatal within months. If the illness was not severe and chronic infection persists, increased risk of cirrhosis or hepatocellular carcinoma may prove fatal in 20 to 30 years. The possibility of such an outcome results in an overall hepatitis mortality rate of 2%. No specific treatment against the virus is available once the infection has occurred.

Other types of hepatitis produce symptoms similar to those of HBV.^{22,29,67,68} HAV has a shorter incubation of approximately 1 month and lower mortality. Individuals infected with HAV do not remain infected or infectious beyond 8 weeks after symptoms subside. HCV is often (75%) anicteric (without jaundice), and elevated levels of liver enzymes and serologic tests help establish the diagnosis. HCV becomes chronic in 75% to 85% of the infected individuals, causing them to remain infectious.^{51,71}

HDV, or delta hepatitis virus, has a curious makeup. It has no outer coating and relies on the cells infected with HBV to provide the required outer layer. When HBV and HDV infect an individual concurrently, usually by the same route and source, the infection becomes much more severe and many times more fatal than infection with HBV alone. Protection against HBV also protects against HDV, but not HAV, HCV, or HEV.⁶⁶⁻⁶⁸

Transmission of Viral Hepatitis

The transmission of HBV, HCV, and hepatitis D virus is mainly through blood, intravenous drug abuse, and sexual contact. Billions of HBV may be present in one milliliter of infectious blood.⁶ HBV also is found in saliva, but at lower concentrations. HBV can be transmitted through contamination of broken skin, the mouth, or the eyes with blood-contaminated saliva. One in three nonvaccinated exposed persons may be infected with HBV. In studies performed during dental treatments of HBV-infected individuals, aerosolization of HBV could not be detected with tests for HBsAg.⁶⁵

HBV is transmitted in the population through the same routes as those for HIV infection. In contrast to HIV, however, HBV has been transmitted to family members through prolonged associations that may involve repeated contamination with saliva or blood (e.g., through sharing of shaving instruments, traces of blood left on bathroom towels, continuous sharing of unwashed toothbrushes, or drinking from the same cup). In public situations, neither HIV nor HBV is transmitted through casual contact.^{49,67} Individuals at risk for HIV infection also are more likely to be carriers of HBV. Of HIV-infected individuals, 90% have been infected with HBV. HAV is excreted from the infected liver into bile. HAV and HEV are transmitted by the fecal-oral route. Poor hygiene and contaminated food and water are common routes of infection. These types, however, are not a major concern in dentistry.

Blood transfusions were a major source of HBV infection until 1985 and of HCV infection until 1991. A test for HCV

was developed in 1990. Tests instituted in hospitals since 1986 for HBV and since 1991 for HCV have virtually eliminated transfusions as a source of infections. A persistent problem is the detection of infectious donors during the incubation period of the pathogens.^{68,71}

Hepatitis B and Hepatitis C Virus Infection Risks for Personnel

Personnel can be infected through parenteral exposure; mucosal exposure to infected blood or blood-contaminated saliva; and spatter of infected blood to the eyes, mouth, or broken skin.⁶ Paper cuts from blood-contaminated request forms have been reported to have transmitted HBV.⁷³ Plain saliva also can be weakly infectious. Aerosolized, blood-contaminated saliva and respiratory secretions that can transmit many respiratory viruses and tuberculosis have not been shown to transmit HBV.^{9,10,42,67,74} One in three parenteral exposures of nonvaccinated personnel to HBV-infected blood has resulted in HBV infection.²⁹ In contrast to the 1 of 300 nonvaccinated individuals who develop HIV after parenteral exposure to HIV-infected blood, 100 of 300 individuals parenterally exposed to HBV develop HBV.

A vaccine against HBV is available. Mortality rates from HBV exposure could approach zero for dental personnel.⁶⁷ Patient protection still depends on the effective use of infection control procedures.

HCV exposure risks for dental personnel have been documented and appear to be low.⁷⁵ Infection control should minimize risks. Data indicate that infection rates from parenteral exposure to HCV-infected blood fall between the rates for HBV and HIV infection—approximately 1.8%.^{71,72,75}

Serologic Tests Related to Hepatitis A, B, and C Viruses

Serologic tests are available for the detection of the several antigens of HBV and for the serum antibodies individuals produce against them.^{29,67} Testing a blood sample for HbsAg can determine the presence of infection by detecting the protein associated with the surface of the HBV in blood. The test is used to identify individuals who are infected, whether or not they are symptomatic. Testing for HBeAg determines presence of an HBV antigen found in blood when HBV concentrations are high and relate to the individual's ability to infect others.

Testing for the antibody against the HBV core antigen (anti-HBc) can detect the antibody against a virus core protein that becomes positive in virtually all individuals a few months after infection and remains positive for years thereafter. The antibody is used as a marker for previous HBV infection, but this antibody is not protective. A test for anti-HBV surface antigen (anti-HBs) is performed to determine the presence of antibodies that can protect against future HBV infection. Detection of anti-HBs means that the individual has been infected and has recovered or has been immunized with a vaccine.

Data Related to the Control of Hepatitis B Virus

HBV is a relatively stable DNA hydrophilic virus that can withstand drying on surfaces and presumably on equipment

and clothing for more than 7 days.⁷⁶ One billion virus particles of HBV can be found per milliliter of infected blood. Disinfectants selected for their ability to inactivate tuberculosis and hydrophilic viruses seem to be able to inactivate HBV.^{77,78} All forms of sterilization destroy the virus.^{5,78}

Immunization Against Hepatitis A, B, and C Viruses

An effective vaccine against HAV has been developed and is recommended for the dentist, dental student, and auxiliary personnel.^{11,79,80}

Vaccination against HBV requires one dose followed by a second dose 1 month later and a third dose 6 months after the first. Hepatitis vaccines must be given in the arm. Protection of individuals who form antibodies is virtually 100%. One in 30 individuals vaccinated may not respond to the vaccine. Follow-up testing is recommended by the CDC to confirm immunity 1 month after immunization is completed because dental personnel are considered to be at high risk for HBV infection.^{1,7,67} Protective immunoglobulin is available for HBV-exposed individuals who have no immunity.

No vaccine is available against HCV. Because the virus mutates rapidly in infected individuals, a vaccine may be difficult or impossible to develop. No protective immunoglobulin is available for exposed individuals.⁷¹

Tests for Hepatitis B Antibody and Boosters

After a period of 1 to 6 months after the vaccination against HBV is completed, it is important that dental personnel obtain a test to determine if protective anti-HBs were formed.^{1,7,67} One or more of 30 vaccinated adults younger than 40 years of age may not respond to three vaccine injections. Higher percentages of individuals older than 40 years do not respond because the immune response gradually diminishes with age.⁶⁷

Routine boosters are not recommended for the general health care profession by the CDC.^{1,32,51,67,81-83} A booster effect usually is experienced by an infected individual who has produced antibodies. In dentistry, because of the crisis situation that can surround an exposure, the time it takes to obtain test results after an exposure, and the frequent problem of never knowing when a small exposure has occurred, dental personnel often prefer to have their blood tested with a radioimmunoassay test for anti-HBs to check their immunity. If test results are less than 10 serum ratio units, they should take a booster dose of the HBV antigen. This is in keeping with the recommendation for receiving a booster dose when exposure is known to have occurred and antibodies in a previously immunized individual are deficient.⁶⁷

Epidemiology of Other Infection Risks

Several agencies want to ensure that dental personnel and patients are protected against risks of all infections borne by blood, saliva, and respiratory secretions. Routine medical histories are important but cannot be relied on to detect infected patients or for selective use of “standard precautions” for individual patients. All patients must be considered infectious. In

addition to HIV, HBV, HCV, and HDV (discussed previously), other transmissible infections of concern include infectious mononucleosis (EBV infection), CMV, herpes simplex virus 1 and 2 (HSV 1 and HSV 2), and tuberculosis.^{11,14,61,84} Without barrier protection, dental personnel’s hands and the mucosa of the eyes and mouth are especially vulnerable to infection with herpes viruses.^{9,44,48,85,86} Agents of measles, mumps, other childhood infections, and some other respiratory infections also are transmissible, especially in indistinguishable early stages of infection.^{57,84} Measles and mumps can be severe in adults (Online Fig. 19-7). In 1990, 23% of measles infections occurred in individuals older than 19 years of age. The mortality rate was 0.3%; one third of fatal cases involved nonimmunized adults.⁸⁴ Measles outbreaks among college students have been severe.⁸⁷

Multidrug-resistant tuberculosis bacteria are an increasing concern.⁶⁰ These bacteria are resistant to two or more of the more common therapeutic drugs and are highly transmissible through aerosols produced by coughing. Infections seldom become active in healthy adults, but an active infection can remove a clinician from practice for months until the infection is controlled and is no longer transmissible. Infection with multidrug-resistant tuberculosis can be rapidly fatal for immunocompromised individuals.⁶⁰

CMV infection, a disease that is transmitted through sexual contact and blood, is not commonly known and often resembles infectious mononucleosis. Especially during pregnancy, a newly infected woman faces the risk of possible intrauterine or perinatal infection of her infant. Developmental defects can occur in 5% to 10% of infected infants, resulting in neuromuscular, auditory, and visual impairments.⁷⁸ CMV is just another infection to which personnel in the dental operator are susceptible, but it can be prevented by universal use of barrier protection.

Personnel should receive immunizations against measles, polio, and tetanus. Annual or semi-annual skin tests for tuberculosis (purified protein derivative) are recommended by the CDC for dental personnel.¹¹ HBV immunization is mandated by federal OSHA, unless an employee documents his or her understanding of the risks and his or her refusal. Measles vaccination is required for individuals born after 1956, or they must show proof of immunity for admission to most colleges.⁸⁸ This is also an important requirement for dental personnel.

Immunizations against viral influenza and pneumococcal pneumonia are advisable. Mumps immunization is highly desirable for both male and female personnel without a history of immunization or childhood infection. Diphtheria and pertussis immunizations usually are received during infancy. Development of vaccines to prevent HIV, HCV, and other common infections is an ongoing process.⁷¹

Exposure Assessment Protocol

The OSHA does not regulate students, but dental students are required to follow the same exposure incident protocol plan as do dental employees, but the appropriate differences for students such as the source of medical care should be taken into consideration.^{30,36} This plan requires that if blood-contaminated bodily fluid from a patient is spattered onto the mucous membranes or comes into contact with the broken or



Online Fig. 19-7 Oral manifestations associated with communicable diseases. **A**, Primary herpetic gingivostomatitis. (Courtesy of Dr. William F. Vann, University of North Carolina, Chapel Hill) **B**, Herpes labialis (gingival mucosa). **C**, Herpes labialis. (Courtesy of Dr. Lauren Patton, University of North Carolina, Chapel Hill) **D**, Herpetic whitlow, index finger. (Courtesy of Dr. James Crawford, University of North Carolina, Chapel Hill) **E**, Chicken pox, rash on the trunk. (Courtesy of Dr. William F. Vann, University of North Carolina, Chapel Hill) **F**, Chicken pox, gingival lesion. (Courtesy of Dr. William F. Vann, University of North Carolina, Chapel Hill) **G**, Herpes zoster (shingles, supra-orbital dermatome distribution). (Courtesy of Dr. Diane C. Shugars, University of North Carolina, Chapel Hill) **H**, Condylomata acuminatum, or venereal wart. (Courtesy of The Centers for Disease Control and Prevention, Atlanta)



Online Fig. 19-7, cont'd **I**, Pseudomembranous candidiasis, facial mucosa. (Courtesy of The Centers for Disease Control and Prevention, Atlanta) **J**, Hairy leukoplakia, lateral border of the tongue. (Courtesy of The Centers for Disease Control and Prevention, Atlanta) **K**, Kaposi's sarcoma, maxillary palate. (Courtesy of The Centers for Disease Control and Prevention, Atlanta) **L**, HIV-gingivitis. (Courtesy of Dr. James R. Winkler, University of California, San Francisco.)

punctured skin of a clinician or if exposure has occurred through a cut or puncture with a contaminated sharp instrument, the protocol must be followed immediately, before the patient leaves. If possible, the patient's potential to transmit HBV, HCV, and HIV is determined, as is the student's susceptibility to HBV. The attending physician who helps with these determinations provides, if indicated, HBV immunoglobulin, hepatitis booster, anti-HIV testing, and counseling (see the section on OSHA regulations).³⁴

Medical History

The medical history serves the following purposes: (1) to detect any unrecognized illness that requires medical diagnosis and care; (2) to identify any infection or high-risk behavior that may be important to a clinician exposed during examination, treatment, or cleanup procedures; (3) to assist in managing and caring for infected patients; and (4) to reinforce the use of adequate infection control procedures, bearing in mind that general history taking cannot help detect all infectious individuals. Only the conscientious use of standard precautions ensures safety. Symptoms of persistent respiratory illness, night sweats, chronic fatigue, and weight loss can be symptomatic of either tuberculosis or HIV infection. With the increasing occurrence of multidrug-resistant tuberculosis bacteria, the medical histories of HIV-infected dental patients and others at high risk should be kept updated with information on current medical care and surveillance from the patient's physician. The clinician should be aware of the

relationship of all infections (and their characteristics) when taking medical history and performing an initial general examination at each appointment.

Personal Barrier Protection Gloves

OSHA regulations specify that all clinical personnel must wear treatment gloves during all treatment procedures. After each appointment, or whenever a leak is detected, gloves are removed, hands are washed, and fresh gloves are donned (see [Online Figs. 19-5 and 19-6](#)). Gloves must not be washed or used for more than one patient. Inexpensive, disposable, well-fitting treatment gloves are available for chairside use. Used gloves should be disposed of carefully to avoid contaminating others in the box. The value of using gloves was emphasized by the finding that without gloves, occult blood persists under dentists' fingernails for several days after patient contact.⁸⁹ Gloves also help prevent painful and transmissible herpetic infections to fingers (whitlow) and hands.^{74,90}

Treatment gloves cannot protect against punctures. Gloves that become penetrated or torn can let patient fluids pass through and therefore should be removed and the hands washed. Instead of acting as a barrier, gloves worn for prolonged periods can harbor blood-borne and saliva-borne microorganisms. *Gloves must not be washed.* Washing reduces the integrity of the glove, leaving personnel more vulnerable. Instead of attempting to wash gloved hands before opening drawers or handling items adjacent to the operatory, tongs, a

paper towel, or a food handler's overglove should be used to prevent contamination.

Dental personnel with chronic HBV or HIV infection should avoid any treatment activities that would jeopardize the patient. All personnel with weeping or draining lesions that could infect patients should abstain from patient contact.^{1,32} Dry, nondraining lesions should be kept well protected from clinical contamination.

Increased marketing competition has reduced the prices of gloves and has improved the quality of latex gloves appreciably. Penetration by viruses has been found to occur in only 1 of 100 intact latex gloves.⁹¹ Gloves must meet the U.S. Food and Drug Administration (FDA) regulations: The allowed leak rate detectable with a water test is less than 4%.⁹² Some companies have set even higher standards, at less than 2% to 3%. Boxes of gloves should be stored away from sunlight, and multiple boxes should be stored in tightly closed, heavy plastic bags to minimize oxidation. If any doubt exists about a supplier's gloves, the distributor should be contacted to verify adherence to FDA regulations and the manufacturing standards of the product. Products that do not meet FDA standards and advertising claims are subject to removal from the market if consumers report lack of compliance.

While cleaning and sorting used sharp instruments, puncture-resistant utility gloves should be worn. Nitrile latex gloves are preferable; they can be washed inside and out, disinfected, or steam autoclaved, as needed. Treatment gloves, if they must be shared, should be worn inside heavy gloves. With the current practice of wearing latex gloves for several hours each day, dental personnel should be aware that the possibility of latex allergy or hypersensitivity is a growing concern for all personnel and patients. In July 1991, the FDA requested that all cases of allergic reactions to latex be reported. The concern among dental health care workers is based on the frequent changes of gloves, which exposes them to the latex protein allergens. The symptoms associated with latex allergy or hypersensitivity should not be confused with the physical irritation caused by frequent handwashing. Currently, no cure for latex allergy exists. Avoidance of latex-based products is the best treatment.

Instructions for Handwashing

At the beginning of a routine treatment period, the clinician should remove his or her wristwatch, jewelry, and rings (or at least those with enlarged projections or stones that can penetrate gloves), then wash hands with a suitable cleanser. Hands should be lathered for at least 15 seconds, rubbing all surfaces, and rinsed. A clean brush should be used to scrub under and around nails. Washing should be repeated at least once to remove all soil. Washing hands well when changing gloves is mandatory.^{34,93} Even good-quality surgical gloves develop minor pinholes or leaks during vigorous use. Washing minimizes infection risks secondary to leakage. Before surgery, the clinician should use a prescribed surgical scrub and wash and rinse from the hands toward the elbows. A separate brush should be reserved to clean the instruments.

Hand cleansers containing a mild antiseptic, such as 3% parachlorometaxyleneol (PCMX) or chlorhexidine, are preferable for controlling transient pathogens and for suppressing overgrowth of skin bacteria.⁹⁴ Hand cleansers with 4% chlorhexidine may have broader activity for special cleansing

(e.g., for surgery, when a glove leaks, or when a clinician experiences an injury), but they can be hazardous to eyes.^{91,95} PCMX cleansers have been found equally effective, nonirritating, and preferable for routine use.⁹⁵ Newer non-opaque chlorhexidine products used especially for surgical scrubs may be less irritating to the hands of some individuals for prolonged use.⁹⁶ Additionally, proper use of alcohol rubs is effective against pathogens and less drying to the hands.¹

Protective Eyewear, Masks, and Hair Protection

Protective eyewear may consist of goggles or glasses with solid side-shields. A mask should be worn to protect against aerosols. Face shields are appropriate for protection against heavy spatter, but a mask still is required to protect against aerosols that drift behind the shield.^{9,34} Spatter also can pass under the edge of a short shield and strike the mouth. Anti-fog solution for eyewear can be obtained from opticians or product distributors.

The clinician should put on eyewear with clean hands before gloving and remove it with clean hands after the gloves are removed. Eyewear should be grasped by the temple pieces. The clinician should grasp the mask only by the string or band at the sides or back of the head to remove it (Online Fig. 19-8). The mask should be changed between every patient or whenever it becomes moist or visibly soiled. When the patient is dismissed after treatment, the mask should be discarded and not worn around the neck, as the contaminated edges can rub against the neck. Touching masks and eyewear during treatments should be avoided to prevent cross-contamination. When eyewear or shields are removed, they should be cleaned and disinfected. To save time, clean replacement eyewear should be readily available while used eyewear is being disinfected. If preferred, goggles that can be autoclaved are available from dental distributors.



Online Fig. 19-8 Remove the mask as shown. Grasp the mask ties or elastic band behind the head instead of grasping the contaminated mask. Before treatment, put on mask and eyewear before washing and gloving hands. After treatment, remove gloves and then eyewear and mask, and wash hands.

Masks with the highest filtration are rectangular, folded types used for surgeries.⁹⁷ Dome-shaped masks are adequate barriers against spatter and are considered effective in preventing HBV and HIV infections;^{7,65} however, they are not adequate to hold back measles, influenza, and other aerosol-borne respiratory viruses or tuberculosis bacteria. To protect against aerosols, the edges of the rectangular mask should be pressed close around the bridge of the nose and face. Masks have been rated according to their porosity and effectiveness.⁹⁷ The claims and test data of mask manufacturers should be consulted and compared before choosing a mask.

Operatory personnel should keep their hair out of the treatment field. Hair can trap heavy contamination that, if not washed away, can be rubbed back from a pillow onto the face at night. Hair must be protected with a surgical cap when the possibility of encountering heavy spatter (e.g., from an ultrasonic scaling device) exists.

Protective Overgarments

An overgarment must protect clothing as well as skin (see [Online Fig. 19-4](#)). Used overgarments should be only minimally handled and laundered or disposed of properly. Overgarments must be changed whenever they become wet or visibly soiled. Operatory clothing is heavily spattered with invisible saliva and traces of blood throughout the day. HBV and many other microbes can live on dry materials for 1 or more days.^{3,14,76,98} The upper surfaces of the wrists and forearms can be contaminated by heavy spatter.⁹ Spatter remains on uncovered arms most of the day if not protected by long sleeves. The large cuffs of the clinic coat sleeves may brush against patient napkins and mouths, become grossly contaminated, and cross-contaminate patients.⁹⁹ Sleeves with knit cuffs that tuck under the gloves are preferable. If not covered, arms must be washed after each patient if any spattering occurred. Most office sinks are not deep or wide enough for effective, routine arm washing.

A simple, lightweight garment that covers the arms and chest up to the neck and the lap when seated may provide adequate protection. Cloth made of cotton or cotton–synthetic fiber similar to isolation garment material may be thick enough to protect skin and street clothing from spatter during most dental treatments. If surgery or other treatment produces splashing that wets a garment, the clothing should be changed as soon as possible, and the skin should be cleaned.

Contaminated garments should not be worn after leaving the clinical area. Such garments can contaminate family members who sort, handle, and launder soiled clothing or may infect young children who may come in contact with adults' clothing (e.g., hugging the parent who has come home from work). Contaminations with HBV, tuberculosis, and respiratory viruses (e.g., respiratory syncytial virus) are of most concern.

Before leaving the clinical area, used overgarments are removed and placed directly into a laundry bag with a minimum of handling or sorting. Guidelines call for managing used clinic garments to avoid handling or sorting (e.g., searching pockets, removing name tags). Persons handling soiled clinical garments must wear protective gloves. Laundering must be provided by the employer.

Laundering with a regular cycle with regular laundry detergent is considered acceptable, following manufacturer's

directions.⁷ Hot water (70°C or 158°F) or cool water containing 50 to 150 parts per million (ppm) of chlorine provided by liquid laundry bleach would provide additional antimicrobial action.^{7,93}

Disposal of Clinical Waste

Infected blood and other liquid clinical waste, except mercury, silver, or other heavy metal chemicals, generally can be poured down a sanitary sewer or drain designated for that purpose. Application of aseptic precautions and cleaning and disinfection of the basin around the drain must be performed. Contaminated materials such as used masks, gloves, blood-soaked or saliva-soaked sponges, and blood-soaked or saliva-soaked cotton rolls must be discarded safely. OSHA regulations presented previously describe the rules and required labels with regard to disposal of sharps and soft waste. OSHA labeling requirements may differ from local protection agency requirements. As pathologic waste, excised tissues require separate disposal and should not be discarded into the trash.

Care must be exercised in bagging medical waste so that injury or direct contact with liquids does not occur, as HIV and HBV can survive beyond a few days in wet blood. Separating needles and sharps into hard-walled, leak-proof, and sealable containers and out of soft trash has been shown to provide adequate safety. Nevertheless, local laws governing waste disposal range from the recommendations of the CDC to regulations requiring stricter management and tracking of waste disposal, usually at an added expense.^{1,7,31} Local city, county, and state regulations should be consulted.

Needle Disposal

The goals with regard to needle disposal are (1) disposing of needles in a hard-walled, leak-proof, and sealable container, which has the OSHA biohazard label; (2) locating the needle-disposal container in the operatory close to where the needle will be used; and (3) avoiding carrying unsheathed contaminated needles or containers in a manner that could endanger others or would allow the needles to be accidentally spilled.³⁴ If approved disposal containers are limited in number, the well-closed container should be moved to where it is needed during cleanup. Local regulations for the disposal of the container should be followed.

Precautions to Avoid Injury Exposure

Pointed instruments without a hollow lumen have minimal capacity to transmit infected blood into a puncture site. The same principles that apply to needles should be reasonably translated and applied, however, to used burs, wires, and sharp instruments from the operatory. Great care should be used in passing instruments and syringes with unsheathed needles to another individual. Sharp and curved ends should be turned away from the recipient's hand. Two-handed resheathing of needles is not permitted. A needle sheath holder or other safety device or technique should be used for the operator to resheath the needle with only one hand.³⁴

Burs should be removed from handpieces when the procedure is finished; if left in the handpiece in a hanger, the bur should be pointed away from the hands and body. Hanging

handpieces upside down in some types of hangers can angle the bur away from the operator. When a cutting instrument must be left in a handpiece, it should be carefully and deliberately rehung.

Overview of Aseptic Techniques

The concept of asepsis is to prevent cross-contamination—all items that are touched with saliva-coated hands must be rendered free of contamination before beginning treatment on the next patient. These contaminated items can be discarded; protected by disposable covers; or removed, cleaned, and sterilized. The clinician should not directly touch what he or she does not want to contaminate. A few simple rules that help avoid wasting costly time and effort between patient appointments are as follows:

During each appointment:

1. Remember, whatever is touched is contaminated.
2. Directly touch only what has to be touched (anticipate your needs).
3. Use one of the following to control contamination:
 - a. Clean and sterilize dental instruments.
 - b. Protect surfaces and equipment that are not sterilized with disposable, single-use covers (barriers). Discard them after every appointment. Use disposable covers on portable items (e.g., curing-lamp handles, amalgam mixers, and plastic air-water syringe tips).
 - c. Use a paper towel, tongs, or plastic bag over gloves to handle equipment briefly or to open cabinets and drawers to get things that were not anticipated during setup.
 - d. Scrub and disinfect noncritical surfaces as well as possible. These include any countertops that cannot be covered (and may collect aerosols or spatter) or things that may be accidentally touched, such as room door handles and light switches. With practice, these areas should not become contaminated.

When consistently practiced, these concepts of asepsis can reduce exposure risks, cross-infection risks, and cleaning and disinfecting numerous items in the operatory between appointments. Good asepsis practice also reduces or eliminates the need to clean or disinfect nonoperatory areas of the dental office because office personnel avoid contaminating these areas. Examples of items found contaminated in studies of dental offices include telephones, faucet handles, switches, cabinet and drawer handles, radiography controls, lamp handles, door handles, charts, and pens.¹⁴ Evidence of potential cross-contamination and cross-infection risks for patients and personnel related to contact with contaminated surfaces was presented at the beginning of the chapter.^{12,14}

With treatment-soiled gloves, the clinician should avoid unnecessary contact with all switches, drawers, dispensers, or surfaces on the unit that need not be touched. The clinician should use the wrist, arm, or paper towel to operate faucet handles and soap dispenser handles that are not automatic. The clinician should wrap in foil or use a paper towel to handle the phone and drawer pulls. When it is necessary to record findings in a patient's chart, the clinician should deglove



Online Fig. 19-9 Specially designed or generic plastic bags are used to cover the chair and unit. Changing bags after each patient is more effective and more rapid than disinfection. Damage to equipment from disinfectants also is avoided. Do not routinely disinfect surfaces that have been covered. (From Bird DL, Robinson DS: *Modern dental assisting*, ed 10, St. Louis, Saunders, 2012.)

and wash hands. If recording electronically, plastic key covers should be used and routinely disinfected.

Single-use plastic bags should be used on the control unit and chair back, foil or small plastic bags on lamp handles, and adherent plastic sheets or a plastic bag on the radiography cone (Online Fig. 19-9). A thin plastic overglove or a gauze or paper towel should be used to avoid contaminating other objects. Foot controls should be used for faucets, dental chair, and radiography button. In addition, light-curing units and amalgamators should be covered with custom-fitting plastic barriers to avoid contamination. Once a day, or as needed, any water-based tuberculocidal disinfectant licensed by the EPA should be used to clean and disinfect other environmental surfaces in the operatory and laboratory.

Operatory Asepsis

Protection of Operatory Surfaces: Rationale, Materials, and Methods

Operatory surfaces that are repeatedly touched or soiled are best protected with disposable covers (barriers) that can be discarded after each treatment (see Online Fig. 19-9).^{11,15,96} Changing the covers eliminates cleaning and disinfecting the surface; saves time, effort, and expense; and can be more protective. White paper sheets (“white newsprint”) are useful for workbenches and operatory surfaces on which dry contaminated materials are placed. For dental unit trays, paper, plastic film, or surgical pack wraps (paper or towels) should cover the entire tray, including edges. Clear-plastic bags are available that fit many chair backs, control units, x-ray equipment, suction handles, and air-water syringe handles (see Online Fig. 19-9).

After each appointment, bags and covers can be discarded and replaced without cleaning and disinfecting the covered equipment items. If the covers come off, become torn, or otherwise allow equipment to become contaminated, the item should be thoroughly cleaned and disinfected before re-covering it for the next appointment.

Preparation of Semi-Critical Items (Attached to the Dental Unit for Reuse) and Noncritical Items (Supporting or Environmental)

Instruments that come in contact with cut tissues or that penetrate tissues are considered critical items that require thorough cleaning and sterilization for reuse.^{1,78,96,100} Many items attached to the dental unit are used intraorally. They are handled by gloved hands coated with blood and saliva or may touch the mucosa. CDC guidelines consider these semi-critical items.^{11,78} Items that are not usually touched during treatments are considered noncritical items.

SEMI-CRITICAL ITEMS

Semi-critical items that touch mucosa are the air-water syringe tip, suction tips, prophylaxis angle, and handpieces. Others (air-water syringe handle, suction hose ends, lamp handle, and switches) are handled or touched interchangeably with treatment instruments that become contaminated with blood and saliva. Semi-critical items must be removed for cleaning and sterilization unless they are disposable or can be protected from contamination with disposable plastic covers. This applies especially to air-water syringe tips.

Semi-critical items should not be merely disinfected. As stated before, they should be covered, cleaned, and sterilized, or they should be discarded. Some bacteria often remain even after the use of the best disinfectant.^{14,62,101} When a cover comes off, or when disinfection is the only recourse, semi-critical items must be scrubbed clean, preferably at the sink, and disinfected. Surface disinfection is inadequate for items with a lumen, such as air-water syringe tips.

NONCRITICAL ITEMS

Noncritical items are environmental surfaces such as chairs, benches, floors, walls, and supporting equipment of the dental unit that are not usually touched during treatments. Contaminated noncritical items require cleaning and disinfection.

One should wear protective utility gloves to clean equipment that cannot be covered. For cleaning and disinfecting environmental surfaces, nitrile latex utility gloves are preferable. Disinfectants can penetrate treatment gloves to irritate covered skin, and these less sturdy gloves are prone to small tears. Uncovered chair arms may become contaminated with spatter and should be covered with a protective barrier or disinfected. Areas of the chair not contaminated by spatter need not be disinfected except for housekeeping purposes. Chair backs and control units are covered to protect control buttons from operator gloved finger contamination and spatter and from the damaging effects of disinfectants, and time for disinfecting is reduced.

DISINFECTANTS

Preferred disinfectants are those that are approved by the Environmental Protection Agency (EPA). Disinfectants also must be active against the *Mycobacterium* species and inactivate polioviruses or coxsackieviruses (because they are non-lipid viruses similar to HBV in resistance), common respiratory viruses, and common bacterial hospital pathogens (e.g., *Staphylococcus* and *Pseudomonas* species). All such disinfectants readily inactivate HIV in 1 to 2 minutes.^{46,77,78,100}

The activity of a disinfectant is reduced by organic debris or blood. Iodines are especially sensitive to the presence of

blood.^{70,102} Most water-based disinfectants are effective in removing dried blood. Alcohols tend to harden whole blood that is dried on surfaces, making the surfaces difficult to clean.¹⁰³ (Alcohols were used to harden and fix blood films on glass slides in hematology laboratories). Disinfectants containing 70% to 79% ethyl alcohol are considered the most effective disinfectants on cleaned surfaces.^{22,70,102}

The chlorine and iodine in some disinfectants can react with or be absorbed by the plastic in some types of dispensing bottles, which must be refilled with fresh solution daily. Manufacturer's directions should be consulted and followed in this regard. Glutaraldehydes at concentrations used for instrument disinfection are too toxic to be used on operator surfaces and take at least 20 minutes to kill the *Mycobacterium* species.

Regarding disinfection, two principles should be remembered: (1) Disinfection cannot occur until fresh disinfectant is reapplied to a thoroughly cleaned surface.^{47,78} (2) Disinfection does not sterilize.^{14,102,104}

Manufacturers specify a time to leave items wet with disinfectant for effective disinfection. Data on kill times should be obtained from the manufacturer. After sufficient time, wet items can be dried with a paper towel.

Step-by-Step Preparation of the Dental Chair, Dental Unit, and Instruments

In addition to being unacceptable for semi-critical items, the disinfectants generally considered most active against microorganisms are the most drying or destructive to plastic chair covers and equipment. This fact validates the use of covers, whenever possible. When covers are used, the effectiveness of the disinfectants becomes less critical, and protecting equipment is easier.

Following are step-by-step standard operating procedures for the preparation of the dental chair, dental unit, and instruments between appointments. (As mentioned earlier, it is unnecessary to disinfect surfaces and items covered with plastic drape after each treatment, unless the plastic cover was torn or came off during treatment.)

1. With gloved hands after the last treatment, remove and invert the chair back cover, discard cotton rolls and other disposable materials into the cover, and discard the cover into the operator trash bin. Remove and discard gloves aseptically.
2. Wash hands with antiseptic hand soap, rinse, and dry or use an accepted alcohol hand rub.
3. Place three paper towels on the seat of the dental chair for later placement of air-water syringe and ends of suction hoses. Don nitrile latex utility gloves.
4. With the used suction tip, clean saliva and debris from the cuspidor trap, if present. Discard the disposable suction tip into the operator trash bin.
5. Remove (unscrew) the resheathed needle from the anesthetic syringe, and discard it with all other sharp disposable items in a sharps container. Using a Stickshield is advised. Remove the anesthetic cartridge before removing the needle to decrease the risk of an occupational needlestick injury. Handling needles without using a protective one-handed capping device and gathering instruments without heavy protective gloves account for most injury exposure incidents.



Online Fig. 19-10 Wear suitable protective gloves to undrape the unit. Remove hoses from their hangers, and lay them on paper towels on the chair. Pull the draping bag off of the control unit so that it will invert. Pull a clean bag over the unit from the front with clean hands and tuck it around the back and bottom. Cover equipment support arms as well.

6. Place any loose sharp instruments and instrument cassettes into a perforated metal basket, and then lower the basket into the disinfectant solution in a covered hard-walled pan. Return the handpieces and the pan of instruments to the cleanup area. Using the handles provided, remove the basket of instruments, rinse, and place into the ultrasonic cleaner.
7. Before handling disinfectant-dispensing bottles, wash the utility gloves (on hands) with antiseptic scrub, rinse, and dry.
8. Spray any used bottles, containers, and tubes with disinfectant, and wipe with a paper towel. Spray again, and leave the items damp with disinfectant as they are put away. Spraying in this manner has been found to be effective.¹⁰² Disinfectant wipes that are available in the marketplace can be used, if any concern exists about breathing in irritating or possibly harmful aerosols from spray disinfectants.
9. Remove the air-water syringe (now minus its removable tip) and suction hoses from the hangers on the control unit. Remove the plastic covers from the hose ends and discard. Lay the air-water syringe and suction hose ends on the paper towels previously placed on the dental chair.
10. Invert, remove, and discard the plastic drapes from the control unit ([Online Fig. 19-10](#)); remove and discard the protective covers from lamp handles and the surface covering from the side table. These disposables may be placed into the large bag and removed from the control unit.
11. For any controls and switches that were not covered, use a disinfectant wipe to wipe the lamp switch and controls that were contaminated. Do not spray control switches. Wipe any contaminated surfaces not previously covered, including the side table, arms of dental chair, contaminated drawer handles, radiographic viewbox switch, and paper towel dispenser. Discard the used disinfectant wipe.
12. Using a second disinfectant wipe, rewet these items, and leave them wet.

13. Spray the outside and inside of the cuspidor, if present, with disinfectant. Use two paper towels to prevent your gloves from contacting the cuspidor while first wiping the outside and then the inside of the cuspidor. Discard the towels. Wipe any overspray of disinfectant from the operatory floor. Discard the towels in the trash bin. Disinfectant wipes could also be used.
14. Spray any contaminated faucet handles, sink countertops, and trash disposal openings with disinfectant, and wipe dry with paper towel. Discard the towel, and re-spray the areas with disinfectant and leave them damp. Disinfectant wipes could also be used.
15. Wash the utility gloves (still on hands) with a strong antiseptic hand scrub or disinfectant cleaner, rinse thoroughly, and dry them with paper towels. Discard the towels into the trash bin. Remove the utility gloves, and re-hang them in the operatory. Wash hands. Contaminated utility gloves can be cleaned and disinfected. Nitrile latex gloves can be autoclaved.

To prepare the unit for the next patient, gloves need not be worn if only the clean surfaces that have been protected with covers are touched. The unit is prepared as follows:

1. Pull a large clear plastic bag cover over the dental control unit from the front, and tuck the excess up under the unit (see [Online Fig. 19-9](#)).
2. Pull another bag down over the chair back; also cover the chair arms.
3. Install the suction and air-water syringe tips. Place a slender bag over each tip, pushing the tip through the end of the bag, then sliding the bag down to cover all of the handle. For the suction tip, wrap autoclave tape at the tip–bag junction to secure the bag against creeping and to prevent contamination of the handle area of the hose ([Online Fig. 19-11](#)). It is usually unnecessary to tape the bag onto the air-water syringe. Press the handles into the forked hangers on the unit that are covered by the plastic bag ([Online Fig. 19-12](#)).
4. Install the sterilized handpieces. A plastic sleeve may be used to cover the motor-end of the low-speed handpiece that is not sterilized (see [Online Fig. 19-9](#)). Re-hang the handpieces. If the plastic film obstructs the electric eye in the hanger, use a small finger to pull out the film when the handle is removed.
5. Set out the materials and instrument packs; open the packs, being careful not to touch the sterilized instruments with bare hands.
6. Seat the patient, and put on a clean mask, eyewear, and gloves.

Protection of Complex Devices Against Contamination

Cameras, light-curing units, lasers, intraoral cameras, computers and air abrasion units are examples of complex devices that must be protected against contamination. They are used in the operatory and cannot be sterilized or readily disinfected. Clear plastic bags of suitable size obtained from plastics or dental supply companies are effective single-use protective barriers.



Online Fig. 19-11 Install the suction tip and cover it with a slender plastic bag. Push the tip through the end of the bag, and continue sliding the bag to cover the handle area of the hose. Wrap a piece of suitable tape at the bag–tip junction, as shown, to secure the bag against creeping and prevent exposing the handle to contamination. After use, the bag comes off with the plastic tip for easy removal and disposal.



Online Fig. 19-12 Replace equipment attached to hoses by using the device to press the loose plastic film into the forked holder.

Procedures, Materials, and Devices for Cleaning Instruments Before Sterilization

According to ADA guidelines and CDC specifications, instruments that touch mucosa or penetrate tissues must be cleaned and sterilized before reuse (Online Box 19-1).^{11,46}

Principles and Procedures for Handling and Cleaning Instruments after Treatment

Instrument cleaning procedures should be designed to be effective, while avoiding risks such as grasping and scrubbing groups of single-ended and double-ended sharp instruments. Instrument grasping and scrubbing are the most exposure-prone tasks encountered after treatments, even when protective utility gloves are worn. Protective utility gloves made of nitrile latex are the most puncture resistant and are obtainable

Online Box 19-1 Do's and Don'ts of Instrument Recycling

Do:

- Wear protective puncture-resistant gloves to handle used instruments.
- Keep instruments wet in an antibacterial solution before cleaning.
- Use an ultrasonic cleaning device.
- Test and maintain the ultrasonic device periodically.
- Use good-quality sterilizer equipment.
- Read the operator's manual, and follow operation instructions for the sterilizer.
- Have sterilizers annually inspected regarding gaskets, timer, valves, and temperature and pressure gauges.
- Use proper water or chemicals to operate, clean, and maintain sterilizer.
- Place only dry instruments in the sterilizer.
- Use a wrap that will be penetrated by the steam or gas used.
- Load the sterilizer loosely; leave air space between large packs.
- Read the sterilizer temperature and pressure gauges daily.
- Use the complete sterilizer monitoring system outlined; use indicators daily and spore tests weekly.
- Keep a record of daily indicators and spore tests.

Don't:

- Place wet instruments into any type of sterilizer unless so instructed.
- Overwrap cloth packs or use impermeable wraps for steam or chemical vapor pressure sterilization.
- Use closed, nonperforated trays, foil, canisters, or other sealed containers in gas or steam sterilizers.
- Overload or cram packs together in the sterilizer.
- Decrease the required time for sterilization.
- Add instruments to a sterilizer without restarting the cycle.
- Sterilize viability control strips supplied with spore tests.

from dental suppliers. These gloves can be washed and wiped with disinfectant or autoclaved after use, as needed. Household utility gloves are not suitable for handling and cleaning sharp instruments. The safest and most efficient instrument cleaning procedures involve ultrasonic cleaning of used instruments kept in a perforated basket or cassette throughout the cleaning procedure.^{22,43,105,106} Protective utility gloves should be worn at all times to safely handle contaminated containers and instruments.

Procedures for Instrument Processing

Instrument cassettes and any loose instruments should be transported to the cleanup area in a perforated metal or plastic basket that can be lowered by its handles into a disinfectant detergent solution contained in a covered hard-walled pan. Organic debris on instruments is likely to reduce the activity of the disinfectant. Soaking used instruments before cleaning primarily keeps fresh debris from drying and also helps soften and loosen any dried debris. Instruments should be left in the basket or cassette while rinsing them well. Next, the instruments in the cassette or basket are moved into an ultrasonic



A



B

Online Fig. 19-13 A commercial ultrasonic cleaner (A) with a rust-inhibiting soaking and cleaning solution (B). (A, Courtesy Midmark Corp., Versailles, OH. B, Courtesy of Certol, Commerce City, CO.)

cleaning device for cleaning (Online Fig. 19-13), rinsed again, and carefully inspected for debris.^{105,106} Tongs should be used to remove any instruments left uncleaned. The debris is removed from these instruments individually, while keeping the hands well protected with utility gloves. Instruments likely to rust should be dipped into a rust inhibitor such as fresh rust-retarding cleaning solution (e.g., solution from Health Sonics, Algonquin, IL). The instruments in cassettes are drained and air dried, or the instruments in the basket are carefully spilled onto an absorbent towel on a tray. Wet instruments can be patted dry with a thickly folded towel. The towels and tray should then be treated as contaminated items. With protective gloves on, the instruments are properly packaged together with internal, and external sterilization indicators suited to the sterilization process are used.¹⁰⁵

Instrument containers are used as specified by the following OSHA regulations:

1. Immediately, or as soon as possible after use, contaminated reusable sharps are placed into appropriate containers until they are properly re-processed. Containers must be puncture-resistant, properly labeled or color coded, and leak-proof on sides and bottom. The

container is covered to transport the instruments to the cleanup area.

2. Reusable contaminated sharps should not be stored or processed in a manner that requires employees (with or without protective gloves) to reach into containers where these sharps have been placed.^{34,45}

When it is necessary to clean the instruments by hand, a suitable brush and a disinfecting cleaner should be used. Severe irritation, infection of unprotected eyes, or both can result from spatter of the disinfectant, detergents, or chlorhexidine gluconate hand cleansers often used to scrub instruments. As mentioned before, hand injury from double-ended instruments is the other main risk.

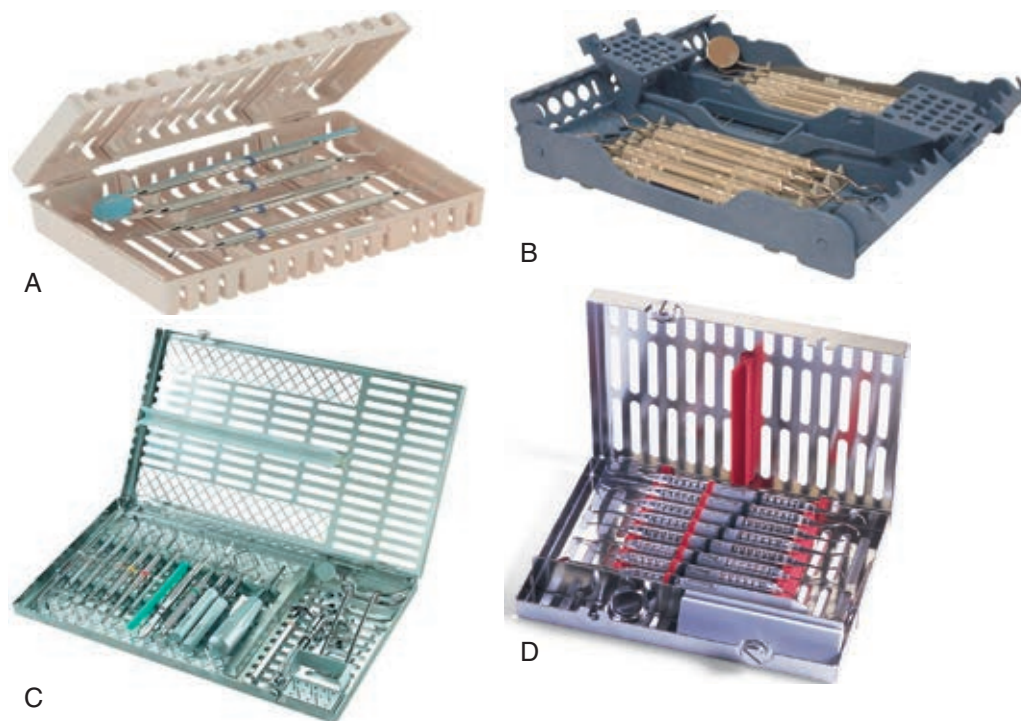
Heavy gloves, eye protection, a mask or a face shield, and a protective garment or apron should be worn as protection against spatter. A long-handled pan-scrubbing brush should be used. The mid-handle portion of only a few instruments should be grasped at a time with fingers and thumb to protect the palm and to rotate the instruments. One should brush away from the self, down into the sink, using at least five strokes per end while rotating them. Attention should be paid to removing visible soil and debris. Rinsing is done with an aerated stream of water to avoid spatter. To remove coatings such as plaster, wax, cement, and impression material, they should be scraped or an appropriate solvent cleaner used. When the cleaning is finished, heavy gloves, disinfectant, and paper towels should be used to clean up the spattered or contaminated surfaces around the sink.

Ultrasonic Cleaners and Solutions

Ultrasonic cleaning is the safest and most efficient way to clean sharp instruments (see Online Fig. 19-13). Burs should be ultrasonically cleaned as well. To contain burs, they can be placed in a fine screen basket, metal tea ball, or bur caddy. Some hinged instruments (e.g., some brands of orthodontics pliers) should not be submerged in ultrasonic or disinfectant cleaning solutions if hinges would corrode or rust. The manufacturer's directions should be followed in this regard.

Ultrasonic cleaning can be nine times more effective than hand cleaning if the ultrasonic device functions properly and is used as directed by the manufacturer.¹⁰⁶ An ultrasonic cleaning device should provide fast and thorough cleaning without damage to instruments; have a lid, well-designed basket, and audible timer; and be engineered to prevent electronic interference with other electronic equipment and office communication systems. Procedures for ultrasonic cleaning are as follows:

1. Observe operating precautions.
2. Operate the tank at one half to three fourths full of cleaning solution at all times. Use only cleaning solutions recommended by the manufacturer of the ultrasonic device. Change solutions, as directed. An antimicrobial cleaning solution is preferable.
3. Operate the ultrasonic cleaner for 5 minutes or longer, as directed by the manufacturer, to achieve optimal cleaning, possibly 1 minute per instrument.
4. Remove coatings such as plaster, wax, cement, and impression material with an appropriate solvent cleaner, and place the instrument(s) and/or impression



Online Fig. 19-14 Examples of cassettes designed to hold instruments while they are cleaned and sterilized. **A**, Steri System Cassette. **B**, E-Z Jett Cassette. **C**, Osung Dental Instrument Cassette. **D**, IMS Signature Series Cassette. (**A**, Courtesy of Dux Dental, Oxnard, CA. **B**, Courtesy of Zirc Company, Buffalo, MN. **C**, Courtesy of Brite Source USA, Chicago, IL. **D**, Courtesy of Hu-Friedy Mfg. Co., LLC, Chicago, IL.)

tray(s) in a beaker in the ultrasonic device. Consult the directions of the ultrasonic device manufacturers or dental product distributors.

- By using a foil test, as described subsequently, verify the performance of the ultrasonic device monthly or when poor performance is suspected. Devices that have fewer than two transducers do not pass the foil test and are not suitable for instrument cleaning.

Performance of ultrasonic devices used without periodic testing and maintenance is often poor.¹⁰⁷

To perform an ultrasonic cleaner foil test, the basket is removed from the device. Solution is added to the tank and the device operated for 5 minutes to expel dissolved gases, as directed by the manufacturer. The depth of the solution and the length (longest dimension) of the tank are measured. A sheet approximately 1 inch more than the depth of the solution in the metal tank is cut from a roll of aluminum foil. The length should be 1 inch less than the length of the tank. The foil is held like a curtain vertically submerged in the solution in the center of the tank approximately 0.5 inch above the bottom. (*Do not immerse fingers.*) Without allowing the edges of the curtain to touch the tank, the device is operated for exactly 20 seconds. On close inspection, every square 0.5 inch of the foil should show small visible indentations or perforations if the ultrasonic device functions properly. The foil test can be performed in the midline, front, and rear areas of the tank to determine uniformity. Labeled foil sheets can be filed to document test results. (This method was adapted from directions of Health Sonics.)

Instrument Containment

Cloth packs, wraps, tubes of nylon film, and commercial paper or plastic bags are suitable for instrument containment if they are compatible with the method and temperature of sterilization. Various kinds of instrument trays and cassettes (Online Fig. 19-14) are manufactured to contain the instruments at chairside, and they can be placed in an ultrasonic cleaner, rinsed, and packaged ready for sterilization. Cassettes provide convenience, safety in handling and cleaning batches of instruments, and maintenance of instrument organization for efficient use.

Sterilization

Dental patients with infections often go undetected. Sterilization provides a method of instrument recycling that can be monitored and documented to show that conditions for control of disease transmission were established. Because most instruments contact mucosa or penetrate oral tissues, it is essential that contaminated reusable instruments be cleaned and sterilized thoroughly by using accepted methods that can be tested and monitored routinely.^{11,46,47} Heat sterilization takes less time compared with high-level sporicidal disinfection, which is required when heat or gas sterilization cannot be used. Sterilization practices were found unreliable in 15% to 31% of dental offices surveyed where routine monitoring was not used to evaluate and maintain correct sterilization performance.¹⁰⁸

The four accepted methods of sterilization are as follows:

1. Steam pressure sterilization (autoclave)
2. Chemical vapor pressure sterilization (chemiclave)
3. Dry heat sterilization (dryclave)
4. Ethylene oxide (ETOX) sterilization

Each method and each commercial modification has specific requirements with regard to timing, temperature, suitable packaging of materials, and kinds of items and materials that can be sterilized safely and effectively.^{29,47,109} Ignoring any of these specifications can prevent sterilization or damage materials or instruments.

It is best to evaluate the office needs, examine various sterilizer capabilities, and then carefully select one or two methods of sterilization. Kinds and sizes of sterilization equipment depend on the treatment instrumentation used in the practice. Stainless steel instruments and mirrors used for operative, endodontic, periodontic, or dental hygiene procedures can be sterilized by any accepted method. High-speed and low-speed handpieces are best autoclaved. Burs (discussed later) can be sterilized safely by dry heat or chemical vapor in a chemiclave or in a gas sterilizer, but they may rust or corrode if not protected from steam in the autoclave. Metal impression trays can be sterilized by any method, but dry heat greater than 345°F (174°C) may remove the soldered handles. Orthodontic pliers of high-quality stainless steel resist corrosion in an autoclave; lower-quality stainless steel found in some pliers must be sterilized by dry heat or chemical vapor. Towels and towel packs of instruments needed for surgery are best sterilized by autoclaving; chemical vapor pressure sterilization does not penetrate cloth effectively. The widest variety of instruments probably would be found in pediatric dentistry, and more than one sterilization method may be required.

A sterilizer is used every day of practice. Therefore, reliable sterilization equipment of proper size and cycle time compatible with needs of the practice should be chosen. Patient load, turnaround time for instrument reuse, size of instrument inventory, instrument variety, and instrument quality all must be balanced against the type and size of sterilizer selected.

Steam Pressure Sterilization (Autoclaving)

Sterilization with steam under pressure is performed in a steam autoclave (Online Fig. 19-15). For a light load of instruments, the time required at 250°F (121°C) is a minimum of 15 minutes at 15 lb of pressure. Time for wrapped instruments can be reduced to 7 minutes if the temperature is increased to approximately 273°F (134°C) to give 30 lb of pressure. Time required for the sterilizer to reach the correct temperature is not included. Bench models may be automatic or manually operated. Manual sterilizers should have a temperature and pressure gauge so that temperatures can be related to corresponding pressure required for sterilization. In contrast to hospital autoclaves, bench models depend on gravity flow to distribute steam throughout the load, rather than first evacuating air from the sterilizer and refilling it with steam. Bench models require more caution against the use of large or tightly packed loads. Steam must enter and circulate around packs easily. Instrument pans or other impermeable instrument containers must be left open so that steam can enter. Except for containers of solutions, all metal items must



Online Fig. 19-15 A steam pressure sterilizer (autoclave). (Courtesy of Midmark Corp., Versailles, OH.)

be dry. Moisture evaporating from instruments can slow the heating process. Sterilization must be tested routinely (see section on [monitors of sterilization](#)).^{11,46}

Advantages of Autoclaving

Autoclaving is the most rapid and effective method for sterilizing cloth surgical packs and towel packs. Other methods are not suitable for processing cloth packs. Automated models are available, although they can be misused; they must be evaluated with a biologic spore test monitoring system.

Disadvantages of Autoclaving

Items sensitive to the elevated temperature cannot be autoclaved. Autoclaving tends to rust carbon steel instruments and burs. Steam seems to corrode the steel neck and shank portions of some diamond instruments and carbide burs.

Autoclave Sterilization of Burs

For autoclave sterilization, burs can be protected by keeping them submerged in a small amount of 2% sodium nitrite solution.^{19,43} Sodium nitrite crystals (not nitrate) can be obtained from distributors of scientific products and chemicals or a pharmacy. Nitrite 20 g (2/3 oz) is added to 1 L of pure

water and stored tightly sealed. After ultrasonic cleaning, burs can be rinsed and placed into any small metal or glass beaker with a perforated lid (e.g., a metal salt shaker). The beaker should be filled with sufficient fresh nitrite solution, with the level of the solution approximately 1 cm above the burs. The container is left uncovered, or a perforated cover is used. The container of burs and fluid is placed into the sterilizer, and a normal sterilization cycle is operated. The fluid from the container is discarded through the perforated lid. Sterile forceps should be used to place the burs into a sterilized bur holder or tray. The burs are stored dry. Before use, any nitrite residue can be wiped away or rinsed off with clean or sterile water, if desired.

Chemical Vapor Pressure Sterilization (Chemiclaving)

Sterilization by chemical vapor under pressure is performed in a chemiclave (MDT Biologic Co, Rancho Dominguez, CA). Chemical vapor pressure sterilizers operate at 270°F (131°C) and 20 lb of pressure. They are similar to steam sterilizers and have a cycle time of approximately 30 minutes. Similar to ETOX sterilizers, they must be used with a prescribed chemical and should be labeled properly to satisfy OSHA's Chemical Hazard Communication Standard. Newer models seem to handle aldehyde vapors well; vapors from older models must be safely vented. Loading cautions similar to those for autoclaving must be used. Water left on instruments loaded into the chamber can prevent sterilization.

Advantages of Chemiclaving

Carbon steel and other corrosion-sensitive burs, instruments, and pliers are said to be sterilized without rust or corrosion.

Disadvantages of Chemiclaving

Items sensitive to the elevated temperature are damaged. Instruments must be lightly packaged in bags obtained from the sterilizer manufacturer. Towels and heavy cloth wrappings of surgical instruments may not be penetrated to provide sterilization. Biologic spore test monitoring strips need to be used routinely to confirm heat penetration of heavy packs before using them (see the section on [monitors of sterilization](#)). Only fluid purchased from the sterilizer manufacturer can be used. Only dry instruments should be loaded, and the door gasket should be checked for leaks to avoid frequent sterilization monitoring failures.

Dry Heat Sterilization Conventional Dry Heat Ovens

Dry heat sterilization is readily achieved at temperatures greater than 320°F (>160°C).⁴⁸ Conventional professional dry heat ovens that have been sold for instrument sterilization have heated chambers that allow air to circulate by gravity flow (gravity convection). Packs of instruments must be placed at least 1 cm apart to allow heated air to circulate. Individual instruments must be heated at 320°F (160°C) for 30 minutes to achieve sterilization.⁴³ Increasing the total time by 50% as a safety factor is recommended. Total time required also depends on the efficiency of the oven based on its size, the size

of the load, and how instruments are packaged. Foil wrap or special nylon bags are used. Approximately 60 to 90 minutes may be required to sterilize a medium load of lightly wrapped instruments in an oven set at a range of 335°F (168°C) to 345°F (174°C). Temperatures vary at least 5 degrees above and below the setting, so a range rather than a specific temperature must be set. Use of a sterilizer not reviewed by the FDA for instrument sterilization or using one inappropriately may result in the dentist being liable for any adverse consequences.

Without careful calibration, more sterilization failures are obtained with gravity convection dry heat ovens than any other type of sterilizer. The only accurate way to calibrate a sterilization cycle in most relatively inexpensive industrial and professional dry heat ovens is by using an external temperature gauge (pyrometer) attached to a thermocouple wire. The other end of the wire is extended inside the oven and tied to an instrument in a centrally located pack to measure its exact temperature. Battery-operated pyrometers are available from scientific supply companies.

Short-Cycle, High-Temperature Dry Heat Ovens

A rapid high-temperature process that uses a forced-draft sterilization chamber (a mechanical convection sterilization chamber that circulates heated air with a fan or blower) is available. It reduces total sterilization time to 6 minutes for unwrapped instruments and 12 minutes for wrapped instruments ([Online Fig. 19-16](#)). These short-cycle, high-temperature dry heat sterilizers operate at 375°F (190°C). The chamber size of one brand is limited to processing about one set of instruments at a time but is more effective for wrapped instruments and may be adapted for a shorter heat disinfection cycle (consult the manufacturer).

Before purchasing a rapid dry heat sterilizer, care must be taken to verify that the sterilizer manufacturer has undergone premarket review by the FDA for its instrument sterilization device. This requirement has been ignored by some clinicians



Online Fig. 19-16 COX Rapid Heat brand rapid heat transfer dry heat sterilizer. (Courtesy of CPAC Equipment Inc., Leicester, NY.)

who have adapted nonprofessional equipment for office use. Legal professionals have begun to anticipate how a jury may view the use of home ovens to sterilize professional treatment instruments. Moderately priced small ovens manufactured for industrial and scientific use by industrial manufacturers (e.g., Blue M Electric Co, Blue Island, IL) are usually more accurate and reliable than ovens designed for home use. Careful calibration with a pyrometer to ensure that instruments reach and maintain sterilization temperatures is imperative. Evidence of FDA review of the equipment for instrument sterilization or legal advice before purchasing and using this type of oven for instrument sterilization should be obtained. Proper, weekly monitoring of all sterilizers, including dry heat ovens, is imperative. Some sterilization monitoring services now refuse to monitor sterilizers that have not undergone premarket review by the FDA.

Advantages of Dry Heat Sterilization

Carbon steel instruments and burs do not rust, corrode, or lose their temper or cutting edges if they are well dried before processing. Industrial forced-draft hot air ovens usually provide a larger capacity at a reasonable price. Rapid cycles are possible at high temperatures.

Disadvantages of Dry Heat Sterilization

High temperatures may damage more heat-sensitive items such as rubber or plastic goods. Sterilization cycles are prolonged at lower temperatures. Heavy loads of instruments, crowding of packs, and heavy wrapping easily prevent sterilization. Cycles are not automatically timed on some models. Inaccurate calibration, lack of attention to proper settings, and adding instruments without restarting the timing are other common sources of error.

Ethylene Oxide Sterilization

ETOX sterilization is the best method for sterilizing complex instruments and delicate materials. The clinician must verify, however, that the sterilizer intended for use has had a premarket review by the FDA for sterilizing handpieces. Automatic devices sterilize items in several hours and operate at elevated temperatures well below 100°C. Less expensive devices operate overnight to produce sterilization at room temperature (Online Fig. 19-17). Both types meet OSHA requirements. Porous and plastic materials absorb gas and require aeration for 24 hours or more before it is safe for them to contact skin or tissues. Units with large chamber sizes hold more instruments or packs per cycle; however, they are expensive. Some chamber designs or sizes are better suited to accept stacks of instrument trays. Manufacturers should be consulted to obtain detailed information about these sterilizers. Consult infection control texts or dental product distributors.

Boiling Water

Boiling instruments in water does not kill spores and cannot sterilize instruments. Heat can reach and kill blood-borne pathogens, however, in places that liquid sterilants and disinfectants used at room temperature cannot reach. Boiling is a



Online Fig. 19-17 Room temperature ethylene oxide sterilizer. (Courtesy of Anderson Products Inc., Haw River, NC.)

method of high-level disinfection that has been used when actual sterilization cannot be achieved (e.g., in case of a sterilizer breakdown).¹⁰⁰ Well-cleaned items must be completely submerged and allowed to boil at 98°C to 100°C (at sea level) for 10 minutes. Great care must be exercised to ensure that instruments remain covered with boiling water the entire time. Simple steaming is unreliable. Pressure cooking, similar to steam autoclaving, is preferable and would be required at high altitudes.

New Methods of Sterilization

Various new methods of sterilization are under investigation and development. The microwave oven has major limitations for sterilizing metal items, including damage of the machine caused by the metal and the inability to reach all sides of the instruments. Research efforts to overcome such limitations are ongoing. UV light is not highly effective against RNA viruses such as HIV and is not effective against bacterial spores.^{50,110} Incomplete exposures of all surfaces and poor penetration of oil and debris are other limitations. UV irradiation may be useful for sanitizing room air to help control tuberculosis bacteria.¹⁰ One valuable guide to whether a commercial device is an effective sterilizer is determining whether the FDA would find it equivalent to other effective and proven devices now in common use. Before purchasing any medical device in question, the clinician should require the manufacturer to provide documentation of FDA premarketing review.

Monitors of Sterilization

Sterilization assurance not only protects patients from cross-infections but also protects personnel from the infections in patients. Effective instrument sterilization is ensured by routine monitoring of instrument sterilization, which has

become a standard of care. Monitoring services are provided by most major schools.

In the microbiology literature, sterilization is defined as killing all forms of life, including the most heat-resistant forms, that is, bacterial spores. For instruments that can penetrate tissues, sterilization provides control of spore-forming tetanus and gas gangrene species and all pathogens borne by blood and secretions. For instrumentation used in body cavities that routinely touch the mucosa, sterilization provides a margin of safety for ensuring destruction of HBV, mycobacteria, and other pathogenic bacteria and viruses that can be involved in cross-infections.

Weekly sterilization monitoring of highly efficient automated sterilizers in hospitals has been mandated for many years by the Joint Commission of Accreditation of Hospitals (Chicago, IL), an organization formed by the profession to monitor and accredit its own performance. Many state examining or disciplinary boards now have provided that type of regulation. In dental offices, sterilization must be monitored weekly with biologic spore tests using heat-resistant spores and color-change, process-indicator strips in each pack (internal and external).^{1,11,46} Documentation of routine monitoring in a daily-entry sterilization log makes it possible to confirm the efficient performance of the sterilizer operator and proper functioning of the equipment. Problems thus can be identified and corrected. Evidence of effective sterilization also is available when unavoidable localized or systemic post-treatment infections occur and instrument sterilization may be questioned. Sterilization monitoring has five components: (1) mechanical monitoring, (2) chemical indicator strip in each pack, (3) external sterilization indicator on the outside of each pack, (4) weekly biologic spore test, and (5) documentation log.

Mechanical Monitoring

Each sterilized load must be mechanically monitored to document time, temperature, and pressure. Many sterilizers have a printout tape that does this automatically. Otherwise, the clinician manually observes the maximum temperature and pressure and documents the data in a log.

Chemical Indicator Strips

Chemical indicator strips provide an inexpensive, qualitative monitor of sterilizer function, operation, and heat penetration into packs. The clinician places one of the inexpensive color-change indicator strips into every pack. Chemicals on the strip change color slowly, relative to the temperature reached in the pack. As soon as the pack is opened, the strip can immediately identify breakdowns and gross overloading. The strip is, however, not an accurate measure of sterilization time and temperature exposure.

External Sterilization Indicators

External sterilization indicators, including tapes and bags, are marked with heat-sensitive dyes that change color easily on exposure to heat, pressure, or sterilization chemicals. Such heat-sensitive markers are important to identify and distinguish the packs that have been in the sterilizer from those that have not. Used alone, these indicators are not an adequate

measure of sterilization conditions. Sterilization is task dependent as much as time and temperature dependent. Packs should always be dated and rotated.

Biologic Monitoring Strips

A biologic monitoring spore test strip is the accepted weekly monitor of adequate time and temperature exposure. Spores dried on absorbent paper strips are calibrated to be killed when sterilization conditions are reached and maintained for the time necessary to kill all pathogenic microorganisms. Additionally, any pack containing an implantable device must be biologically monitored. An assistant processes a spore strip in a pack of instruments in an office sterilizer each week. Tests can be evaluated in the office. By sending the strip to a licensed reference laboratory for testing, however, the dentist obtains independent documentation of monitoring frequency and sterilization effectiveness. In the event of failure, such laboratory personnel provide immediate expert consultation to help resolve the problem.

Documentation Log

In a log, a single, dated, initialed indicator strip is attached to a sheet or calendar for each workday, followed by a weekly spore strip report. The log provides valuable sterilization documentation. Dated sterilized instrument packs, bags, and trays provide the final evidence of the sterilization program.

Liquid Sterilants and High-Level Disinfectants

Liquid sterilants can kill bacterial spores in 6 to 10 hours. These sterilants are high-level disinfectants and are EPA registered. Sterilants used for high-level disinfection of items for reuse are glutaraldehydes at 2% to 3% concentrations. Repeated use greater dilutions are not advisable.

Organic matter and oxidation reduce the activity of reused disinfectant baths. Placing wet items into disinfectant trays dilutes the solution. Despite reuse claims of several weeks' duration, studies have shown that disinfectants in heavy use often lost activity during the second week.¹¹¹ Glutaraldehydes are irritating, are sensitizing to skin and respiratory passages, and can be toxic as indicated in manufacturers' safety data sheets.⁷⁸ Trays should be kept tightly covered in a well-vented area. Use of 2% or greater glutaraldehyde solutions to wipe counters or equipment (e.g., dental unit and chair) should be avoided. Most glutaraldehydes require 20 minutes to kill tuberculosis bacteria, in contrast to some synthetic phenol complexes and alcohols, which act in 10 minutes or less and are much less toxic.

Uses of High-Level Disinfection

According to the CDC, instruments that penetrate tissues or contact mucosa are termed critical or semi-critical and require cleaning and heat or gas sterilization before reuse.^{5,11,78} Few, if any, instruments now exist that cannot be heat sterilized. High-level disinfection is used mainly for plastic items that enter the mouth and that cannot withstand heat sterilization. Plastic cheek retractors, photographic mirrors, and similar heat-sensitive devices should be replaced with metal types that

can be heat sterilized. Disinfection for 20 to 90 minutes in glutaraldehyde germicides is inappropriate for instruments used in the mouth. Most require 6 or more hours for sterilization. Liquid sterilants cannot process pre-packaged instruments or be completely monitored with biologic indicators. Prophy cups should be discarded and never disinfected for reuse. Used anesthesia carpules and anesthesia needles must be discarded after a patient appointment and never be disinfected or heat sterilized for reuse.

Types of Instruments and Sterilization Methods

Periodontal, restorative, and endodontic instruments are readily processed by autoclave or chemical vapor pressure sterilization. Carbon steel instruments and burs, if dried well before sterilizing, are best sterilized by dry heat and chemical vapor pressure sterilizers because these methods reduce the risk of rust.

Dental Control Unit Water Systems and Handpiece Asepsis

The high-speed handpiece is one component of a complex system of instrumentation operated by the dental operatory master control unit. Within the head of the handpiece and supported by delicate bearings, a turbine assembly holds and rotates the cutting instrument at the speeds preferred for tooth preparation. The handpiece is attached by flexible plastic lines to the dental unit that controls air and water supplied to the handpiece. A small orifice located below the neck of the handpiece near the bur supplies either a jet of air to blow away cutting debris or an air-water spray emitted from the same orifice to lubricate and clean the cutting site; this spray also cools the cutting bur.

These components constitute a complex system that is vulnerable to several unique kinds of contamination by and through the handpiece. Oral fluid contamination problems of rotary equipment, especially the high-speed handpiece, involve (1) contamination of handpiece external surfaces and crevices, (2) turbine chamber contamination that enters the mouth, (3) water spray retraction and aspiration of oral fluids into the water lines of older dental units, (4) growth of environmental aquatic bacteria in water lines, and (5) exposure of personnel to spatter and aerosols generated by intraoral use of rotary equipment.^{9,43,57,112,113}

If not controlled, external and internal contamination of this equipment by oral fluids holds infection potentials for dental patients. Even sterilization of handpieces cannot control contamination related to water spray retraction and bacterial colonization of water lines that holds infection potentials for immunocompromised patients.

Handpiece Surface Contamination Control

Blood and saliva contaminate the surfaces of handpieces during various dental treatments. Irregular surfaces and especially crevices around the bur chuck are difficult to clean and disinfect, especially by briefly wiping with a disinfectant-soaked sponge. Submersion of a high-speed handpiece in a high-level disinfectant has not been an option accepted by

manufacturers. In tests, thorough scrubbing and applying the best disinfectants to inoculated smooth handpiece surfaces reduced numbers of simple test bacteria but did not completely eliminate them.¹⁰⁴ Only sterilization can accomplish complete infection control of handpiece surfaces.

Turbine Contamination Control

Contaminated oral fluids may be drawn back into the turbine chamber by negative pressure created by a Venturi effect during operation or when the turbine continues to spin whenever the drive air is stopped. Oral fluids also may enter around worn bearing seals or be aspirated into the vent holes in the top of older hand-chuck-operated handpieces or possibly into the air-water spray orifice that communicates with the turbine chamber in some handpieces. The question is whether debris that contains viable microbes in the turbine chamber may be vented from holes in the top of the turbine chamber during the next treatment, as indicated by some investigators.^{41,59,114}

Although turbine contamination can be shown experimentally under extreme conditions on a laboratory bench, it is not clear under what conditions this may occur during clinical treatments, and air-driven high-speed handpieces have not been clearly implicated in this manner of cross-infection. Cross-contamination potentials of water-driven handpieces that have been used in a hospital have been shown more easily.²⁰

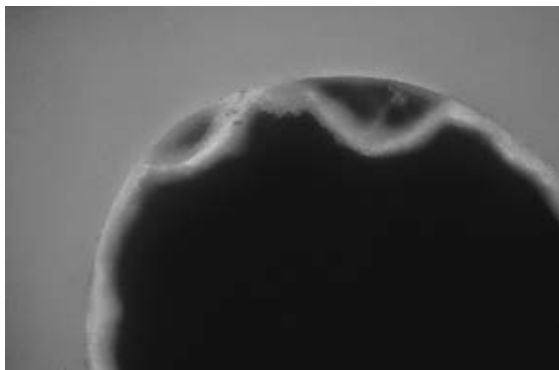
Water Retraction System Correction

Dental unit water control systems made before the mid-to-late 1980s used water lines that easily expanded when air-water spray was used and gradually contracted when water pressure was relieved. Handpieces had an annoying tendency to continue to drip immediately after use. To overcome the problem in those units, a device was installed that retracted water in the line whenever the spray was stopped. However, more than just water could be retracted. After use, oral bacteria have been readily recovered from water samples obtained from the handpieces and water lines of those older dental units.^{59,115}

Agencies recommend correcting water retraction by placing a one-way check valve in the water line.^{5,48,109} Check valves, however, clog and fail. Systems should be tested monthly, if not weekly, to verify lack of water retraction.¹¹³ A simple, inexpensive water retraction testing device is available from major dental supply companies that takes only approximately 1 minute.⁵⁹ The industry also has responded to correct the retraction problem. Since 1988, nearly all manufacturers have produced dental control units that simply cut off the water spray without retraction. The best solution for older dental control units is to replace them with newer units that do not retract unless the older units can be overhauled.^{11,59,113}

Inherent Water System Contamination

Microbes exist in the dental unit water line as free-floating bacteria and as a sessile form known as biofilm. The microorganisms in the biofilm produce a protective polysaccharide matrix that provides them a mechanism for surface attachment and retention to the water line.^{116,117} This matrix, which can be 30 to 50 mm thick, affords the biofilm flora resistance to antimicrobial agents on the order of 1500 times greater than



Online Fig. 19-18 Magnification of cross-section of biofilm formation in dental unit waterline. (From Bird DL, Robinson DS: *Modern dental assisting*, ed 10, St. Louis, Saunders, 2012. Courtesy of Dr. Shannon Mills.)

normal free-floating bacteria. Because of this resistance to antimicrobial agents, when the biofilm is established, it is difficult to remove.

Bacterial growth in biofilms on the inner walls of dental unit water lines (Online Fig. 19-18) is a universal occurrence unless steps are taken to control it.¹¹⁶ Counts of bacteria that are shed from the biofilms into water of the dental unit may range from thousands to hundreds of thousands of bacteria per milliliter.^{112,118-120} This bioload could be compared with bacterial counts of some foods (e.g., juices, milk, yogurt) except that the bacterial types present are not carefully controlled. The main inhabitants are opportunistic, gram-negative, aquaphilic bacteria. Similar species are found in biofilms that form in swimming pools or wherever nonsterile water remains in prolonged contact with habitable surfaces. The bacteria may include atypical mycobacteria, pseudomonas, and possibly *Legionella* bacteria, which can present an infection risk to immunocompromised individuals.^{4,111,121,122} Flushing or sterilizing high-speed handpieces cannot be expected to overcome this potential source of contamination of patients and personnel that extends throughout the dental unit water system.

The threat of biofilm in dental unit water lines to public health has not been established. As the characteristics of the population change, however, the link between biofilm bacteria and infection may be verified. The CDC has recommended that dental unit treatment water contain less than 500 colony-forming units (cfu) per milliliter of bacteria.¹ Suggested mechanisms to accomplish this goal of 500 cfu/mL include use of microbial point-of-use filters and independent water systems. The uses of biocide solutions to treat the water lines overnight and as a continuous addition to the treatment water also have been investigated.^{117,123,124}

Although much work currently is being done in the area of biofilm and dental unit water line contamination, care has to be exercised in selecting the system to control the biofilm. Clean water reservoir systems combined with disinfection or sterilization of equipment downstream have been developed by several companies (Online Fig. 19-19).^{62,119}

Disinfectants such as an iodophore or diluted sodium hypochlorite that are used to clean the system must be flushed out with clean, boiled, or sterile water before using the system. The handpiece always must be removed before disinfecting the system because 0.5% sodium hypochlorite solution and other



Online Fig. 19-19 A water reservoir can provide uncontaminated water to the syringe and to cool the high-speed bur if the reservoir and water lines downstream are disinfected regularly. (Courtesy of A-DEC Inc., Newberg, OR.)

strong chemicals would damage the high-speed handpiece and other metal products. Highly diluted biocides that are used continuously in the treatment water must be researched thoroughly because some of them can decrease composite bond strengths to enamel and dentin.^{69,125} As stated earlier, when biofilm is generated, it can be difficult to remove. Educating dental personnel and periodically monitoring compliance with procedures is paramount for success in preventing dental unit water line contamination.¹¹⁶

Control of Contamination from Spatter and Aerosol

Valid concerns exist regarding contamination from spatter and aerosol created by rotary equipment. Operating this equipment in the mouths of patients spatters oral fluids and microorganisms onto the attending clinical personnel, and aerosols can be inhaled. Aerosolization of mycobacteria that cause pulmonary tuberculosis (*M. tuberculosis*) always has been a concern, although an infectious patient coughing in the waiting room or operatory is much more likely to infect others.¹⁰ The rubber dam and high-volume evacuation are important and helpful methods for reducing exposure to contamination.^{42,44} High-volume evacuation can be 80% effective in reducing aerosol contamination. Complete elimination of airborne contamination, however, is impossible unless some method of continuous air purification can be used. Without the universal use of personal barriers, drapes, or effective cleanup procedures, personnel and patients can be subjected to oral fluid-borne contamination.

Sterilization of Handpieces and Related Rotary Equipments

Prophy angles, latch angles, burs, and rotary stones used in the mouth must be cleaned and sterilized for reuse. All such items are readily sterilized by three or more methods of sterilization. Carbon steel burs require special protection in the autoclave (see the section on [sterilization of burs by autoclaving](#)). Handpieces are semi-critical instruments that require

sterilization.^{11,46} Few brands now exist on the market that cannot be routinely autoclaved. Sterilization of handpieces must be monitored and documented. The motor end of the attached low-speed handpiece can be covered by pulling a disposable, single-use, slender plastic bag up over it and pushing (popping) the handpiece through the sealed end of the bag so that the bag covers the motor end and part of the hose (see Online Fig. 19-11). If the handpiece cannot be sterilized, the motor-end is scrubbed and disinfected for each reuse.

Steam Sterilization of Handpieces

Autoclave sterilization of handpieces is one of the most rapid methods of sterilization. If proper cleaning and lubricating are performed as prescribed by the manufacturer, the usefulness of the instruments can be maintained with regular autoclaving. Fiberoptics tend to dim with repeated heat sterilization in several months to a year, apparently owing to oil residue and debris baked onto the ends of the optical fibers. Cleaning with detergent solution and wiping ends of optics with alcohol or other suitable organic solvents may prolong use before factory servicing. Manufacturers continue to improve the methods of preparing handpieces for sterilization. The manufacturer should be consulted for current advice and warnings.

Other Methods of Handpiece Sterilization

Chemical vapor pressure sterilization recommended for some types of handpieces apparently works well with ceramic-bearing handpieces, but it may impair others. One always must obtain the handpiece manufacturer's recommendations. ETOX gas is the gentlest method of sterilization used for handpieces. Internal and external cleaning is important. Otherwise, preparation of handpieces before sterilization is not as critical because no heat is involved. In some types of ETOX sterilizers, gas seems to penetrate high-speed handpieces. Oil left in handpieces, however, can impair sterilization. Premarket review of the sterilizer and approval from the FDA for sterilizing handpieces must be confirmed with the manufacturer.

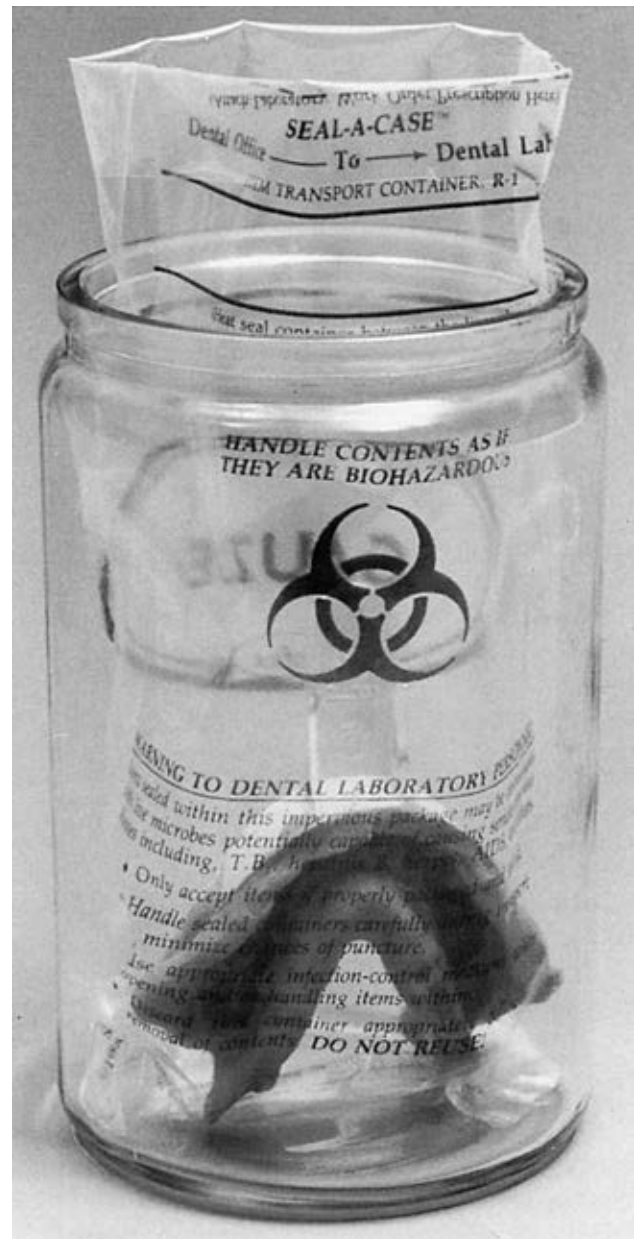
ETOX processing takes the handpiece out of circulation for several hours or overnight. Some practitioners have purchased an adequate number of low-cost handpieces to treat a maximum number of their patients per day and then use overnight ETOX sterilization. This approach may be effective with sufficient handpiece cleaning and disassembly. The FDA may not agree, however, with use of certain types of ETOX sterilizers for sterilizing handpieces. Further research on the effectiveness and any limitations of ETOX handpiece sterilization still may be needed. (Consult the manufacturer.) Dry heat sterilization of handpieces is generally not recommended.

Infection Control for Impressions and Related Registrations Factors in Making Impressions and Associated Registrations to be Sent to a Remote Laboratory

Precautions are required for infection control in making impressions and associated bite registrations. Universal barrier protection for personnel against contamination from mucosa, saliva, and blood by use of adequate PPE such as gloves, mask,

and appropriate overgarment should be ensured. Before making the impression and associated bite registrations, clean, gloved hands should be used to dispense as many materials and disposable items as possible. This avoids contaminating the containers. Wiping material containers with a disinfectant after the procedures is the least satisfactory, but adequate, measure. An EPA-approved tuberculocidal disinfectant is considered satisfactory.

For infection control, custom resin trays for impressions made with nonaqueous rubber impression materials are used once and then discarded. Likewise, stock trays are used only

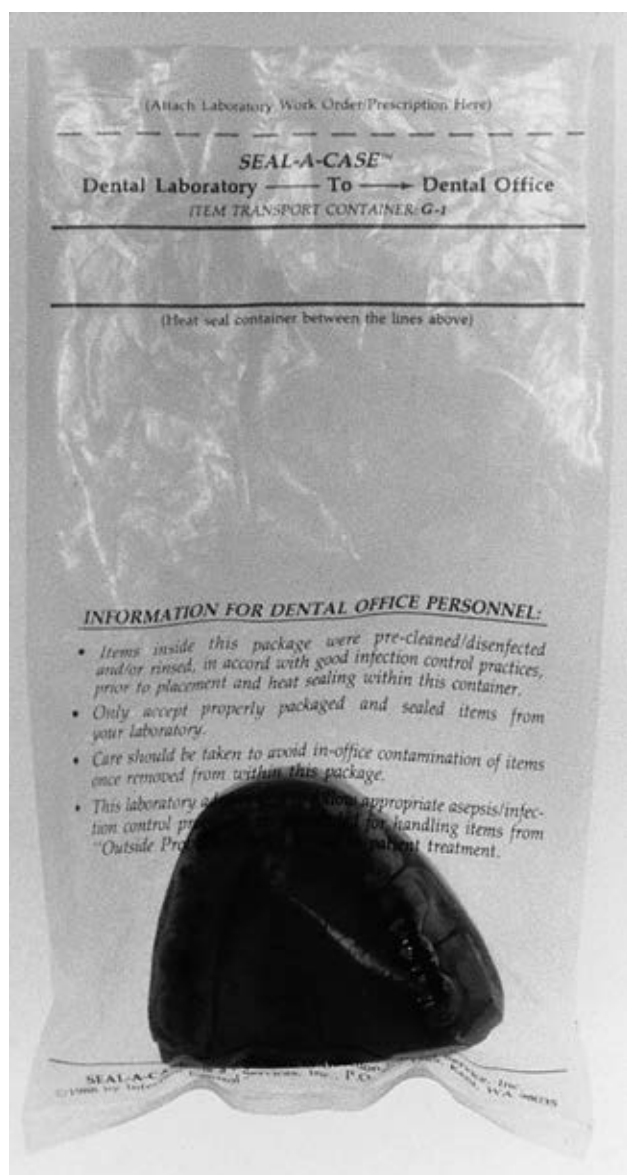


Online Fig. 19-20 The dentist or the dental assistant prepares a potentially infectious impression for transport (to remote laboratory or to onsite laboratory) by rinsing the impression and placing it in a biohazard-labeled plastic bag without contaminating the bag's outer surface.

once and discarded. The tray size is indicated on the patient's chart to eliminate further try-ins.

Concepts for Transporting Impressions and Associated Registrations to a Remote Laboratory

Transport of impressions and associated bite registrations to a remote laboratory is regulated by OSHA's specifications for handling and transporting specimens of blood or other potentially infectious materials: "Potentially infectious materials shall be placed in a container which prevents leakage during collection, handling, processing, storage, transport, or shipping (to the laboratory). Labeling or color coding is required when such specimens/containers leave the facility."^{34,127} Controversy exists over two choices that may be used for preparing a potentially infectious item for transport: (1) Send it well



Online Fig. 19-21 The laboratory disinfects the appliance and then transports it in a heat-sealed bag to the dentist.

cleaned (rinsed) and undisinfected in a biohazard-labeled, heat-sealed, plastic bag, or (2) debride, clean (rinse), and adequately disinfect it, place it in a sealed transport bag labeled with the precautions taken, and assume responsibility for the aseptic condition of the item. In either case, most laboratories disinfect the item (a second time in the second choice) to ensure protection of laboratory personnel. Disinfecting twice wastes time, and multiple exposures to disinfectant should be avoided.¹⁰¹ The National Association of Dental Laboratories recommends disinfecting all items received from the dental office and disinfecting all appliances before shipping them from the laboratory.¹²⁷

Inexpensive, biohazard-labeled, heat-sealable bags are commercially available in various sizes made of sturdy clear plastic, and they are stamped with warnings to transporters and personnel (Online Fig. 19-20). The U.S. Postal Service also has specifications for double, leak-proof packaging and external labeling of such packaging if contaminated items must be sent through the U.S. Postal Service. Similar bags are available for returning finished items to the office. They have no biohazard labels, but provide stamped instructions in green lettering advising office personnel that the contents are precleaned and disinfected and to handle the enclosed items appropriately for delivery to the patient (Online Fig. 19-21). Generic, heat-sealable bags are available, but these must be labeled appropriately.

Summary and Other Information Sources

It is not possible to provide all the details on disease updates, tests, vaccines, barriers, standard operating procedures, sterilization methods, and equipment in one chapter, even one as comprehensive as this. Infection control and auxiliary personnel are referred to other, more detailed literature and texts provided in the reference list and are advised to attend continuing education programs to expand and update their infection control information.^{11,46,85,86,96,107,126}

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Pain Control for Operative Dentistry

Aldridge D. Wilder, Jr.

Pain Control

Historically, the public has associated dental treatment with pain. This association is no longer valid because techniques for the elimination of pain, including atraumatic injection, have been available for years and are essential to a successful dental practice. Local anesthesia for operative dentistry must be profound, often to depths required for pulpal anesthesia. The following information, if understood and practiced, should eliminate pain associated with dental procedures. For additional information the reader is referred to *Malamed's Handbook of Local Anesthesia*.¹

Local Anesthesia

Injection is used to achieve local anesthesia in restorative dentistry. The administration of local anesthesia to all tissues in the operating site is recommended for most patients to eliminate pain and reduce salivation associated with tooth preparation and restoration. To administer effective anesthesia, the dentist must have a thorough knowledge of the patient's physical and emotional status and an understanding of the effects of the drug to be injected and the advantages and disadvantages of adding vasoconstrictors.

A *therapeutic dose* of a drug is the smallest amount that is effective when properly administered and does not cause adverse reactions. An *overdose* of a drug is an excessive amount that results in an overly elevated local accumulation or blood level of the drug, which causes adverse reactions. The normal healthy patient can safely receive five to eight cartridges of anesthetic per appointment. Each 1.8-mL cartridge contains anesthetic, with or without a vasoconstrictor (e.g., lidocaine 2% [anesthetic] with epinephrine 1:100,000 [vasoconstrictor], lidocaine 2% plain [no vasoconstrictor]). The number of permissible cartridges increases as body weight increases. According to Malamed, the maximum recommended dose of 2% lidocaine with epinephrine 1:100,000 is 4.4 mg/kg, or 2 mg/lb, to an absolute maximum of 300 mg ([Online Table 20-1](#)).¹ [Online Tables 20-1 and 20-2](#) will help calculate the

maximum dose for a specific agent depending on the weight of the patient. These dosages are averages, however, and the dentist must be alert to adverse systemic effects when injected dosages approach the recommended limits.¹

Local anesthetics have different durations of action for pulpal and soft tissue anesthesia. Pulpal (deep) anesthesia varies from 30 to 90 or more minutes. Soft tissue anesthesia varies from 1 to 9 hours, depending on the specific agent and whether or not a vasoconstrictor is included. Local anesthetics are selected on the basis of the estimated length of the clinical procedure and the degree of anesthesia required ([Online Box 20-1](#)). Two (or more) anesthetic agents can be administered when needed. The total dose of both anesthetics should not exceed the lower of the two maximum doses for the individual agents. Anesthetics also are available in amide and ester types. Hypersensitivity and allergic reactions in affected patients are much less frequent with the amide type of local anesthetic.¹

Patient Factors

CARDIOVASCULAR SYSTEM

Before administering any drug, the condition of the cardiovascular system (heart and blood vessels) must be assessed. At minimum, blood pressure, heart rate, and rhythm should be evaluated and recorded for all patients. According to the latest guidelines, patients with a systolic pressure less than 160 mm Hg and a diastolic pressure less than 100 mm Hg (stage 1 hypertension) are good candidates for all dental procedures. Patients with blood pressure consistently greater than the aforementioned numbers (stage 2 hypertension) should be referred to their physicians, particularly if the elevation is greater than 20 mm Hg.² Malamed suggested that any resting patient with a pulse rate less than 60 beats per minute (beats/min) or greater than 110 beats/min be questioned further. Athletes in good physical condition may have a lower heart rate, but without this information, the lower heart rate may indicate a heart block. Additionally, five or more “missed beats” (premature ventricular contractions) per minute with no obvious cause is an indication for medical consultation.

Online Table 20-1 Maximum Recommended Dosages (MRDs) of Local Anesthetics Available in North America

Local Anesthetic	MANUFACTURER'S AND FDA (MRD)		
	mg/kg	mg/lb	MRD, mg
Articaine With vasoconstrictor	7.0	3.2	None listed
Bupivacaine With vasoconstrictor	None listed	None listed	90
With vasoconstrictor (Canada)	2.0	0.9	90
Lidocaine With vasoconstrictor	7.0	3.2	500
Mepivacaine No vasoconstrictor	6.6	3.0	400
With vasoconstrictor	6.6	3.0	400
Prilocaine No vasoconstrictor	8.0	3.6	600
With vasoconstrictor	8.0	3.6	600

CALCULATION OF MILLIGRAMS OF LOCAL ANESTHETIC PER DENTAL CARTRIDGE (1.8 ml CARTRIDGE)

Local Anesthetic	Percent Concentration	mg/ml	× 1.8 ml = mg/Cartridge
Articaine	4	40	72*
Bupivacaine	0.5	5	9
Lidocaine	2	20	36
Mepivacaine	2	20	36
	3	30	54
Prilocaine	4	40	72

MRD, Maximum recommended dose.

*Cartridges of some drugs in the United States read, "1.7 ml. each" The actual volume of all local anesthetic cartridges is approximately 1.76 ml.

(From Malamed SF: *Handbook of local anesthesia*, ed 6, St. Louis, 2013, Mosby.)

Patients with valvular heart disease or a predisposition to bacterial endocarditis should have prophylactic antibiotics prescribed before dental treatment; the American Heart Association defines the recommended regimen for these antibiotics.³

Overdose of any vasoconstrictor causes increased blood pressure, elevated heart rate, and possible dysrhythmias. These symptoms also may occur if a retraction cord treated with epinephrine is applied to abraded gingiva, which would result in the rapid uptake of the drug into the circulatory system. With careful operative dentistry, the gingiva should be minimally abraded, even in subgingival tooth preparations.

Online Box 20-1 Approximate Duration of Action of Local Anesthetics*

Short Duration (Pulpal anesthesia approximately 30 minutes)

Mepivacaine, HCL 3%
Prilocaine, HCL 4% (by infiltration)

Intermediate Duration (Pulpal anesthesia approximately 60 minutes)

Articaine, HCL 4% + epinephrine 1:100,000
Articaine, HCL 4% + epinephrine 1:200,000
Lidocaine, HCL 2% + epinephrine 1:50,000
Lidocaine, HCL 2% + epinephrine 1:100,000
Mepivacaine, HCL 2% + levonordefrin 1:20,000
Mepivacaine, HCL 2% + epinephrine 1:200,000
Prilocaine, HCL 4% (via nerve block only)
Prilocaine, HCL 4% + epinephrine 1:200,000

Long Duration (Pulpal ≥90 minutes) anesthesia approximately 90+ minutes

Bupivacaine 0.5% + epinephrine 1:200,000

*These anesthetics all are from the amide category.
(From Malamed SF: *Handbook of local anesthesia*, ed 6, St. Louis, 2013, Mosby.)

CENTRAL NERVOUS AND RESPIRATORY SYSTEMS

The central nervous system (CNS) is more easily affected by overdose of injected anesthetic drugs compared with the cardiovascular system. Anesthetics depress the CNS, but when administered properly for local anesthesia, little or no clinical evidence of depression is encountered. At minimal to moderate overdose levels, depression is manifested in excitation (e.g., talkativeness, apprehension, sweating, elevated blood pressure and heart rate, elevated respiratory rate) or drowsiness. At moderate to high overdose levels, tonic-clonic seizure activity may occur, followed by generalized CNS depression, depressed blood pressure, reduced heart rate (<60 beats/min), depressed respiratory rate, and respiratory arrest. With lidocaine and procaine, the usual progression of excitatory signs and symptoms described previously may not be seen, and the first clinical evidence of overdose may be mild sedation or drowsiness.¹ The respiratory system is not affected by properly administered therapeutic doses of anesthetic drugs. The system may, however, be depressed and arrested by CNS depression resulting from overdose.

ALLERGY

Malamed stated that documented, reproducible allergy is an absolute contraindication for administration of local anesthetic.¹ When a patient reports a history of "sensitivity" or "reaction" to an injected dental anesthetic, the dentist must believe the patient until further investigation disproves the patient's claim. Anaphylactic shock from an allergic reaction can be immediate and life threatening. Fast injection and intravascular injection of anesthetics are reasons for

allergy-like reactions reported by patients. Some patients have proven allergy to bisulfite, an antioxidant used in anesthetic cartridges as a preservative for the vasoconstrictor.¹

Any special condition of the patient should be recorded in the chart. The health status of the cardiovascular system, CNS, respiratory system, liver, kidneys, and thyroid gland should be noted, as well as the patient's age, allergies, and pregnancy status. A medical history form must be completed and signed by the patient.

Benefits

COOPERATIVE PATIENT

When a local anesthetic appropriate for the procedure is properly administered, patient anxiety and tension should be minimal. The appreciation and trust of the patient for the dentist (and dental assistant) are expressed in a more relaxed and cooperative attitude. Physically and emotionally, the patient and the dentist benefit from a relatively calm environment.

SALIVATION CONTROL

Saliva control is a primary reason for the use of profound anesthesia in most patients. For years, it has been observed that complete anesthesia of all tissues (teeth and gingival tissues) in the dental operating site results in a marked reduction of salivation.⁴ Sometimes, a tooth is not sensitive and does not require anesthesia. If all other sensations from the operating site are eliminated, however, salivation is controlled.

HEMOSTASIS

The term *hemostasis*, as used in operative dentistry, refers to the temporary reduction in blood flow and volume in tissue (ischemia) where a vasoconstrictor is used. The alpha effect of the vasoconstrictor causes constriction of the small blood vessels; the affected tissue bleeds less if cut or abraded. The principal function of a vasoconstrictor in operative dentistry is the prolongation of anesthesia because of reduced blood flow to and from the anesthetized site. Without epinephrine, anesthesia from 1 mL of lidocaine 2% lasts only 5 to 10 minutes; with epinephrine, the anesthesia lasts 40 to 60 minutes. Reduced blood flow helps keep the patient's blood level of the anesthetic and the vasoconstrictor at a low level by reducing the rate of absorption into the circulatory system.

OPERATOR EFFICIENCY

Local anesthesia greatly benefits the dentist and the patient and is beneficial for successful tooth preparation and restoration. It improves operator efficiency, and usually, the patient is calmer and more cooperative. This increased cooperation may reinforce the dentist's confidence and calmness, which may promote more efficient treatment. Without distractions or management problems from the patient, the dentist can focus on the treatment and its completion within a reasonable time frame.

Administration

PSYCHOLOGY

Patients have varying degrees of concern about receiving an intraoral injection. A concerted effort by the dentist and

dental assistant is required to make the procedure more acceptable, and a positive approach is desirable with all patients during this phase of treatment. Probably the greatest positive effect is achieved through a caring manner, rather than by what is said. Words such as *pain*, *sting*, *hurt*, and *inject* should not be used because no matter what else is said, the patient will remember these potentially fear-invoking words. The operator must use a kind, considerate, and understanding approach. Every assurance should be made that the comfort of the patient is paramount and that the teeth and soft tissues will be treated with care. Such assurances, confidently and softly spoken, are welcomed during the administration of local anesthesia. One example is, "I may be taking longer than you expected, but we are giving the solution slowly to be kind to your tissues." Patients who feel secure (safe from pain and in caring hands) gratefully accept local anesthesia. The art of tactfully keeping the syringe and needle from the view of the patient should be practiced. Here, the chairside assistant can be a tremendous help.

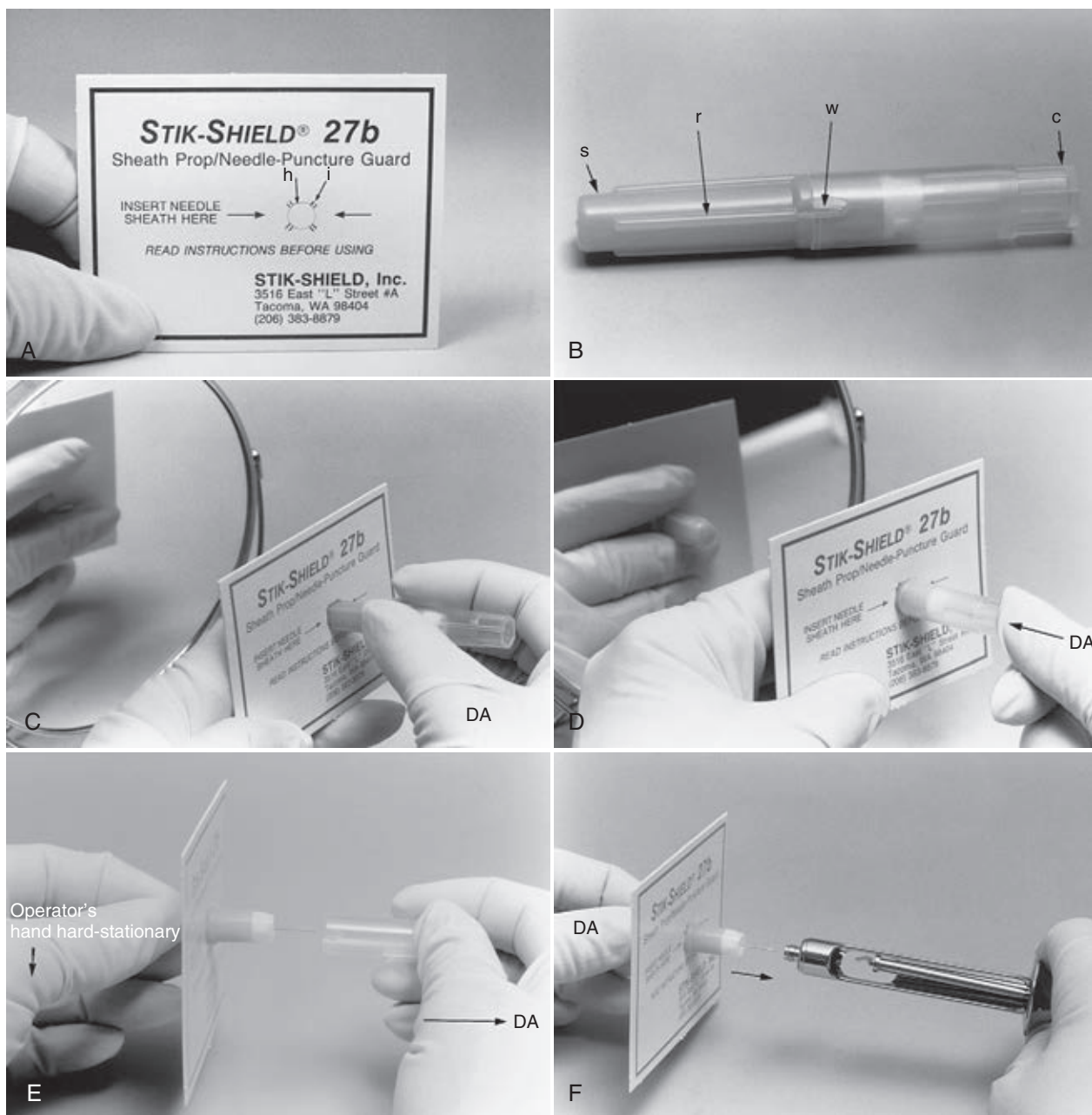
TECHNIQUE STEPS AND PRINCIPLES

Because profound, painless anesthesia of teeth and contiguous soft tissues is so important in operative dentistry, the salient features of a recommended technique for infiltration anesthesia of a maxillary canine are presented here. Technique instructions for injection and infection control (particularly avoiding accidental needlestick injury) are described, and the following principles for the injection of a local anesthetic and epinephrine are also applicable to infiltration and conduction anesthesia. Infiltration anesthesia involves a supra-periosteal or field block, where deposition is near the nerve ends in the operating site. Conduction anesthesia involves a nerve block, where deposition is near a nerve trunk at a distance from the operating site.

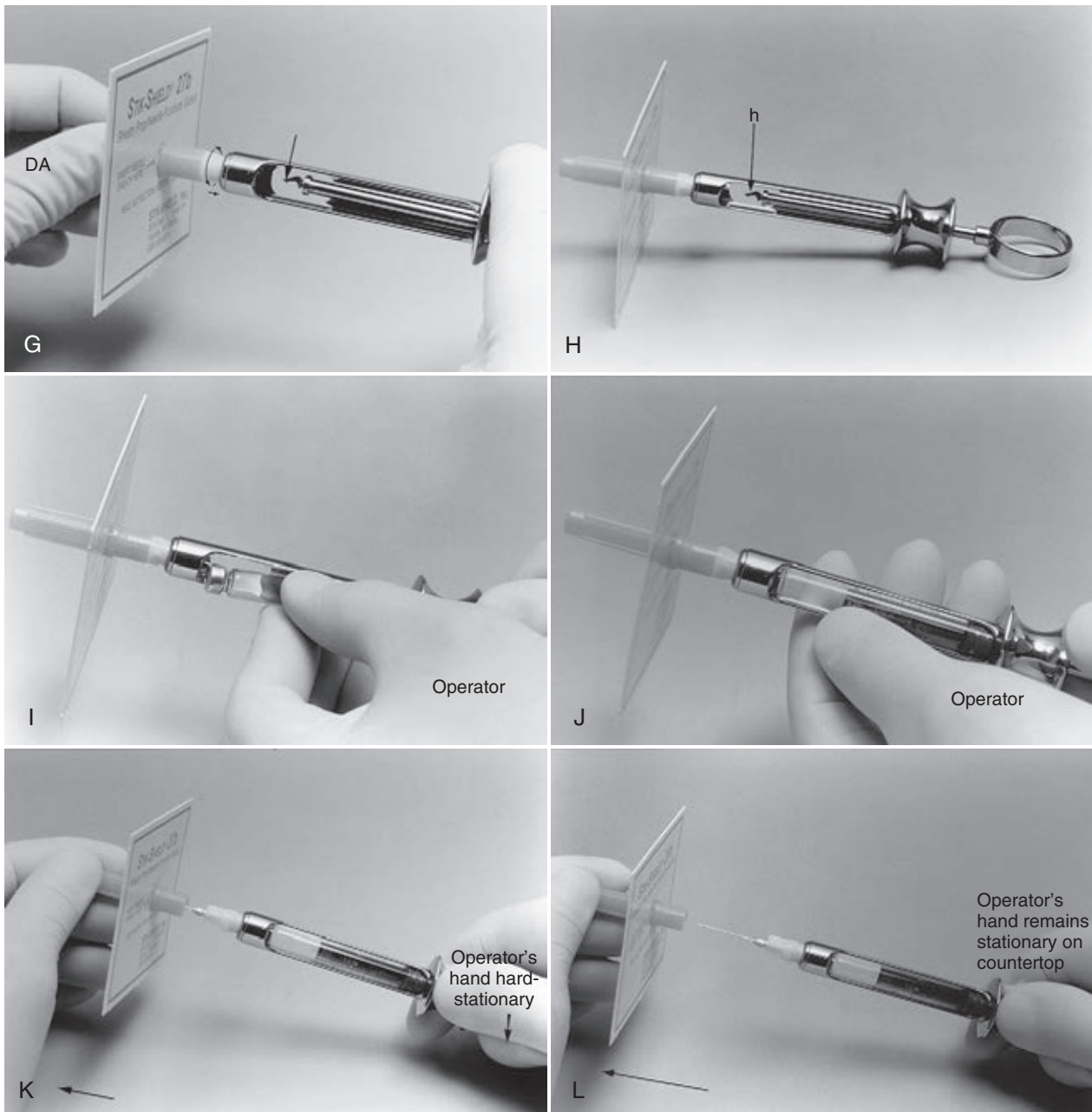
In this example of infiltration anesthesia, the needle entry spot and direction are different from that presented in some textbooks on local anesthesia. Aspiration and slow deposition of solution are emphasized. For other local anesthesia injections (inferior alveolar, Gow-Gates mandibular, posterosuperior alveolar, infraorbital, mental, and periodontal ligament), the reader is referred to a textbook on local anesthesia.

The routine supine position of the patient helps prevent vasodepressor syncope because it maintains blood supply and blood pressure to the brain. As a precaution, the upper torso should never be more than 10 degrees below the horizontal plane because this may cause respiratory distress secondary to the force of viscera against the diaphragm. Occasionally, patients may complain of breathing difficulty that is relieved only by sitting upright or standing (orthopnea), in which case a compromise in patient position is necessary. Another exception to the supine position is when symptoms suggest an epinephrine overdose; in this case, a semi-erect or sitting position is best because it minimizes any further elevation in cerebral blood pressure. Symptoms of overdose include fear, perspiration, weakness, pallor, palpitations, anxiety, and restlessness.¹

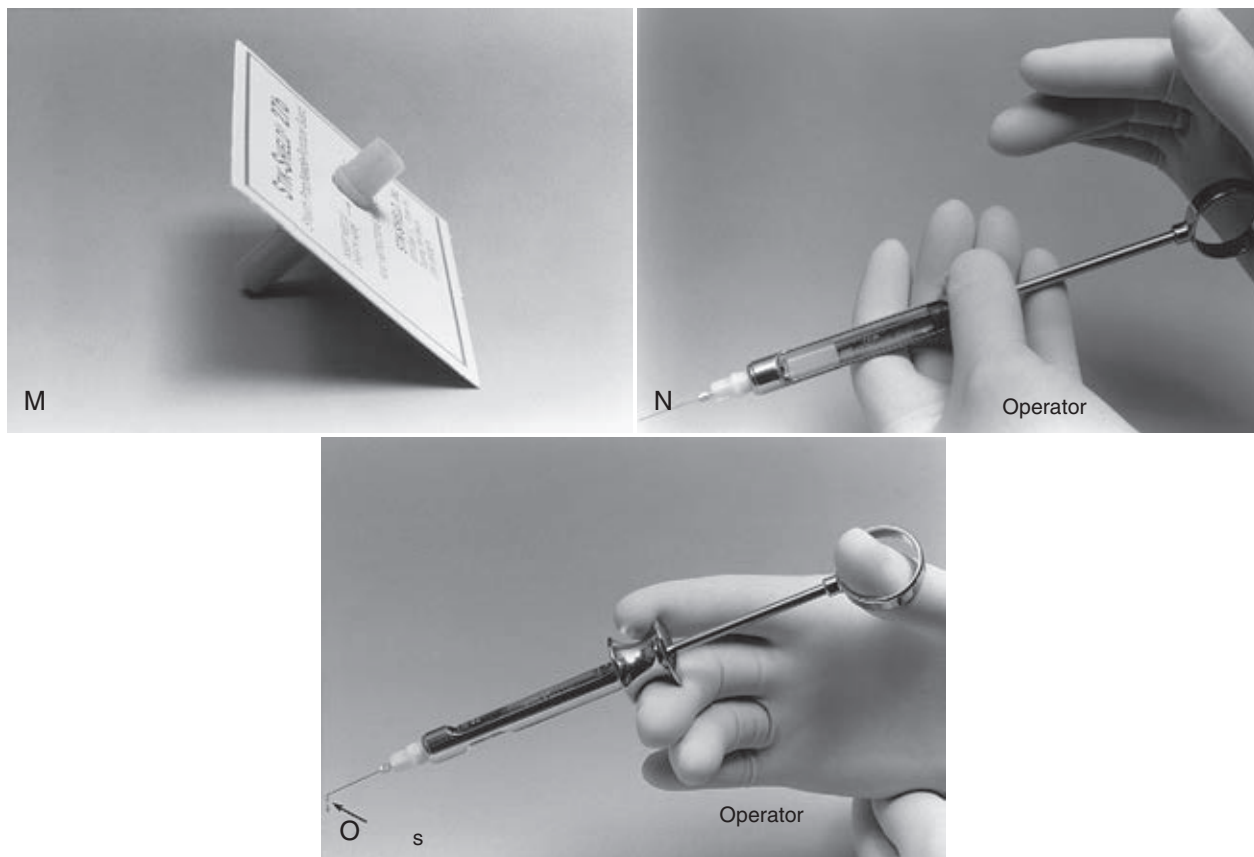
The syringe must have an aspirating feature. When anesthetic is administered, aspiration is second in importance only to slow deposition of solution. For this purpose, the rod (piston) has a harpoon on its cartridge end and a thumb ring on the other end ([Online Fig. 20-1, H](#)). The harpoon engages the cartridge plunger, which results in its potential reverse



Online Fig. 20-1 **A**, Prop/guard (Stik-Shield) card. The periphery of the hole (*h*) is indexed (*i*) (four pairs of short cuts) to accept four external ridges (*r*) of the sheath (*s*) shown in **B**. **B**, The sheath (*s*) covers the injection portion of the needle, and the cap (*c*) covers the reverse end (cartridge needle). Sheath and cap are joined by spot plastic weld (*w*). Note the external ridge (*r*). **C**, With the fingers of one hand holding the prop/guard card printed-side up (and supporting it), the dental assistant (DA) uses the ends of the thumb, index, and middle fingers of the other hand to press the last one third of the sheath through the hole while lining up external ridges to align with the card indices. (Do not, at this time, jar the cap [on reverse end] loose with hand.) **D**, The dental assistant applies thumb pressure (*arrow*) on the end of the cap to insert sheath fully to its collar. (Do not, at this time, loosen the cap by any twisting motion.) **E**, The dental assistant's left hand holds the sheath (card on sheath) and presses down on the countertop in a stationary position (*left arrow*), while the fingers of right hand "twist-break" plastic weld at cap/sheath union and deliberately move the cap off of the reverse-end needle. Note the horizontal right arrow depicting the movement of the hand (away from needle), which discards the cap. **F**, The dental assistant's left hand, still holding the carded sheathed needle, now inserts the reverse-end needle into the hole in the threaded end of the syringe held by the other hand (kept at least 3 inches away from card).



Online Fig. 20-1, cont'd **G**, The dental assistant's left hand screws the sheathed needle clockwise onto the syringe threads to a full-seating position against the syringe nose. Note the protection of both hands by the guard card during such threading. The harpoon (*h*) is used later. **H**, The dental assistant lays the prepared syringe (minus anesthetic cartridge) on the countertop or tray behind the patient, propped up because of the guard card and ready for the operator. Note the harpoon (*h*) on the piston end. **I** and **J**, While fully retracting the spring-loaded, movable, rear cartridge seat of the syringe by hand retraction of the piston, the operator or assistant (behind the patient) inserts the cartridge, rearward end first (*I*), and "drops" the forward end (diaphragm end) of the cartridge into position (*J*) without dragging across or bending the reverse-end needle. The operator or the assistant slowly releases the piston retraction, moving the rear cartridge seat and the cartridge forward, allowing the reverse-end needle to pierce diaphragm. (Leakage of cartridge during later attempted deposition is usually caused by a bent reverse-end needle poorly centered on the diaphragm.) **K** and **L**, With the syringe propped by the card on countertop (or tray) behind the patient, the operator or assistant holds the sheath by the fingers of one hand (card protected) and the syringe by the other hand, which is kept stationary (*K*) as the sheath is loosened and removed away from the needle (*L*). **M**, The guard card now props the sheath.



Online Fig. 20-1, cont'd N, The operator or the assistant sets the harpoon by gentle palm-thump of the thumb ring and then (O) tests the syringe for preparedness by thumb pressure moving the plunger forward 1 to 2 mm while verifying emission of solution (s) from the needle without leakage at the forward end of the syringe body.

movement to create negative pressure when the operator's thumb (in the ring) pulls back gently.

Injection into infected tissue should be avoided because of the risk of spreading the infection. Also, the anesthetic becomes less effective because the infected tissue is acidic rather than basic. Alternative approaches such as nerve block should be used.

Disposable Needle

The sheath covers the needle and the cap covers the reverse end (cartridge end) of the disposable needle (see *s* and *c* in [Online Fig. 20-1, B](#)). For each patient (appointment), the dental assistant selects a sheathed, capped, new disposable needle of the desired length and gauge. The sheathed needle comes sterile from the manufacturer. The needle remains sheathed except for setting the harpoon and testing the syringe preparedness (see the later discussion on principles), until the moment of entry at the injection site. This helps prevent accidental needlestick injury, which among other things indicates needle replacement. For each patient appointment, using a new, sterile needle contaminated only by that patient's oral tissue eliminates cross-infection via the needle. Keeping the sheath in place ensures that the needle is sharp. When the needle contacts the firm periosteal tissue or bone, a minute barb can be formed that causes pain on withdrawal or during subsequent re-injection.

The needle must be sufficiently long that its full length is never out of sight (never completely within tissue). This means that in the unlikely event that a needle breaks at the hub junction, some of the needle is exposed for grasping and withdrawal. Needles of 27-gauge are generally recommended, although some operators prefer the 30-gauge, short needle for infiltration anesthesia of maxillary teeth. The 30-gauge needle may not allow aspiration, and some authorities believe that it does not pierce or move in tissue more easily than the 27-gauge needle. Also, the 30-gauge, long needle may deviate during injection for conduction anesthesia of the inferior alveolar nerve.

Prop/Guard Card

The dental assistant inserts the sheathed needle end into the prop/guard card (Stik-Shield; Tacoma, WA) (see [Online Fig. 20-1, A through D](#)) and removes the cap on the reverse end of the needle (see [Online Fig. 20-1, E](#)). The dental assistant inserts the reverse end of the needle into the hole at the threaded end of the syringe and screws the sheathed needle to a full seating position against the nose of the syringe (see [Online Fig. 20-1, F and G](#)). The guard card protects both hands. The card hits the nose of the syringe before the needle could injure the hand holding the syringe. The dental assistant inserts the cartridge and sets the harpoon or lays the propped (by card) syringe on a tray or countertop (see [Online Fig. 20-1, H](#)) behind the

patient for the operator to insert the cartridge, set the harpoon, remove the sheath, and test for preparedness.

Anesthetic Cartridge

Using a new cartridge for each patient is imperative. Because some ingredients do not have an extended shelf life, the anesthetic cartridge should not be more than 18 months past the date of manufacture. The expiration date is printed on the packing container. Some manufacturers place an expiration date on the cartridge. The diaphragm end of the cartridge should not be contaminated by contact with potentially infected surfaces. The cartridge should not be immersed in a sterilizing solution (cold sterilizing solution or alcohol) because this can diffuse through the diaphragm and cause tissue damage. Cartridges should not be exposed to sunlight and should be stored at room temperature.¹

Anesthetic Solution

The weakest solution of anesthetic that will be effective should be used. Lidocaine 2% with 1:100,000 epinephrine is commonly used in operative dentistry and is generally recommended; 1 mL (half a cartridge) provides infiltration anesthesia for 40 to 60 minutes for anterior teeth. The addition of a vasoconstrictor to the anesthetic solution is necessary to prolong anesthesia by decreasing the rate of absorption of the anesthetic into blood. The vasoconstrictor may reduce the potential of anesthetic toxicity. As previously described, the vasoconstrictor in the anesthetic solution administered by infiltration is useful in reducing occasional hemorrhage by producing slight, transient ischemia of the cut or abraded soft tissue.

Before its use, the anesthetic solution should be warmed to approximately body temperature. Otherwise, the relatively cold solution contributes to the pain of injection. An approximately 30°F difference exists between room temperature and body temperature. The anesthetic cartridge can be warmed in an anesthetic warmer, which is usually heated by a low-watt light bulb, or the cartridge can be held tightly in the palm of the hand for 10 to 15 seconds.

Anesthetic Syringe

The anesthetic syringe includes a rod (or piston) that has a harpoon (or barb) on the cartridge end and a thumb ring on the other end. The harpoon and thumb ring are features that allow the operator to aspirate during injection. The harpoon engages the cartridge plunger. During injection, the operator should use the thumb ring and periodically reverse the movement of the rod to create negative pressure causing aspiration. Periodic aspiration during injection is important to ensure that the solution is not being injected into a blood vessel. If the tip of the needle is in the vessel, blood is aspirated into the cartridge, indicating the need to reposition the needle. For patient safety and comfort, periodic aspiration is as important as slow deposition of the anesthetic solution.

Assembly of Syringe

To assemble the syringe, the assistant or operator picks up the syringe and, while holding the piston fully retracted, inserts the cartridge (see [Online Fig. 20-1, I and J](#)). The cartridge needle should be diaphragm centered. If it is not, the assistant or the operator guides the axial alignment of the cartridge such that the needle pierces the center of the diaphragm as the

spring-loaded, retracted piston is slowly released. If the cartridge needle is malpositioned or bent as the cartridge is loaded, leaking can occur as injection is initiated. The distasteful solution may drip freely into the patient's mouth. If so, injection must be aborted, and another cartridge must be placed properly in the syringe.

The harpoon is set into the cartridge plunger by a light, quick thrust from the palm of the hand on the thumb ring (see [Online Fig. 20-1, N](#)). Too strong a blow may crack or break the cartridge.

The sheath should be removed out of the patient's view, carefully moving it away from the hand holding the needle and syringe; the hand is held stationary on the tray or countertop (see [Online Fig. 20-1, K and L](#)). The prop/guard card protects the hand during sheath removal (see [Online Fig. 20-1, L](#)). It also props the sheath, thus preventing contamination (see [Online Fig. 20-1, M](#)).

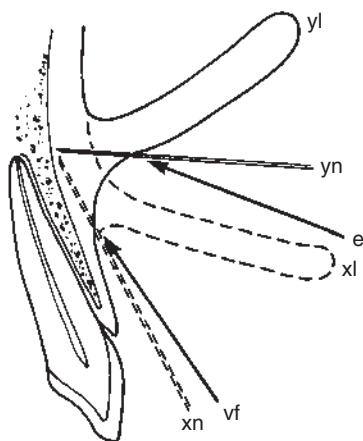
The assembled syringe is tested by pressing the plunger forward 1 to 2 mm to verify that it slides easily and to ensure that the solution is emitted from the needle tip without leakage (see [Online Fig. 20-1, O](#)). If preparation of the injection site has been accomplished previously by wiping of the entry site with gauze and the 1- to 2-minute placement of topical anesthetic (see the next discussion on principles), the injection procedure follows.

Topical Anesthetic

Before needle entry, the mucosa at the injection site should be wiped free of debris and saliva with a sterile gauze. After this, a lidocaine topical anesthetic ointment is applied for a minimum of 1 to 2 minutes to the selected entry spot (using a cotton-tipped swab, limiting the area of application to the swab dimension). This procedure often is started immediately after positioning the patient in the chair and following the wiping. The chairside assistant may perform the wiping and the application of the topical anesthetic. The use of a topical anesthetic is generally recommended. However, effective injection techniques, including a slow deposition rate (approximately 60 seconds per cartridge), a warmed cartridge, and the use of sharp needles, are more important factors in achieving painless injection than the use of a topical anesthetic.

Injection Site

If in place, the needle sheath should be removed in a one-person procedure, taking care to protect the hand with the shield (see [Online Fig. 20-1, K and L](#)). With the left hand, a right-handed operator gently raises the lip outward and upward to identify the vestibular fornix, or the mucogingival junction, where the attached gingiva joins the alveolar mucosa ([Online Fig. 20-2](#)). Holding the lip high enough, the operator visualizes the location of the root end and determines the injection site in the alveolar mucosa (1) as it is stretched perpendicular, or nearly so, to the long axis of the tooth and (2) toward the periosteal target area, which is very near the root end of the tooth to be operated on (see [Online Fig. 20-2](#)). The injection site should be 5 to 10 mm lateral of the mucogingival line, allowing some freedom of needle movement and avoiding causing tissue tension. If the needle is held parallel to the tooth long axis, rather than at an angle as recommended, the needle tends to enter too close to the attached mucosa and thus to the sensitive periosteal lining, which would cause pain



Lip position *yl* and needle direction *yn* recommended

Online Fig. 20-2 Recommended entry spot (*e*), direction of needle (*yn*), and lip position (*yl*) for infiltration anesthesia of the maxillary canine. Direction of needle (*xn*) and lip position (*xl*) are not recommended. Vestibular fornix (*vf*) is the junction of the loose and fixed mucosa.

from touching or stripping the periosteum from the bone. The needle tip should not be close to the periosteum until it has reached its target area.

Injection

With the injection site identified and the needle directed properly, two things are done simultaneously in preparation for injection: (1) A slight, gentle tug is applied to the lip (outward and upward) to have the entry spot tissue slightly taut, and (2) the needle is inserted about 3 mm into the mucosa (all the bevel under the epithelium). The slight, gentle tug while tensing the tissue, coupled with topical anesthesia, masks any sensation from the needle entry. After this, the lip may be relaxed, maintaining visibility of the needle. Initially, a small amount of solution is deposited slowly while observing and reassuring the patient. The operator waits several seconds for the anesthetic to take effect near the injection site before continuing the injection. Still maintaining proper needle direction, the operator gently continues inserting the needle toward the targeted periosteum. The operator needs to be careful to sense resistance when the needle tip touches the lining of the bone, at which time the needle immediately is withdrawn 1 to 2 mm.

The operator aspirates by slightly reversing the harpooned plunger a few millimeters by gentle backward movement of the thumb ring. Aspiration (negative pressure) verifies that the needle is not in a blood vessel. If blood appears in the cartridge, the aspiration is positive; the needle immediately is withdrawn 1 to 2 mm, and the operator aspirates again until blood does not appear.

If aspiration is negative, the operator slowly deposits 1 mL (slightly more than half the cartridge) over the next 30 seconds, continually observing and reassuring the patient. A rate of deposition of 1 minute for 1 mL is a good rule of thumb. Slow deposition is the most important safety procedure for the prevention of adverse reactions from high blood levels of the anesthetic or epinephrine. Aspiration is second in importance. Malamed defined overly rapid deposition as taking less than

30 seconds for 1.8 mL (one cartridge).¹ This fast rate separates tissue and is too rapid to allow diffusion along normal tissue planes. If the injection is intravascular, it can lead to serious adverse reactions. Also, it is painful or at least uncomfortable. Malamed stated that a 1-minute rate for 1.8 mL of anesthetic (30 seconds for 1 mL, or half a cartridge) would not cause tissue damage and would not lead to serious overdose reactions, even if the anesthetic is accidentally injected intravascularly.¹

An important principle is to deposit the smallest volume that will provide effective anesthesia. A common error is to deposit excessive anesthetic (with epinephrine) causing overdose reactions.

After deposition, the needle is gently withdrawn and resheathed. A one-handed procedure is recommended. The operator inserts the needle partially into the propped sheath (remaining after the unsheathing procedure), uprights the sheath on the tray or countertop, and seats the needle fully into the sheath (Online Fig. 20-3, A and B). The sheathed syringe is left propped for possible reuse or for later removal and disposal (see Online Fig. 20-3, C). Resheathing is crucial in the prevention of needlestick injuries, which can cause cross-infection to the operator and other office personnel. The Occupational Safety and Health Administration (OSHA) stipulates that needle resheathing should be in a one-handed procedure.⁵ It is also recommended that resheathing should be done by the same person who gave the injection; this eliminates the hazard of passing exposed needles. Even though multiple injections using the same needle for a patient creates no infection control concerns, multiple uses are discouraged because the used needle and the contents of its lumen may be infectious to dental personnel if accidental needlestick injury occurs.

It is important that the patient be continually observed during and after the administration of local anesthesia. An anesthetized patient should never be left unattended and unobserved. Adverse reactions, if they occur, demand immediate attention by the dentist.

Disposal of Needle and Cartridge

Proper disposal of the needle and cartridge is crucial. Removal and disposal of the sheathed, used needle is done by the dental assistant, who carefully unscrews the sheathed needle from the syringe (see Online Fig. 20-3, D) and moves it away from the syringe with a shield-protected hand (see Online Fig. 20-3, E). Tissue contact with the uncapped, exposed cartridge needle should be avoided. If the needle hub is too tight to remove with controlled finger pressure alone, a suture-needle holder (or similar instrument) should be used to loosen the needle hub. The reverse end of the used needle should never be manually recapped. The assistant's hands should be gloved, preferably with utility gloves.

Disposal of the sheathed, used needle immediately follows its removal from the syringe. With the protective guard card still in place, the needle is placed in a nearby sharps disposal container by laying the attached card on the orifice rim (see Online Fig. 20-3, F). With the thumb pressing on the plastic, the sheathed needle is pushed out of the card into the container (see Online Fig. 20-3, G). The cartridge also should be disposed of in the sharps container. The sharps container must be leak-proof and hard walled and display an OSHA biohazard label.⁵

Emergency Procedures

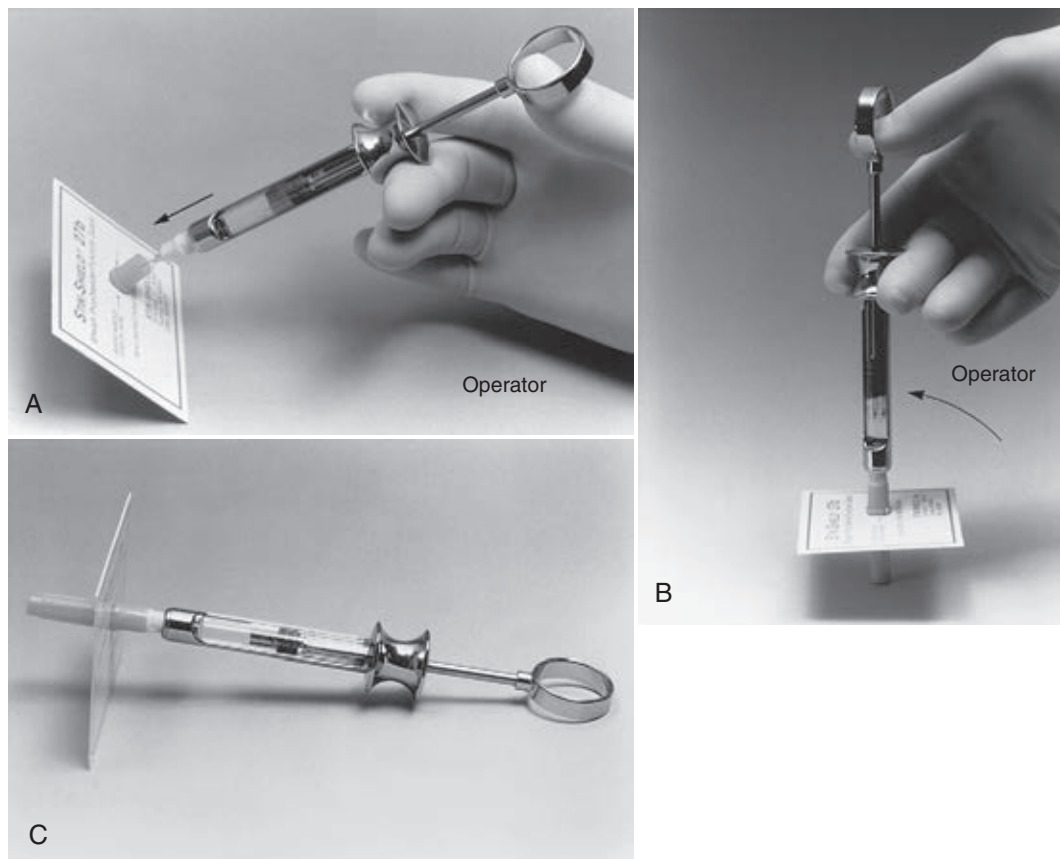
The importance of taking pretreatment vital signs cannot be overemphasized. The patient's pretreatment blood pressure and pulse rate should be recorded in the chart. These vital signs are useful to uncover previously unknown cardiovascular problems and to serve as a baseline if an adverse reaction occurs during treatment. Adverse reactions occurring during or after administration of local anesthesia can lead to serious complications that require emergency procedures. Foremost among these procedures are the following: (1) Place the patient in a supine position (note the exception below), (2) summon medical assistance, (3) monitor vital signs, and (4) apply basic life support (open the airway and use cardiopulmonary resuscitation [CPR], if needed). The supine position, with legs (only) slightly elevated, increases the volume of circulating blood and aids in increasing blood pressure. This procedure for a patient in syncope, or with syncopal symptoms, should relieve hypoxia of the brain and return the patient to, or help maintain, consciousness. The supine position should not be used, however, when symptoms (e.g., fear, perspiration, weakness, pallor, palpitations) suggest an epinephrine overdose. In this case, a semi-erect or sitting position is best because it minimizes any further elevation in cerebral blood pressure.¹

Analgesia (Inhalation Sedation)

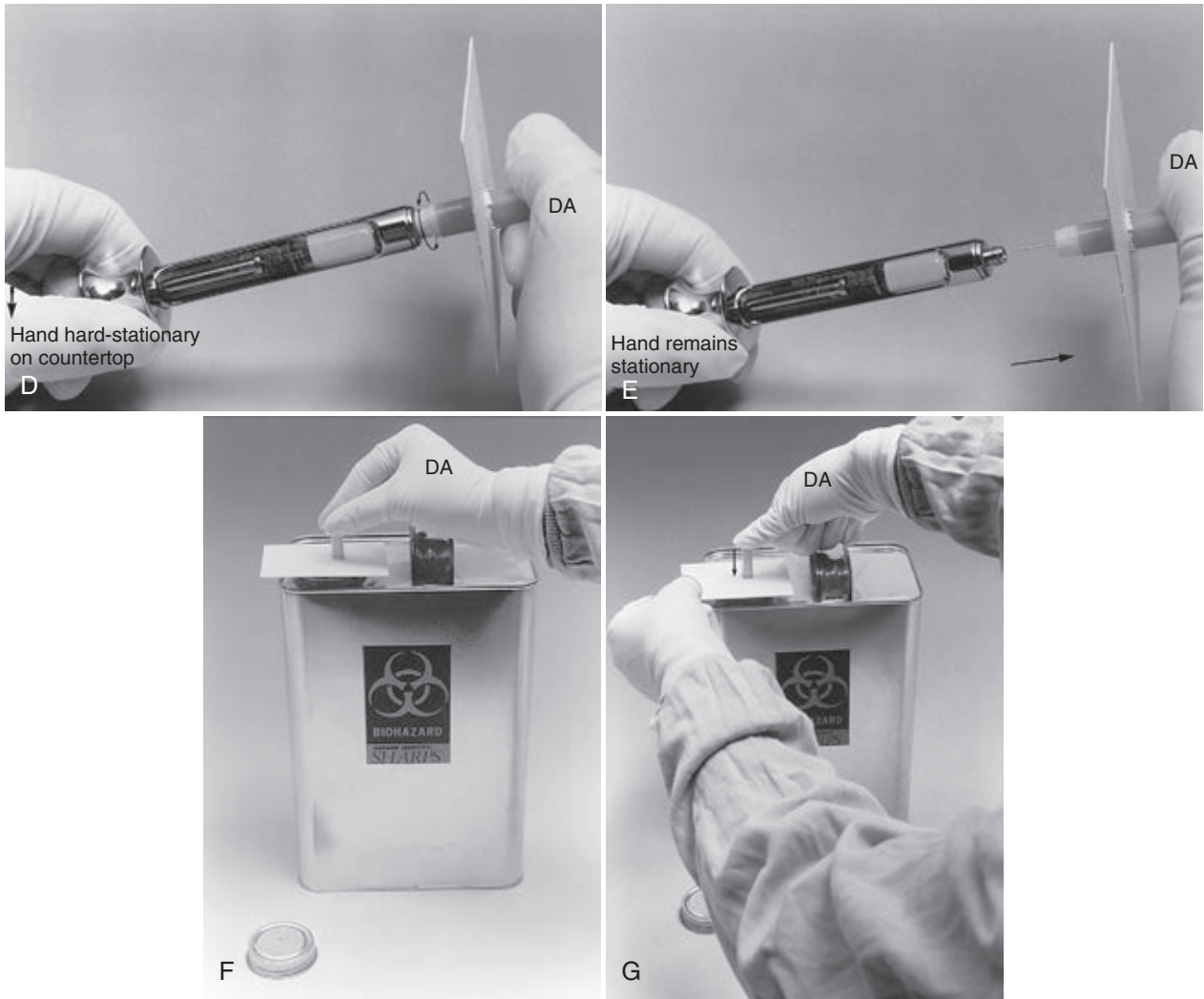
The most appropriate method of preventing pain is by blocking the nerve pathways capable of conducting nerve impulses. For patients who have a low threshold of pain and are apprehensive (hyper-responders), raising the threshold by inhalation sedation is an adjunctive aid to anesthesia by injection. The use of nitrous oxide and oxygen is one method of inhalation sedation. The reader is referred to a textbook on anesthesia that covers inhalation sedation in detail. The operator should understand that this method of pain control has definite limitations. Analgesia should not be thought of as general anesthesia in any stage or depth. It is simply a condition in which the pain threshold is elevated. With inhalation sedation, the patient is conscious of the activities around him or her.

Hypnosis

The fear of pain associated with dental procedures sometimes can be controlled by hypnosis. A favorable mental attitude may be established through suggestions of relaxation. The dentist and the patient may derive certain benefits through hypnosis. The dentist has the opportunity to work on a more relaxed and cooperative patient and has better control over patient habits such as talking and rinsing and oral tissue



Online Fig. 20-3 **A**, Behind the patient, the operator (or individual who gave the injection), using only the syringe-holding hand, inserts the needle partially into the sheath propped by prop/guard card. **B**, The operator then places the syringe and sheath upright on the tray or countertop and presses the needle fully into the sheath. **C**, The operator lays the resheathed syringe propped by the card on the countertop.



Online Fig. 20-3, cont'd D–G, The dental assistant, after patient dismissal, holds the syringe stationary with the fingers of one hand at least 2 inches away from guard card as the fingers of the stronger hand unscrew (counterclockwise) the sheathed, used needle from the syringe (D) and immediately move it (with reverse-end needle exposed) away from the syringe (distance from card to end of reverse-end needle is only 1 inch, and card stops needle from sticking syringe-holding fingers, which are ≥ 2 inches away) (E). The dental assistant continues to hold the sheathed needle and conveys it to a nearby (within a few feet) leak-proof, hard-walled, OSHA biohazard–labeled container with a suitable size orifice, gently laying (on the rim) the guard card with the reverse-end needle down (F), and steadies the card with fingers of one hand and presses (with the thumb of the other hand) the sheathed needle out of the card to free-fall into the container (G). The container should be kept upright, tightly closed between disposals of sharps, and out of the reach of children.

tension. The patient who is relaxed is less fatigued at the end of the appointment and has no specific recollection of having experienced discomfort.

Hypnosis has some merit under certain circumstances and has produced satisfactory results for some practitioners when it is properly applied. Before hypnosis is attempted, the operator must know how to recognize and cope with conditions associated with psychological, emotional, and mental factors and must be thoroughly familiar with all of the principles involved in hypnosis.

Hypnosis is not a way to eliminate all other accepted means of minimizing dental pain or discomfort, but it may be a valuable adjunct in improving accepted procedures.⁶ Also, post-hypnotic suggestion has been found to be successful in alleviating certain noxious dental habits.

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Bonded Splints and Bridges

Harald O. Heymann

Acid-Etched, Resin-Bonded Splints

Mobility of teeth has many causes, including traumatic injury to the face, advanced periodontal disease, habits such as thumb sucking and tongue thrusting, and malocclusion. In addition, teeth often need stabilization and retention after orthodontic treatment. In the past, clinical procedures for the stabilization of teeth either involved extensive loss of the tooth structure or were poor in appearance. A conservative and esthetic alternative has been made possible by using acid-etched, resin-bonded splints.

Certain criteria must be met when mobile teeth are splinted. Occlusal adjustment may be necessary initially. The splint should have a hygienic design so that the patient is able to maintain good oral hygiene. It also should allow further diagnostic procedures and treatment, if necessary. The acid-etched, resin-bonded splinting technique satisfies these criteria. Light-cured composites are recommended for splinting because they afford extended working time for placement and contouring.

Periodontally Involved Teeth

Loss of bone support allows movement of teeth, resulting in increased irritation to the supporting tissues and possible malpositioning of teeth. Stabilizing mobile teeth is a valuable treatment aid before, during, and after periodontal therapy. Splinting of teeth aids in occlusal adjustment and tissue healing, thus allowing better evaluation of the progression and prognosis of treatment.

A resin-bonded splint via the acid-etch technique is a conservative and effective method of protecting teeth from further injury by stabilizing them in a favorable occlusal relationship. If the periodontal problem is complicated by missing teeth, a bridge incorporating a splint design is indicated (see the section on conservative bridges).

Techniques for Splinting Anterior Teeth

In short-span segments subject to minimal occlusal forces, a relatively simple technique can be used for splinting periodontally involved teeth. [Online Figure 21-1, A](#), illustrates a maxillary lateral incisor that remains mobile because of insufficient

bone support even after occlusal adjustment and elimination of a periodontal pocket. Esthetic recontouring with composite augmentation can be accomplished along with the splinting procedure.

Anesthesia generally is not required for a splinting procedure when enamel covers the clinical crown. When root surfaces are exposed and extreme sensitivity exists, however, local anesthesia is necessary. Teeth are cleaned with a pumice slurry, and the shade of light-cured composite is selected. A cotton roll and retraction cords are used for isolation in this instance.

With a coarse, flame-shaped diamond instrument, enamel on both teeth at the proximal contact area is reduced to produce an interdental space approximately 0.5 mm wide. This amount of space enhances the strength of the splint by providing more bulk of composite material in the connector between teeth. Other enamel areas of the tooth or teeth that need more contour are prepared by roughening the surface with a coarse diamond instrument. Where no enamel is present, such as on the root surface, a dentin adhesive is used, according to the manufacturer's instructions. Additionally, a mechanical lock is prepared with a No. $\frac{1}{4}$ round bur in the dentin at the gingivoaxial line angle of the preparation. After the prepared enamel surfaces are acid-etched, rinsed, and dried, a lightly frosted appearance should be observed (see [Online Fig. 21-1, B](#)).

The adhesive is applied, lightly blown with air, and polymerized. A hand instrument is used to place a small amount of composite material in the gingival area. Additional shaping with a No. 2 explorer reduces the amount of finishing necessary later. It is helpful to add and cure composite in small increments, building from the gingival aspect toward the incisal aspect. Finishing is accomplished with round and flame-shaped carbide burs, fine diamonds, and polishing disks and points. The retraction cord is removed, and the occlusion is evaluated to assess centric contacts and functional movements. Instructions on brushing and flossing are reviewed with the patient. The result at 4 years is shown in [Online Figure 21-1, C](#).

Splinting also can be used when the mandibular incisors are mobile because of severe bone loss. The same general steps are followed as described earlier. If further reinforcement is deemed necessary, however, a plasma-coated woven polyethylene strip, such as Ribbond (Ribbond Inc., Seattle, WA) can



Online Fig. 21-1 Splinting and recontouring a mobile tooth using a light-cured composite. **A**, Maxillary right lateral incisor is mobile from lack of bone support. **B**, Preparations completed and etched. **C**, Splinted and recontoured tooth after 4 years.

be used to strengthen the splint. Additionally, the use of flowable composites greatly facilitates the placement of interproximal composite connectors.

A typical case is illustrated in [Online Figure 21-2](#). Following isolation with a rubber dam, small spaces (approximately 0.5 mm in width) are created between teeth with a flame-shaped diamond instrument to enable cross-sectionally strong composite connectors (see [Online Fig. 21-2, A through C](#)).

Because a fiber-reinforcing material will be used, the lingual surfaces to be bonded also should be lightly roughened with an oval diamond to enhance the resin bonds. All interproximal and lingual surfaces to be bonded are etched for 15 seconds with a phosphoric acid-etching gel (see [Online Fig. 21-2, D](#)), followed by thorough rinsing and drying. Round wooden wedges can be used to stabilize the mobile teeth and to help maintain an open gingival embrasure form. To prevent any resin from sticking to the wooden wedges, a light coat of petroleum jelly can be placed on the wedges prior to positioning the wedges interproximally. Bonding agent is applied and cured to all etched surfaces (see [Online Fig. 21-2, E](#)). The interproximal composite connectors are then generated by injecting flowable composite into these areas and shaped (if needed) with a #2 explorer (see [Online Fig. 21-2, F](#)). A small amount of flowable composite is placed onto the lingual surfaces (but not cured) to receive the auxiliary splinting strip. An appropriate length of splinting material (polyethylene-coated woven fabric) is cut and first saturated with bonding agent. Then, by using a gloved finger, the strip is pressed into uncured composite and cured initially into place (see [Online Fig. 21-2, G](#)). The bonded strip is then covered incrementally with flowable composite, resulting in a smooth lingual surface (see [Online Fig. 21-2, H](#)). Facial and incisal embrasures are defined with finishing burs to enhance esthetics. After finishing procedures, the rubber dam is removed, and the occlusion is evaluated. The final result is seen in [Online Figure. 21-2, I and J](#).

Stabilization of Teeth After Orthodontic Treatment

After orthodontic treatment, teeth may require stabilization with either fixed or removable appliances. The latter method allows continued minor movements for the final positioning of teeth. When this position is reached, it is better to stabilize teeth with a fixed retainer. Removable retainers tend to irritate soft tissue. Also, they may be damaged, lost, or not worn, which usually leads to undesired movement of teeth.

[Online Figure 21-3, A](#), shows a patient with a removable orthodontic retainer. Optimal positioning of teeth has been

achieved by orthodontic movement; however, stabilization of teeth is required, and the unattractive spaces caused by undersized maxillary teeth need to be closed (see [Online Fig. 21-3, B](#)). A carefully planned appointment is required to accomplish the following: (1) remove any fixed orthodontic appliance, (2) add composite to close the diastemas, and (3) stabilize teeth with a twisted stainless steel wire and composite.

Technique

After the orthodontic appliance is removed and routine procedures are followed for closing the diastemas (see [Online Fig. 21-3, C](#)), the occlusion is examined carefully to determine the best position for locating the twisted wire because it will be placed only on the lingual surfaces. A sufficient length of twisted stainless steel wire (i.e., 0.0175 inch [0.45 mm] in diameter) is adapted to the lingual surface of anterior teeth. A stone cast is helpful for adapting the wire. The wire must rest against the lingual surfaces passively without tension or interference with the occlusion. In the mouth, waxed dental tape is used to position the wire against teeth and hold it in place while the occlusal excursions are evaluated. The wire is attached only to the lingual fossa of each tooth. After the position of the wire has been determined, it is removed, and only the enamel in the fossae (not the marginal ridges or embrasures) is etched, rinsed, and dried.

Light-cured composite is best used for attaching the fixed wire splint. The wire is repositioned and held in place with dental tape, while a sparing amount of resin-bonding agent is applied and lightly blown with air. After polymerization of the adhesive, a small amount of composite material is placed to encompass the wire in each fossa and bond it to the enamel. The operator must be careful not to involve the proximal surfaces (see [Online Fig. 21-3, D](#)). After polymerization of composite, the occlusion is evaluated and adjusted, as needed, for proper centric contacts and functional movements.

This unique splint allows some physiologic movement of teeth, yet it holds them in the correct position. The splint should remain in place for at least 6 months to ensure stabilization. Longer retention may be necessary, depending on the individual situation and recommendations of the orthodontist.

Avulsed or Partially Avulsed Teeth

Facial injuries often involve the hard and soft tissues of the mouth. The damage may range from lacerations of soft tissue to fractures of teeth and alveolar bone. Partial or complete



Online Fig. 21-2 Splinting of mobile mandibular incisors reinforced with a plasma-coated, polyethylene-woven strip (Ribbond; Ribbond Inc.). **A** and **B**, Facial and lingual preoperative views of mobile mandibular incisors that need splinting. **C**, Preparation consists of roughening proximal surfaces and creating slight interdental spaces to provide bulk to the connector areas of the composite splint. **D**, All interproximal and lingual surfaces to be bonded are etched with a phosphoric acid gel. **E**, Teeth are stabilized with wooden wedges, and a bonding agent is applied. **F**, Interproximal composite connectors are generated by injecting flowable composite.

avulsion of teeth can occur. Maxillary central incisors are involved more often than are other teeth. A thorough clinical examination of soft tissue, lips, tongue, and cheeks should be made to locate lacerations and embedded tooth fragments and debris. Radiographic examination is necessary to diagnose deeply embedded fragments or root fractures.

Treatment of soft tissue lacerations should include lavage, conservative debridement, and suturing. Consultation with or referral to an oral surgeon may be necessary. A partially avulsed tooth is repositioned digitally and may or may not

need splinting. Traumatically avulsed teeth that are reimplanted immediately or within 30 minutes have a good prognosis for being retained.^{1,2} After 30 minutes, the success rate declines rapidly. The avulsed tooth should be repositioned as soon as possible. In the interim, it should be placed in a moist environment such as saliva (i.e., held in the cheek or under the tongue), milk, saline, or wet towel. The replacement of avulsed teeth has immediate psychological value and maintains the natural space in the event that a fixed prosthesis is required later.



Online Fig. 21-2, cont'd **G**, A fiber-reinforcing strip is pressed into the uncured composite on lingual with a gloved finger. **H**, The bonded strip is covered incrementally with flowable composite. **I** and **J**, Completed fiber-reinforced composite-bonded periodontal splint seen from facial and lingual views.



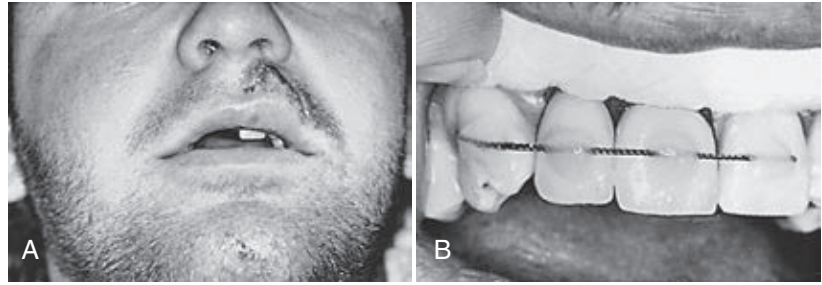
Online Fig. 21-3 Stabilizing teeth after orthodontic treatment. **A**, Patient with existing removable retainer. **B**, Residual spaces resulting from undersized teeth. **C**, Closure of spaces with composite additions is completed. **D**, Orthodontic wire is held in position with dental tape and bonded into place with composite.

Technique

The maxillary right incisors that were completely avulsed in an accident ([Online Fig. 21-4, A](#)) are repositioned immediately. After the teeth are repositioned, radiographs reveal that no other complications exist. Isolation with cotton rolls or gauze is preferable to the use of a rubber dam, which could

cause malpositioning of the loose teeth. The occlusion should be evaluated to ensure that the teeth are properly positioned.

The facial surfaces of the crowns are quickly cleaned with hydrogen peroxide, rinsed, and dried by blotting with a gauze or cotton roll or by lightly blowing with air. The dentist should avoid blowing air into areas of avulsion or deep wounds to prevent air emboli. If a crown is fractured, any deeply exposed



Online Fig. 21-4 Splinting avulsed teeth. **A**, Patient with traumatically avulsed maxillary right incisors. **B**, Completed splint stabilizes repositioned incisors.

dentin should be covered with calcium hydroxide to protect the pulp. A twisted orthodontic wire (0.0195 inch [0.49 mm]) must be long enough to cover the facial (or lingual) surfaces of enough teeth to stabilize the loose teeth. The wire is adapted and the ends rounded to prevent irritation to soft tissue. In an emergency, a disinfected paper clip can be used as a temporary splint.

No preparation of the enamel surface is necessary other than that provided by acid-etching. The middle third of the facial surfaces are etched, rinsed, and dried of all visible moisture. Drying should be accomplished by blotting with a gauze or cotton roll and a light stream of air. Self-cured or light-cured composite may be used. The wire is positioned and held lightly in place, and the ends are attached with composite material (see Online Fig. 21-4, B). Light pressure is applied to the repositioned teeth as the facial surfaces are bonded to the wire in succession (see Online Fig. 21-4, C). Care is exercised not to allow composite to flow into the proximal areas. When the teeth are stabilized, any fractured areas can be conservatively repaired by the acid-etch, resin-bond technique. Finishing is accomplished by a flame-shaped carbide finishing bur and abrasive disks. The occlusion is evaluated carefully to ensure that no premature contacts exist.

The patient is advised to maintain gentle care of the involved teeth. Antibiotic therapy may be required if the alveolar bone is fractured or significant soft tissue damage has occurred. Tetanus shots or boosters are advised, if indicated by the nature of the accident; the patient's physician should be contacted about this. Appointments are made for follow-up examinations on a weekly basis for the first month. The patient is warned about symptoms of pulpal necrosis and advised to call if a problem develops. If root canal therapy is required, it is better accomplished with the splint in position.

Removal of the splint is accomplished in 4 to 8 weeks provided that recall visits have shown normal pulp test results and the teeth are asymptomatic. The wire is sectioned, and the resin material is removed with a flame-shaped, carbide finishing bur at high speed with air-water spray and a light, intermittent application. Abrasive disks are used to polish the teeth to a high luster.

Conservative Bridges

In selected cases, conservative bridges can be made by acid-etching enamel and bonding a pontic to the adjacent natural teeth. These conservative bridges are classified according to the type of pontic: (1) natural tooth pontic, (2) denture tooth pontic, (3) porcelain-fused-to-metal pontic or all-metal pontic with metal retainers, and (4) all-porcelain pontic.

Although the four types differ in the degree of permanency, they share a major advantage—conservation of the natural tooth structure. In addition, they can be viable alternatives to conventional fixed bridges in circumstances where age, expense, and clinical impracticality are considerations.

Because of the conservative preparation and bonded nature of all of these bridge types, retention is never as strong as in the case of a conventional bridge. As part of informed consent, patients should be told of the risk, although remote, of swallowing or aspirating bonded bridges that are dislodged. To reduce the risk of dislodgment, patients should be cautioned not to bite hard foods or objects with bonded bridge pontics.

The ideal site for a conservative bridge is where the edentulous space is no wider than one or two teeth. Other considerations include bite relation, oral hygiene, periodontal condition, and extent of caries, defects, and restorations in the abutment teeth. Conservative bridges are especially indicated for young patients because the teeth usually have large pulp chambers and short clinical crowns. Many older patients with gingival recession and mobile teeth are prime candidates because splinting can be incorporated with the bridge. More specific indications and clinical procedures for each of the four types of bridges are presented in the following sections.

Natural Tooth Pontic

The crowns of natural teeth (primarily incisors) often can be used as acid-etched, resin-bonded pontics. Considerations for this type of treatment include the following: (1) Periodontally involved teeth warrant extraction, (2) teeth have fractured roots, (3) teeth are unsuccessfully reimplanted after avulsion, and (4) root canal treatment has been unsuccessful. However lost, the immediate replacement of a natural anterior tooth has great psychological value for most patients, although the procedure may be temporary. Natural tooth pontics also can be placed as interim restorations until an extraction site heals if conditions require a conventional bridge or an implant.

Certain prerequisites must exist to ensure a successful result: (1) The extracted tooth and abutments must be in reasonably good condition, especially the pontic, because it may become brittle and more susceptible to fracture; (2) the abutment teeth should be fairly stable; and (3) the tooth to be replaced because a pontic must not participate in heavy centric or functional occlusion. Because of this third restriction, canines and posterior teeth are not usually good candidates for this procedure. If the adjacent teeth are mobile, it is frequently necessary to secure them by splinting with composite (see the section on acid-etched, resin-bonded splints).



Online Fig. 21-5 Resin-bonded maxillary natural tooth pontic. **A**, Preoperative photograph before extraction of periodontally involved maxillary right central incisor. **B**, Extraction site immediately after the removal of an incisor. **C**, Enlarged apical opening ready to be filled with composite. The pontic tip has been contoured to an ovate design. **D**, The abutment teeth are isolated, roughened, and acid-etched. **E**, Immediate postoperative photograph of natural tooth pontic bonded in place. **F**, Resin-bonded natural tooth pontic with healed residual ridge 6 weeks later.

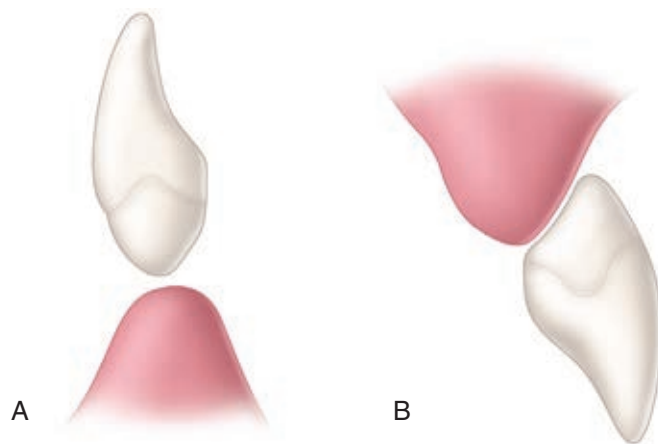
Technique

A maxillary right central incisor must be extracted for periodontal reasons (Online Fig. 21-5, *A* and *B*). Before the tooth is extracted, a small, round bur is used to place a shallow identifying mark on the facial surface to indicate the level of the gingival crest. After extraction, a 2 × 2 inch (5 × 5 cm) sponge is held in the space with pressure for hemorrhage control.

By using a separating disk or a diamond instrument, the extracted tooth is transversely cut a few millimeters apical to the identification mark. When pontic length is determined, shrinkage of the healing tissue underlying the pontic tip must be anticipated. The root end is discarded.

If the pulp canal and chamber have completely calcified, the next procedure is shaping and polishing the apical end of the natural tooth pontic as described in the following paragraphs. If the chamber is calcified as disclosed on the radiograph and the canal is nearly calcified, the canal is opened from the apical end by using a small round bur or diamond to the extent of the canal. The operator should be as conservative of the tooth structure as possible and yet provide access for subsequent injection of the composite material to fill the canal. A large chamber and canal are instrumented and debrided using conventional endodontic procedures with access from the apical end (see Online Fig. 21-5, *C*). Access is provided for subsequent injection of composite. Removal of the pulpal tissue in this manner prevents discoloration of the tooth caused by degeneration products. Traditional lingual access for instrumentation is avoided to prevent weakening the pontic. After these procedures, the canal (and chamber, if present) is filled and closed with self-cured or light-cured composite. Light-cured materials must be placed incrementally to ensure complete polymerization.

After composite has been polymerized, the apical end is contoured to produce a bullet-shaped ovate design (see Online Fig. 21-5, *C*). This design provides adaptation of the pontic

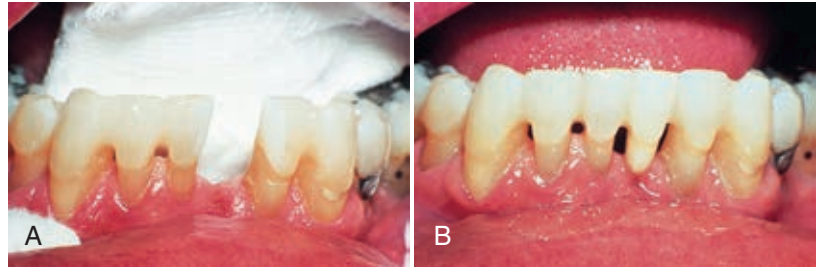


Online Fig. 21-6 Pontic tip design. **A**, Hygienic-type pontic with ovate or bullet-shaped tip. **B**, Modified ridge lap-type pontic with slight concavity conforming to residual ridge.

tip to the residual ridge, and yet it allows the tissue side of the pontic tip to be cleaned with dental floss. It is also the most esthetic pontic tip design that can be used. While being contoured, the tip is occasionally evaluated by trying the pontic in the space. In the maxillary arch, passive contact between the pontic tip and the healed residual ridge is considered ideal for maximal phonetic and esthetic potential. In the mandibular arch (where esthetics is not generally a problem), the pontic tip is best shaped into the same bullet-shaped design but positioned as a hygienic pontic type that does not contact tissue (Online Fig. 21-6, *A*). The pontic tip is smoothed and polished using a proper sequence of abrasive disks or polishing points. A polished pontic tip not only is easier to clean but also retains less plaque.

Usually, a rubber dam is needed for isolation of the region to prevent seepage of blood and saliva. Isolation using cotton rolls and gingival retraction cords is acceptable if the

Online Fig. 21-7 Resin-bonded mandibular bridge splint using natural tooth pontic. **A**, The anterior segment is splinted with composite, and the abutment teeth are isolated, roughened, and etched. **B**, Natural tooth pontic is bonded in place.



hemorrhage has been controlled. Any carious lesions or faulty proximal restorations on involved proximal surfaces of the pontic and the abutments are restored with light-cured composite (preferably the same material to be used subsequently for the bridge connectors) by using modified preparation designs. It is recommended that the resulting restored surfaces be under-contoured rather than over-contoured to facilitate positioning of the natural tooth pontic.

Next, the involved proximal surfaces on the abutment teeth and the pontic are roughened with a coarse, flame-shaped diamond instrument. Spaces of approximately 0.5 mm should exist between the pontic and the abutment teeth because stronger connectors are provided by the additional bulk of the composite material. Now, the operator should acid-etch, rinse, and dry all the prepared (i.e., roughened) surfaces (see Online Fig. 21-5, *D*).

Light-cured composite is preferred for bonding natural tooth pontics because the extended working time allows the operator to contour the connectors before polymerization. First, the adhesive is applied to the etched surfaces of the pontic and lightly blown with air to remove the excess. Then it is polymerized by application of light, and the pontic is set aside (ready for bonding in the mouth). Next, the adhesive is applied to the etched surfaces of the abutment teeth and cured. A small amount of composite material is placed on the proximal contact areas of the natural tooth pontic, and the pontic is inserted carefully in the proper position in the mouth. The composite is shaped around the contact areas with an explorer tip. After final verification that the pontic position is correct, composite is polymerized with light. Next, additional composite is applied in the proximal areas (more material is added on the lingual than on the facial surface), contoured, and cured. Adequate gingival embrasures must be provided to facilitate flossing and ensure gingival health. After sufficient material has been added and polymerized, the embrasure areas should be shaped and smoothed with carbide finishing burs or fine diamonds and polishing disks or points. The rubber dam is removed, and the occlusion is evaluated for centric contacts and functional movements. Heavy contacts on the pontic or the connector areas must be adjusted. The finished bridge immediately after bonding is illustrated in Online Figure 21-5, *E*. The patient should return in 4 to 6 weeks for evaluation of the relationship of the pontic tip to the tissue. Passive contact should exist between the pontic tip and the underlying tissue to prevent ulceration. If tissue ulceration is present, the pontic must be removed, recontoured, and rebonded. The finished bridge and healed residual ridge are shown in Online Figure 21-5, *F*.

As stated earlier, abutment teeth that are mobile often can be splinted with composite to afford stability to periodontally

involved teeth. The abutments are isolated, roughened, and acid-etched (Online Fig. 21-7, *A*). Because esthetics is not as crucial, a hygienic pontic tip is recommended for mandibular incisors (see Online Fig. 21-6, *A*). The finished bridge splint is illustrated in Online Figure 21-7, *B*.

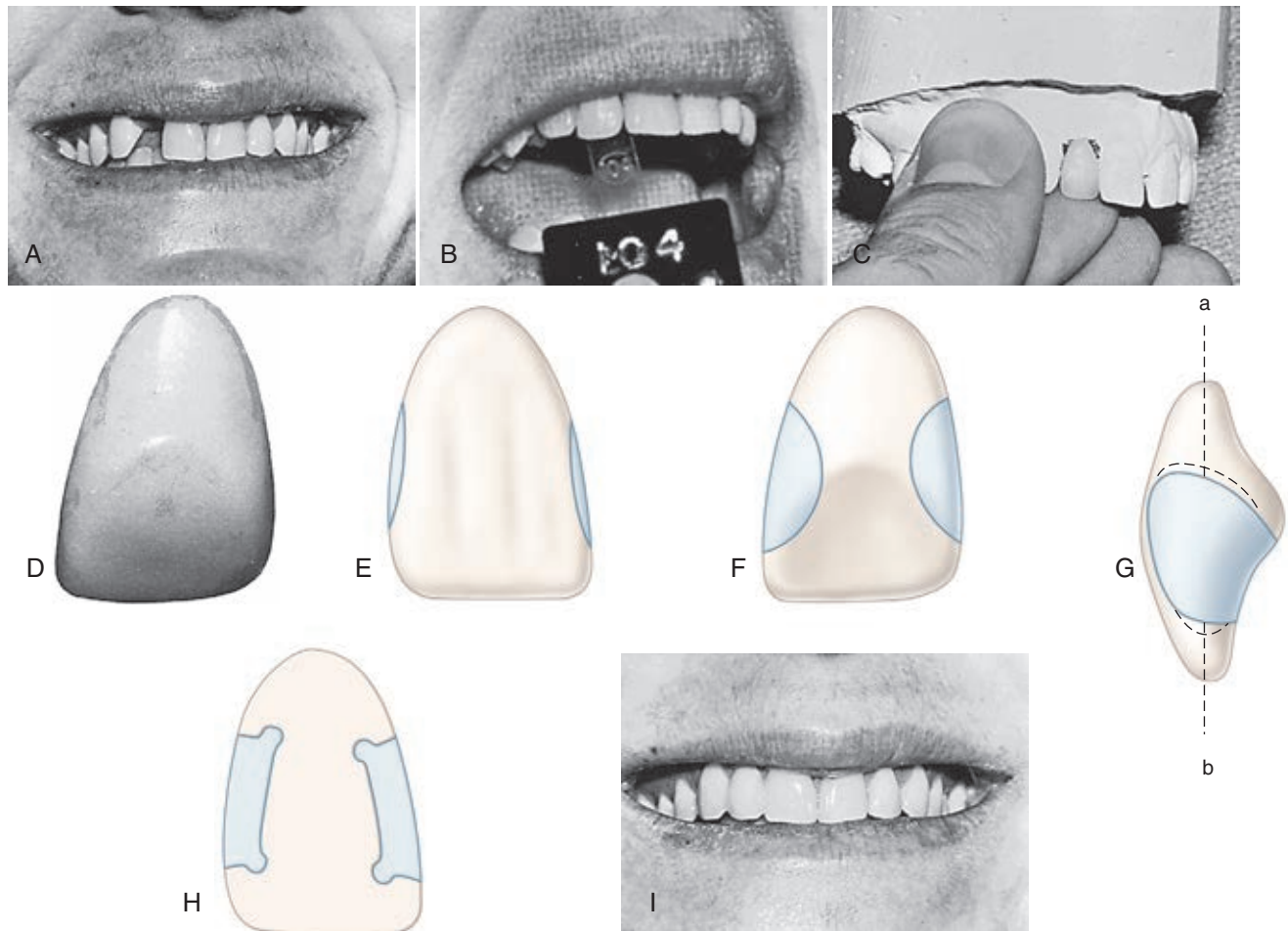
Denture Tooth Pontic

An acrylic resin denture tooth can be used as a pontic for the replacement of missing maxillary or mandibular incisors by using the acid-etch, resin-bonding technique (Online Fig. 21-8, *A through H*). Although this type of bridge is sometimes used as an interim prosthesis and is called *temporary bridge*, it can be a viable alternative to a conventional bridge and may last for years in some circumstances. As with the natural tooth pontic, the major contraindications to this type of resin-bonded bridge are abutment teeth that have extensive caries, restorations, or mobility or a pontic area that is subjected to heavy occlusal forces. In the illustrated example, the permanent maxillary right lateral incisor is missing, and the adjacent teeth are in favorable condition and position (see Online Fig. 21-8, *A*). Further examination reveals an ideal situation for a conservative bridge that uses a denture tooth pontic.

Technique

Although the entire procedure can be completed at chairside in one appointment, considerable time can be saved by an indirect technique. During the first appointment, the shade (see Online Fig. 21-8) and mold of the denture tooth are selected, and alginate impressions are made. In the laboratory, stone casts are poured, and the ridge area is relieved slightly and marked with a soft lead pencil. As the pontic is trial positioned, the pencil markings rub off onto its tip to facilitate contouring of this area (see Online Fig. 21-8, *C*). Contouring is best accomplished with acrylic burs and a Burlew wheel in a straight handpiece. The tissue side of the pontic should be contoured to a modified ridge lap configuration that is convex mesiodistally and slightly concave faciolingually (see Online Fig. 21-6, *B*). This type of design not only allows the pontic tip to adapt to the residual ridge, but it also allows for effective cleaning with dental floss. After it is contoured, the pontic tip should be smoothed and highly polished with pumice and an acrylic-polishing agent (see Online Fig. 21-8, *D*).

Because composite does not normally bond to acrylic resin, provisions must be made to facilitate a strong connection between the pontic and the adjacent teeth. One provision may be completed in the laboratory by preparing large Class III conventional preparations in the pontic that mechanically retain the composite material. The outline of the preparations



Online Fig. 21-8 Resin-bonded denture tooth pontic. **A**, Preoperative photograph shows a missing maxillary lateral incisor. **B**, Shade and mold selection. **C**, Positioning pontic on working model while contouring. **D**, Contoured and polished pontic (lingual view). **E–G**, Outline form of Class III preparations: facial (**E**), lingual (**F**), and proximal (**G**) views. **H**, Cross-section of denture tooth (longitudinal section) in plane *ab* as seen in **G** showing the mechanical retention form incisally and gingivally as prepared with a No. $\frac{1}{2}$ bur. **I**, Denture tooth pontic is bonded in place with composite.

must be large enough to provide adequate surface area of the composite restoration for bonding to the adjacent teeth (see Online Fig. 21-8, **E** through **G**). An appropriately sized round bur (No. 2 or No. 4) is used to cut each preparation to a depth of approximately 1.5 mm and extend the outline approximately 0.5 mm past the contact areas into the gingival, incisal, and facial embrasures. Even more extension should be made into the lingual embrasure to provide for bulk of composite material in the connector areas. The lingual extensions should not be connected because this unnecessary step would unduly weaken the pontic. Mechanical undercuts are placed at the incisioaxial and gingivoaxial line angles with a No. $\frac{1}{2}$ bur to lock the composite material (to be inserted later in the technique) mechanically in the acrylic resin pontic (see Online Fig. 21-8, **G** and **H**).

At the next appointment, the pontic is tried in place to confirm that the shade and contours are correct. Approximately 0.5 mm of space should exist between each proximal “contact” and the abutment tooth. The pontic is cleaned with acetone to remove dust and debris. Retention of the pontic by undercuts, as previously described, also can be augmented by a second provision—the conditioning of the proximal aspects of the pontic with two applications of ethyl acetate, a polymer

softener. A thin layer is applied in the Class III preparations and on the cavosurface areas and allowed to dry for 5 minutes. This process is repeated to ensure optimal bonding. The preparations are filled with the same light-cured composite material expected to be used for bonding the pontic in place. The composite should be applied and cured in the retentive areas before the remainder of the preparation is filled. This step ensures complete polymerization. After the entire preparation is filled, it should be polymerized again with the light source. It is better to leave the contact areas slightly undercontoured for the pontic to fit easily between the abutment teeth. The pontic is set aside in a safe place for some time.

Isolation of the abutment teeth should be accomplished with cotton rolls and retraction cords (rather than with a rubber dam) to relate the pontic better to the residual ridge area. Any caries or old restorations in the adjoining proximal areas of the abutment teeth should be removed at this time, and any indicated liners should be applied. The proximal surfaces of the abutment teeth are roughened with a coarse flame-shaped diamond instrument. This step is followed by acid-etching, rinsing, and drying. The adhesive is applied, lightly blown with air, and cured. Tooth preparations, if present, are restored with the same composite material.

Care is taken not to over-contour the restoration or restorations.

The pontic is evaluated by positioning it temporarily in the edentulous space. If adjustments are made, the surfaces should be cleaned with acetone. Next, a small amount of composite is wiped onto the contact areas (mesial and distal) of the pontic, and the pontic is placed into the proper position between the abutment teeth. An explorer tip is helpful in placing the material evenly around the contact area. Care must be taken to place the pontic so that it lightly touches the ridge, but does not cause tissue blanching. The composite material used to position the pontic is polymerized. It is helpful to add and cure the additional composite in small increments to obtain the correct contour and minimize finishing procedures. The facial, incisal, and gingival embrasures should be defined with a flame-shaped finishing bur or fine diamond and polished with appropriate disks or points. The lingual aspect of the bridge is contoured with a round finishing bur without defining lingual embrasures because this could weaken the connectors. The retraction cords are removed from the gingival crevice. Articulating paper is used to mark the occlusion, and any offensive contacts are removed. The final restoration is shown in Online Figure 21-8, I.

Porcelain-Fused-to-Metal Pontic or All-Metal Pontic with Metal Retainers

A stronger and more permanent type of acid-etched, resin-bonded bridge is possible by use of a cast metal framework.^{3,4} In anterior areas where esthetics is a consideration, the design of the bridge includes a porcelain-fused-to-metal (PFM) pontic with metal winged retainers extending mesially and distally for attachment to the proximal and lingual surfaces of the abutment teeth. In posterior areas where esthetics is not a critical factor, the bridge can have either a PFM or an all-metal pontic. The technique is more complicated and time consuming than the previously described methods because it requires some initial tooth preparation, an impression, laboratory procedures, and a second appointment for etching and bonding. Compared with conventional bridges, resin-bonded bridges of this type offer five distinct advantages:

1. Anesthesia is usually not required.
2. The tooth structure is conserved (i.e., no dentin involvement).
3. Gingival tissues are not irritated because margins usually are not placed subgingivally.

4. An esthetically pleasing result can be obtained more easily.
5. The cost is lower because less chair time is required, and laboratory fees are lower as well.

Ideally, this type of conservative bridge is used for short spans in the anterior or posterior areas with sound abutment teeth in good alignment. The most favorable occlusal relationship exists where little or no centric contact and only light functional contact are present. However, teeth can be prepared and the bridge framework designed to withstand moderately heavy occlusal forces. Orthodontics may be required to improve tooth alignment. The bridge also can be extended to splint adjacent periodontally involved teeth. Surgical crown-lengthening procedures sometimes are indicated for teeth with short clinical crowns.

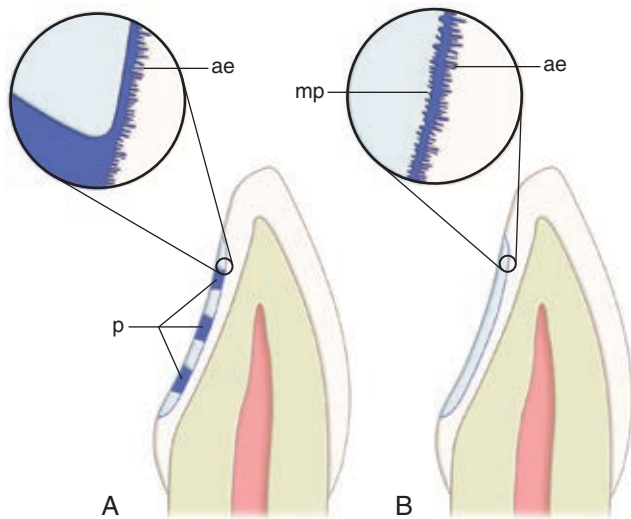
Although minimal, some preparation of the enamel of the abutment teeth is mandatory in the retainer area of the bridge to (1) provide a definite path of insertion or seating or both, (2) enhance retention and resistance forms, (3) allow for the thickness of the metal retainers, and (4) provide physiologic contour to the final restoration. The importance of the tooth preparation design cannot be overemphasized. The success of these types of bridges depends on the preparation design. The bridges must be independently retentive by design and cannot rely solely on resin bonding for retention. Preparation design for these types of bridges is similar to that for a cast three-quarter crown; however, it is restricted to enamel.

The preparation for each abutment varies, depending on the individual tooth position and anatomy. Approximately the same amount of surface area should be covered on each abutment tooth. In some situations, recontouring of the adjacent and opposing teeth may be indicated. The details of the preparations are described later.

Two primary types of resin-bonded bridges with metal retainers currently exist: (1) Rochette and (2) Maryland.^{3,4} Each type has advantages and disadvantages. The Rochette type uses small countersunk perforations in the retainer sections for retention and is best suited for anterior bridges (Online Fig. 21-9, A).⁴ Care must be exercised in placing the perforations to prevent weakening the framework. Perforations that are too large or too closely spaced invite failure of the metal retainer by fracture. The perforations should be approximately 1.5 to 2 mm apart and have a maximum diameter of 1.5 mm on the tooth side. Each hole is countersunk so that the widest diameter is toward the outside of the retainer. When the bridge is bonded with a resin cement, it is



Online Fig. 21-9 Acid-etched, resin-bonded metal bridges. **A**, Rochette type. **B**, Maryland type. **C**, Scanning electron micrograph of etched metal surface. (Courtesy of Dr. John Sturdevant.)



Online Fig. 21-10 Cross-sectional diagram of two types of resin-bonded bridges. **A**, In addition to acid-etching prepared enamel surfaces (*ae*), the Rochette type uses small countersunk perforations (*p*) in the retainer section. **B**, In the Maryland type, the tooth side of the framework is either etched to produce microscopic pores (*mp*) or bonded with no etching with an adhesive cement.

mechanically locked in place by microscopic undercuts in the etched enamel and the countersunk holes in the retainer (Online Fig. 21-10, *A*).

The advantages of this design include the following:

- It is easy to see the retentive perforations in the metal.
- If the bridge must be removed or replaced, the bonding medium can be cut away in the perforations to facilitate easy removal.
- No metal etching is required.

The disadvantages of this design include the following:

- The perforations, if improperly sized or spaced, could weaken the retainers.
- The exposed resin cement is subject to wear.
- It is not possible to place perforations in proximal or rest areas.

A second type of cast metal framework, commonly known as the Maryland bridge, is reported to have improved bonding strength (see Online Fig. 21-9, *B*).^{3,5} Instead of perforations, the tooth side of the metal framework is electrolytically or chemically etched, which produces microscopic undercuts (see Online Fig. 21-9, *C*). The bridge is attached with a self-cured, resin-bonding medium that locks into the microscopic undercuts of the etched retainer and the etched enamel (see Online Fig. 21-10, *B*). It can be used for anterior and posterior bridges. Although this design has been reported to be stronger, it is more technique sensitive because the retainers may not be properly etched or may be contaminated before cementation. Because the retentive features cannot be seen with the unaided eye, the etched metal surfaces must be examined under a microscope to verify proper etching (minimum magnification).

More recently, Maryland bridges have been fabricated with no electrolytic etching of the surface and chemically bonded to the tooth after a process called *silicoating* or with a 4-META or phosphate ester-containing, resin-bonding medium.^{6,7} Resin materials containing 4-META or other resin monomers are capable of strongly bonding to metal surfaces.^{8,9} Surface roughening with microetching (i.e., sandblasting) is commonly used in conjunction with these adhesive cements. These types of Maryland bridges are referred to as *adhesion bridges* and differ only in the means of retention. The design of adhesion bridges is the same for this alternative Maryland bridge design. Successes and failures have been observed with both bonded bridge designs. Because the procedures are technique sensitive, every step must be followed carefully.

Maxillary Anterior Bridge

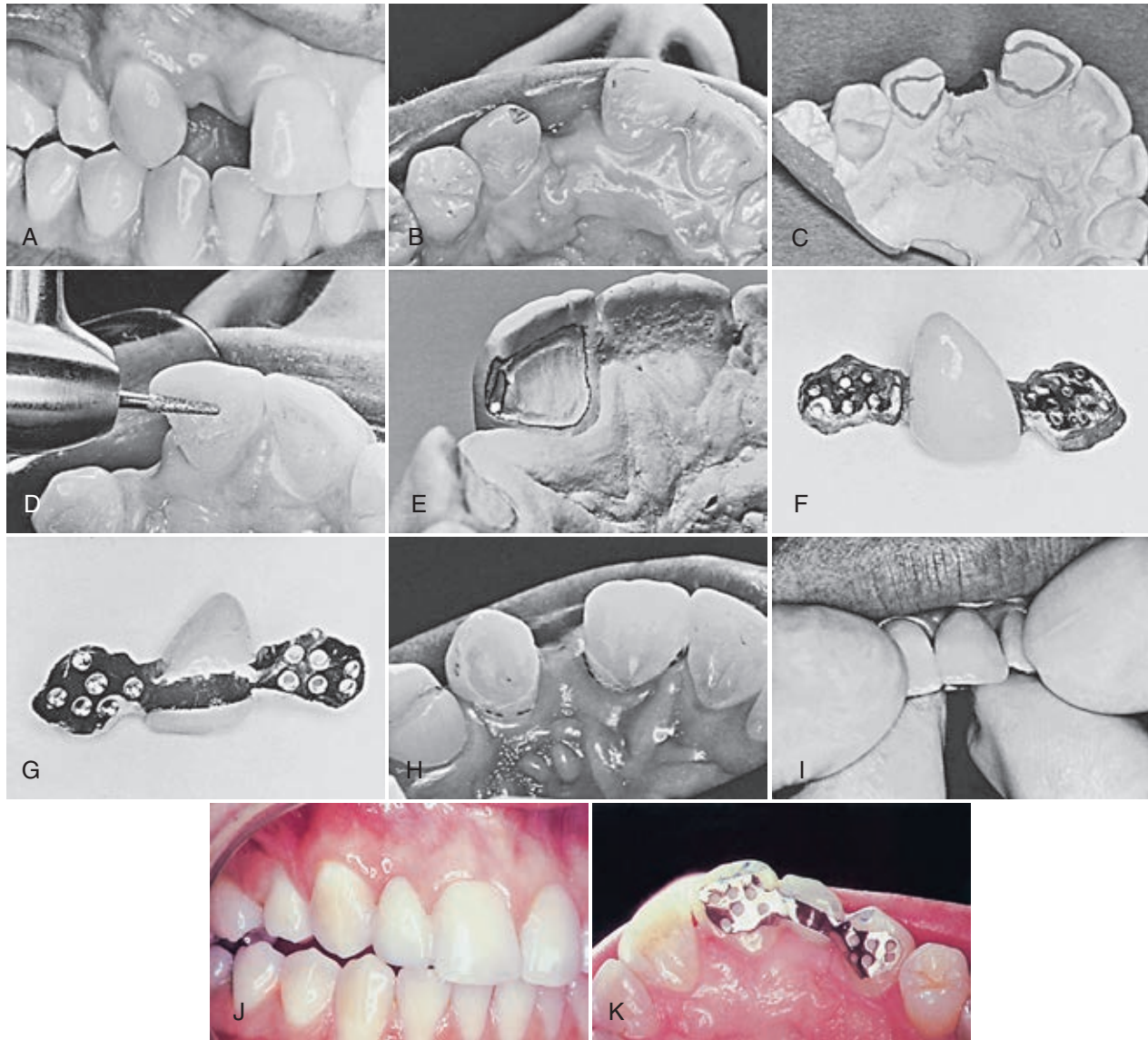
In Online Figure 21-11, *A*, a maxillary lateral incisor is congenitally missing, and the teeth on either side are sound. The occlusion is favorable, and no periodontal problems are present (see Online Fig. 21-11, *B*). The patient has been wearing a removable partial denture that is undesirable. Radiographs and study casts are made to complete the diagnosis and to facilitate preparation design. The outline of the proposed preparation is penciled on the cast to cover as much enamel surface as possible for maximal bonding area but with the following two stipulations: (1) The lingual portions are extended neither subgingivally nor too far incisally; and (2) the proximal portions are not extended facially of the contact areas but enough to allow preparation of retention grooves (see Online Fig. 21-11, *C* and *E*).

Before tooth preparation, the dentist cleans the teeth, selects the shade of the pontic, and marks the occlusion with articulating paper to evaluate centric contacts and functional movements. If adjustment or recontouring of the abutment teeth is indicated, it should be accomplished at this time. When a base metal alloy rather than a high-gold alloy is used for the bridge framework, less tooth structure is removed because the metal retainers can be made thinner. Base metal alloys have superior tensile strength.

PREPARATION

Several depth cuts (0.3–0.5 mm) are made in the enamel with a small, round, coarse diamond instrument (1–1.5 mm in diameter). The depth cuts are joined with the same instrument or a round diamond instrument (see Online Fig. 21-11, *D*). A large surface area (i.e., outline form) is desirable to obtain maximum bonding and strength of the bridge. A shallow groove is cut in the enamel of each proximal portion of the preparations with a small, tapered, cylindrical diamond instrument to establish a path of draw in an incisal direction. This feature provides a definite path of insertion and positional stability for the prosthesis during try-in and bonding (see Online Fig. 21-11, *E*). In addition, the retention of the bridge is improved because a shear force is required to unseat the bridge. Online Figure 21-11, *E*, illustrates this groove on the working cut.

The dentist makes an elastomeric impression of the completed preparations and a bite registration. The patient continues to wear the partial denture as a temporary prosthesis. A small amount of self-curing acrylic resin is added to the



Online Fig. 21-11 Resin-bonded, porcelain-fused-to-metal maxillary anterior bridge. **A**, Congenitally missing maxillary lateral incisor. **B**, Occlusion marked with articulating paper. **C**, Model with outline of preparations. **D**, Preparing the lingual surface with a diamond instrument. **E**, The working cast shows the proximal groove prepared (a second groove is on mesial of canine) to establish path of insertion for prosthesis and provide positional stability and increase the retention form. **F** and **G**, Completed Rochette-type bridge from the facial (*F*) and lingual (*G*) views. **H**, Teeth isolated with a gingival-retraction cord and cotton rolls. Preparations are etched and ready for bonding. **I**, Holding the bridge in place during polymerization. Bonded bridge: facial view (*J*) and lingual view in mirror (*K*).

mesial and distal portions of the removable partial denture tooth to maintain proximal relationships.

LABORATORY PHASE

The impression, bite registration, patient information, and instructions are sent to the dental laboratory. A perforated retention design (i.e., Rochette) is specified in this instance, although the other types could be used. The bridge is fabricated in the laboratory (porcelain contoured but unglazed, and perforations prepared in the retainers).

TRY-IN STAGE

During the initial try-in, the bridge is examined for proper shade, contour, tissue compatibility, marginal fit, and

occlusion. Adjustments are made, and the bridge is returned to the laboratory for corrections (if needed), glazing, and polishing of the metal framework. Online [Figure 21-11, F and G](#), shows the completed bridge from facial and lingual views.

BONDING STEPS

The steps in bonding require an exacting coordination between the dentist and the assistant. All of the equipment and materials needed for isolation, etching, and bonding must be kept ready at the beginning of the appointment: prophylaxis angle handpiece; pumice slurry; self-curing resin cement kit with all accessories; plastic hand instrument; polyester strip; and cotton rolls. Alternatively, rubber dam isolation can be used;

Online Fig. 21-12 A and B, Anterior resin-bonded bridge with multiple pontics. Before and after views of a porcelain-fused-to-metal, resin-bonded bridge replacing both maxillary central incisors.



it is particularly recommended for the placement of posterior bonded bridges.

The abutment teeth are cleaned with pumice slurry, rinsed, dried, and isolated with cotton rolls. If the cervical area of the retainer is subgingival, the dentist inserts a retraction cord in the gingival crevice to displace the tissue and prevent seepage. The bridge should be carefully tried in place to review the path of insertion and to verify the fit. On removal, the bridge is placed in a convenient location near where the resin-bonding medium will be mixed.

The dentist artfully applies the etching gel for 30 seconds to the prepared enamel and slightly past the margins. The acid must not be allowed to flow onto the unprepared proximal areas of the abutment or adjacent teeth. After rinsing, the teeth are dried of all visible moisture (see Online Fig. 21-11, *H*). If a lightly frosted surface is not present, the etching procedure is repeated. A clean, dry surface is absolutely essential. The slightest amount of saliva contaminates the etched enamel and necessitates an additional 10 seconds of etching, followed by rinsing and drying. A rubber dam is preferred for isolation; however, cotton rolls and gingival retraction cord provide adequate isolation in selected areas where salivary flow can be controlled.

The manufacturer's instructions for the bonding procedure should be read and followed. Usually, equal parts of the resin cement (i.e., base and catalyst) are placed on one mixing pad, and equal parts of the adhesive (i.e., base and catalyst) are placed on another mixing pad. The operator mixes the adhesive with a small, foam sponge or brush and quickly paints a thin layer on the tooth side of the bridge and then onto the etched enamel. While the operator uses the air syringe to blow the excess adhesive off the bridge and then the enamel, the assistant mixes the resin cement and places a thin layer on the tooth side of the bridge retainers. The bridge is positioned on the abutment teeth and held in place with a polyester strip over the lingual surface. The retainers are seated and held firmly in place with the index fingers positioned on the strip over the lingual retainers, and the thumbs are held on the facial aspect of the abutment teeth to equalize the pressure (see Online Fig. 21-11, *I*). The amount of resin cement at the facial and gingival embrasures is quickly inspected. Sometimes, the assistant may need to add more cement or remove excess unpolymerized resin with an explorer or plastic instrument. Priority is given to the gingival embrasure because later correction is more difficult in this area.

FINISHING PROCEDURE

After the resin cement has hardened, the dentist removes the polyester strip and inspects the lingual area. If voids are present, more resin is mixed and added. Additions bond to the

previously placed resin cement without additional surface treatment. The dentist removes excess resin along the lingual margins with a discoid–cleoid hand instrument, evaluates the occlusion, and makes any necessary adjustment. Contouring and polishing are accomplished in the usual manner with carbide finishing burs, fine diamonds, hand instruments, and disks. A completed Rochette-type bridge is shown in Online Figure 21-11, *J and K*, as viewed from the facial and lingual aspects. When the bridge is complete, the patient is instructed on how to use a floss threader and dental floss to clean under the pontic and around the abutment teeth. Another example of an anterior resin-bonded bridge replacing both maxillary central incisors is shown in Online Figure 21-12.

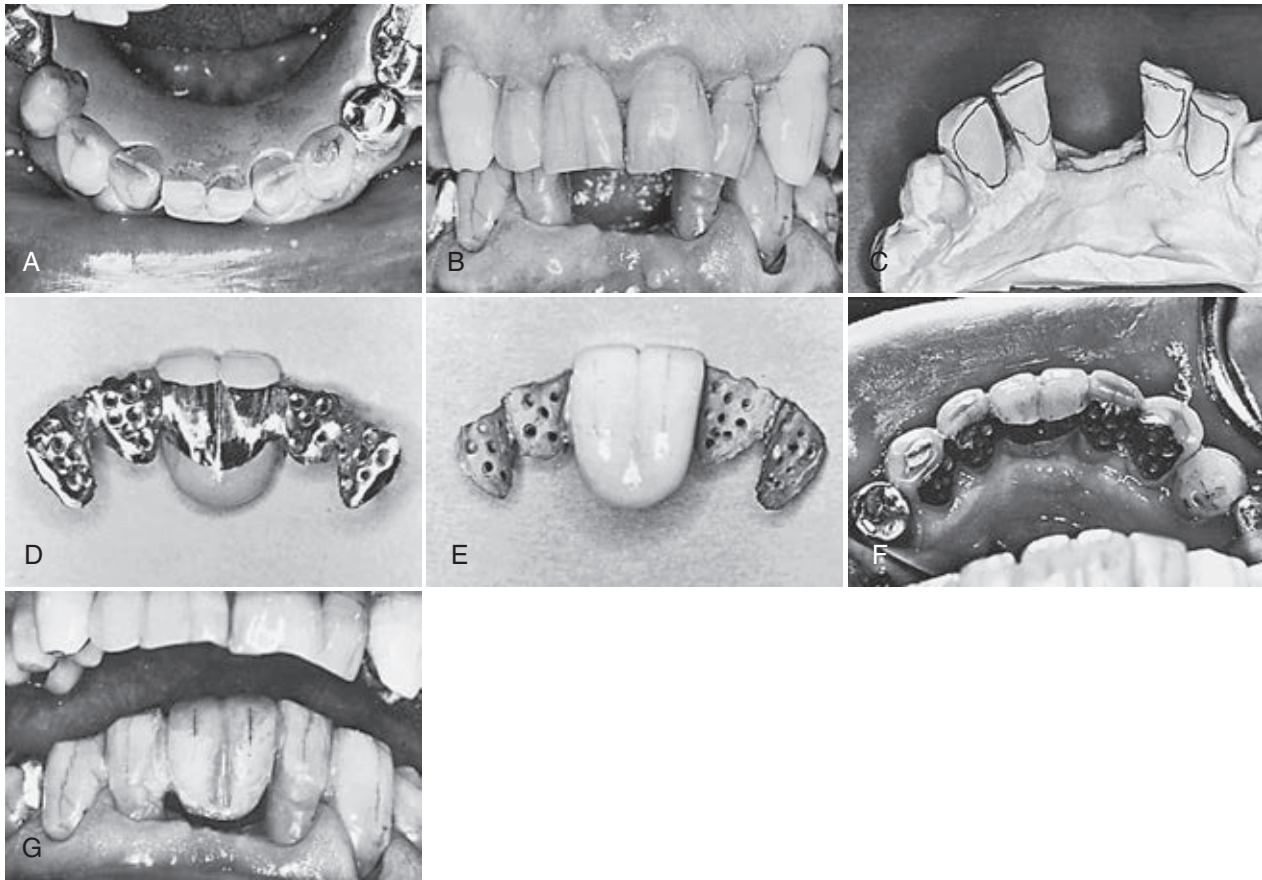
Mandibular Anterior Splint-and-Bridge Combination

An indication for a conservative bridge that incorporates a splint design of the PFM framework is illustrated in Online Figure 21-13. The patient's mandibular central incisors were extracted because of advanced periodontal disease. The weak lateral incisors are stabilized by including the canines in a splint-and-bridge design. These teeth are caries-free and have no restorations. An ill-fitting removable, partial denture was uncomfortable and did not support the adjacent teeth (see Online Fig. 21-13, *A and B*).

The preparations for the splint-and-bridge combination consist of removing approximately 0.3 mm of enamel on the lingual aspect of the lateral incisors and canines (as outlined on the laboratory cast) and preparing proximal retention grooves (see Online Fig. 21-13, *C*). The perforated design of the winged retainers was the Rochette type for ease of replacement or repair (see Online Fig. 21-13, *D and E*). The splint bridge is bonded by the method previously described (see Online Fig. 21-13, *F and G*). The gingival aspect of the pontic is free of tissue contact and has sufficient space for cleaning. A similar splint also can be achieved with a Maryland bridge design.

Mandibular Posterior Bridge with Metal-and-Porcelain Pontic

In Online Figure 21-14, *A*, a missing mandibular first molar needs to be replaced to maintain proper occlusal contacts and to preserve the integrity of the arch. A clinical examination with radiographs confirms that the abutment teeth are in good alignment and are sound and that the occlusion is favorable. Conservative amalgam restorations have been inserted to correct the occlusal fissures on the abutment teeth. Impressions and a bite registration are made for study casts. An acid-etched, resin-bonded, cast metal bridge (Maryland type),



Online Fig. 21-13 Resin-bonded mandibular anterior porcelain-fused-to-metal bridge and splint. **A**, The patient is wearing ill-fitting removable acrylic partial denture. **B**, Edentulous space resulting from missing mandibular central incisors. **C**, Laboratory model with preparations outlined. **D**, Lingual view of completed prosthesis (Rochette type with multiple countersunk perforations). **E**, Facial view of completed prosthesis. **F**, Lingual view of prosthesis bonded in place with composite. The anterior segment is stabilized by the splinting effect of the bridge retainers. **G**, Facial view of porcelain-fused-to-metal pontics bonded in place.

including a porcelain pontic with metal, occlusal, and centric stops, provides for optimal occlusal wear resistance and an acceptable esthetic result.

The dentist uses a surveyor to determine the most favorable path of draw and marks the outline of the retainer area with a pencil (see Online Fig. 21-14, *B*). The occlusal rest areas provide rigidity and resistance form to vertical forces, and the extensions on the facial and lingual surfaces provide a “wrap-around” design for added retention and resistance against lateral forces. In this example, the patient’s teeth have sufficient crown length to avoid subgingival margination.

PREPARATION

Prophylaxis, shade selection, and any needed occlusal adjustment are accomplished before the preparations are begun. As with the anterior teeth, some preparation is necessary to provide draw, to increase retention and resistance forms, and to provide bulk to the retainers for strength without overcontouring. Preparation is minimal and involves only enamel. Using the surveyed penciled cast as a reference, the dentist prepares the patient’s teeth with a coarse, tapered, rounded-end diamond instrument (see Online Fig. 21-14, *C*). The occlusal rests are prepared with a round diamond instrument. An elastomeric impression and a bite registration are made for laboratory use.

LABORATORY PHASE

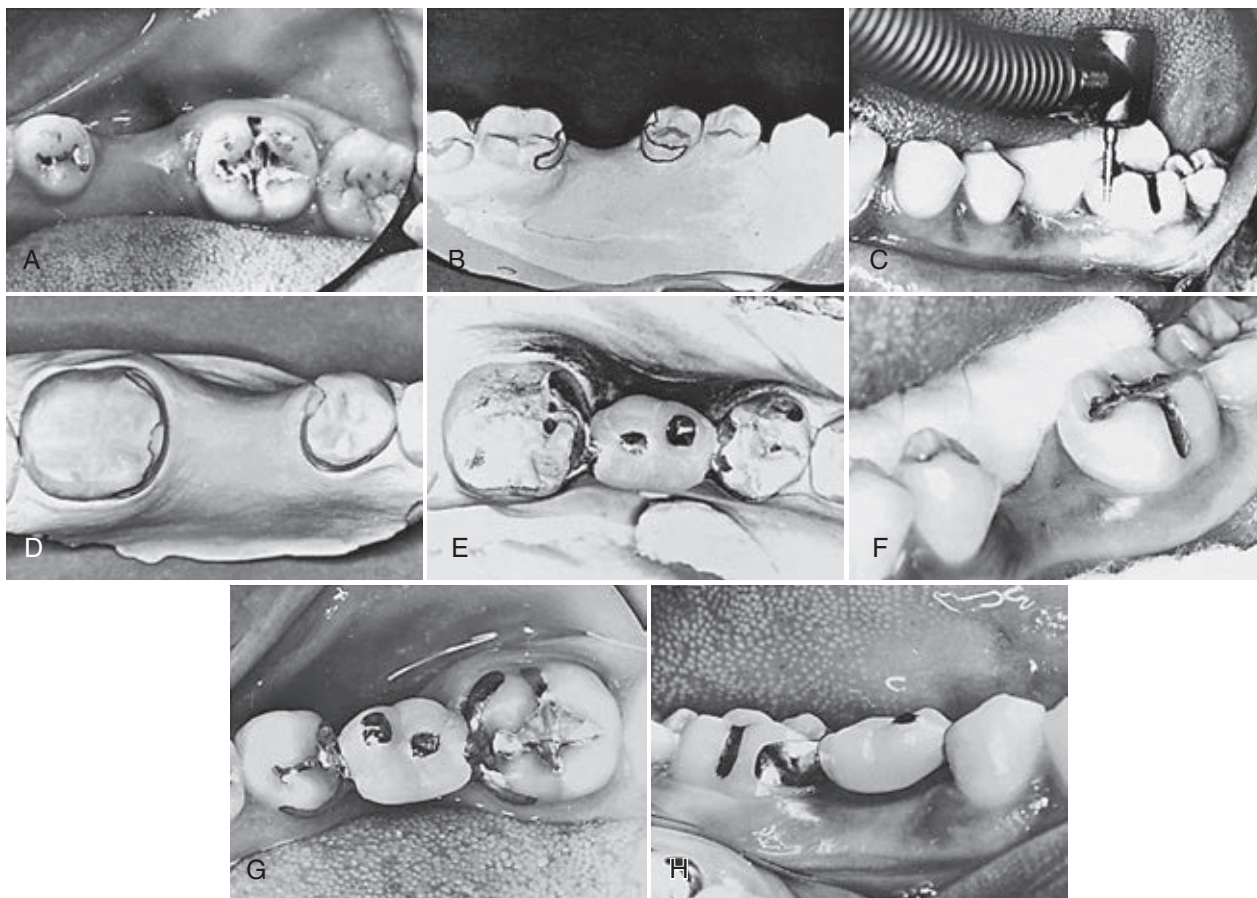
The dentist includes a sketch of the bridge design with the laboratory instructions. The nonperforated, etched metal design (Maryland) is specified in this instance because the “wings” are very thin, and other areas of the bridge are inaccessible for placing perforations. It is helpful to the technician if the margins of the preparation are marked with an indelible pencil (see Online Fig. 21-14, *D*). Before any glazing of porcelain or polishing of framework or etching of metal, the bridge is returned to the dentist for the try-in stage (see Online Fig. 21-14, *E*).

TRY-IN STAGE

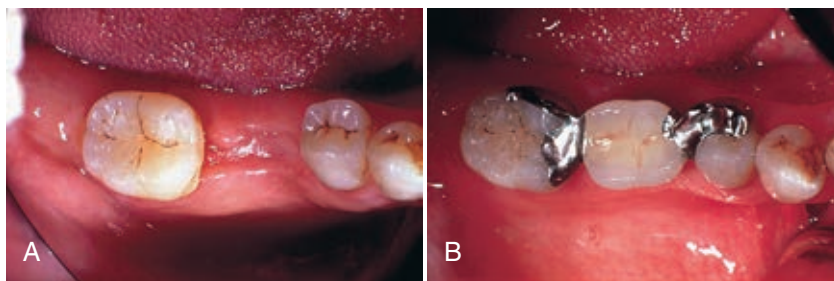
The dentist seats the bridge and evaluates for proper fit, occlusion, and color matching. After adjustments are made, the bridge is returned to the laboratory for corrections, final glazing, polishing of the metal framework, and etching or other metal treatment procedures. The etched metal must be examined under a microscope to ensure that proper etching of the metal has occurred.

BONDING STEPS

Care must be exercised in handling the bridge because the etched area can be contaminated easily. The bridge should not



Online Fig. 21-14 Conservative mandibular posterior bridge with a combination metal and porcelain pontic. (A, G, and H are mirror views.) **A**, Missing mandibular first molar with occlusion identified by marks from articulating paper. **B**, Study model surveyed and outlines of the preparation marked with pencil. **C**, Preparation of axial surfaces with coarse, cylindrical, diamond instrument. **D**, Laboratory model with margins outlined. **E**, Completed bridge on cast ready for try-in. Note the centric contacts on metal to minimize wear of the opposing teeth. **F**, Teeth cleaned, isolated, and etched. **G**, Occlusal view of bonded bridge. **H**, Facial view of the bonded bridge.



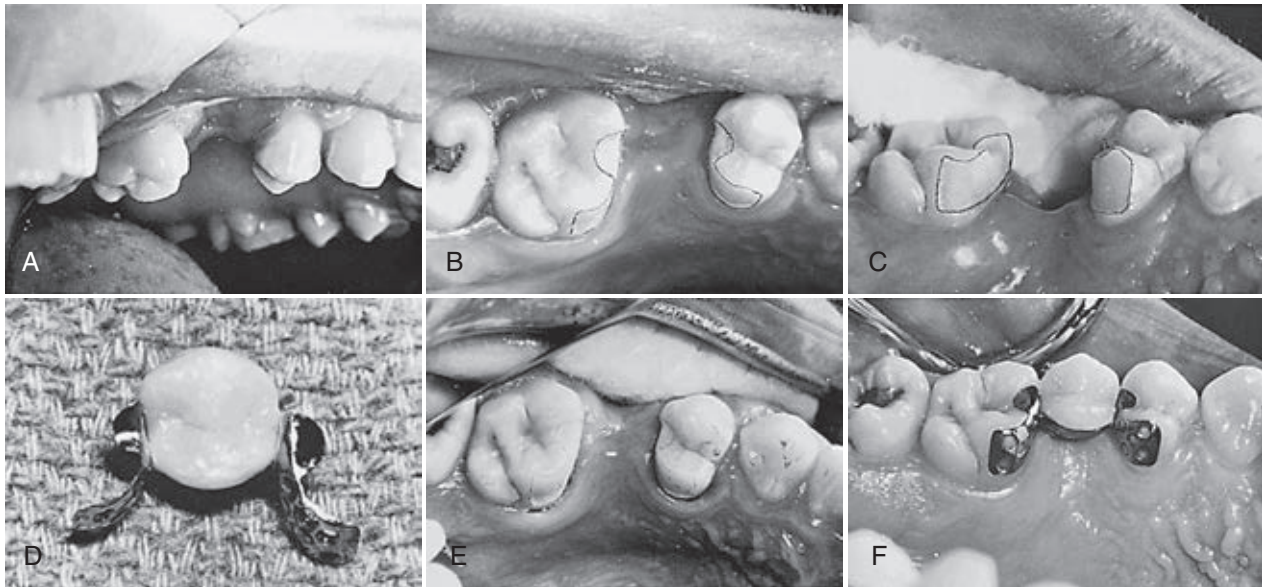
Online Fig. 21-15 **A** and **B**, Maryland-type, resin-bonded posterior bridge. A missing mandibular right first molar is conservatively replaced by a porcelain-fused-to-metal, resin-bonded bridge.

be tried in place (again) until teeth are isolated, and enamel has been etched (see Online Fig. 21-14, F). Rubber dam isolation is preferable when bonding mandibular resin-bonded bridges. Cotton roll isolation can be used with retraction cords if a rubber dam cannot be placed. Being careful not to touch or contaminate the etched metal, try-in of the bridge is done to verify fit and path of draw. Everything must be “ready to go” as the manufacturer’s instructions are followed for mixing and applying the bonding materials to teeth and the bridge. The preparations must be clean and dry to ensure proper bonding. When the bridge is in place, a polyester strip is placed over the pontic, and finger pressure is used to secure the bridge until polymerization is complete. After removal of

the excess resin, the occlusion is evaluated. The occlusal and facial views are esthetic with only the centric contacts in metal (see Online Fig. 21-14, G and H). Another example of a posterior, resin-bonded, Maryland-type bridge is shown in Online Figure 21-15.

Maxillary Bridge with Porcelain-Fused-to-Metal Pontic

Online Figure 21-16, A, illustrates a space resulting from the extraction of a maxillary second premolar. As with the mandibular bridge, resistance to lateral forces must be provided by the design of the preparations and resulting prosthesis.



Online Fig. 21-16 Maxillary posterior resin-bonded bridge with porcelain-fused-to-metal pontic. **A**, Preoperative photograph (*mirror view*) of a missing maxillary second premolar. **B** and **C**, Outlined final tooth preparations: occlusal (**B**) and lingual (**C**) views. **D**, Completed prosthesis. **E**, Etched preparations isolated and ready for bonding. **F**, Porcelain-fused-to-metal bridge bonded in place.



Online Fig. 21-17 Resin-bonded mandibular posterior all-metal bridge. **A**, Edentulous space resulting from loss of first molar and distal migration of second premolar. **B** and **C**, All-metal bridge with electrolytically etched retainers (Maryland type) bonded in place: occlusal view (**B**) and lingual view (**C**). Note non-tissue-contacting, hygienic-type pontic. (Courtesy of Dr. William Sulik.)

Because esthetics is more critical in the maxillary arch, however, the wrap-around design used in the mandibular arch cannot be employed to as great an extent, especially in the area adjacent to the facial aspect of the pontic. Proximal grooves are prepared (in enamel) in the same occlusogingival orientation as the path of draw to provide additional resistance form to lateral forces. The lingual extensions and occlusal rests are prepared as described for the mandibular bridge (see Online Fig. 21-16, *B* and *C*). For retention, perforations in the retainer (e.g., Rochette design) are used in addition to acid-etching the preparations. Perforations are placed in the accessible lingual extensions. This design aids in removing the bridge if replacement becomes necessary (see Online Fig. 21-16, *D*). The etched preparations, which are ready for bonding, are illustrated in Online Figure 21-16, *E*. The completed bonded bridge is shown in Online Figure 21-16, *F*.

Mandibular Posterior Bridge with Metal Pontic

Online Figure 21-17, *A*, illustrates a space between the mandibular premolars resulting from extraction of the permanent

first molar at an early age and subsequent distal migration of the second premolar. Because esthetics was not a factor, an all-metal bridge (e.g., Maryland type) with a hygienically designed pontic was used. The steps are identical to the steps for the mandibular posterior bridge with a PFM pontic (as discussed earlier). The bridge is shown in Online Figure 21-17, *B* and *C*, after several years of service.

All-Porcelain Pontic

Improvements in dental porcelains along with the capacity to etch and bond strongly to porcelain surfaces have made all-porcelain pontics a viable alternative to pontics with metal winged retainers (e.g., Maryland and Rochette bridges).^{10,11} Although all-porcelain pontics are not as strong as pontics with metal retainers, far superior esthetic results can be achieved because no metal substructure or framework is present. All-porcelain pontics often can be used when tooth anatomy precludes or restricts the preparation and placement of a metal winged pontic. Long, pointed canines with proximal surfaces exhibiting little occlusogingival height often lack adequate areas for the placement of retention grooves. Anterior teeth that

are notably thin faciolingually also are not good candidates for metal, resin-bonded bridge retainers and often are esthetic failures because of metal showing through the tooth. In both instances, custom-fabricated, etched porcelain pontics frequently can provide an esthetic, functional alternative.

All-porcelain pontics are particularly indicated in adolescents and young adults, in whom virgin, unrestored teeth are often encountered. Because teeth are not extensively prepared, this procedure is almost entirely reversible. This is a major benefit in young patients, where all-porcelain pontics can be placed as interim restorations until implants or a more permanent prosthesis can be placed at an older age. Because of their limited strength, all-porcelain pontics should be considered provisional in nature, similar to the natural tooth pontic and the acrylic denture tooth pontic.

Similar to the natural tooth and denture tooth pontics, certain prerequisites must be met to ensure a successful result. First, the abutment teeth must be in reasonably good condition with proximal enamel surfaces that are intact or contain very small composite restorations. Second, the abutment teeth should be stable with little mobility present. If the abutment teeth are mobile, it is frequently necessary to secure them as well by splinting with composite to adjacent teeth before placement of the bonded pontic (see the section on acid-etched, resin-bonded splints). Third, the pontic must not be placed in a position that would subject it to heavy centric or functional occlusal contacts. Because of these occlusion concerns, canines and posterior teeth are not usually good candidates for these types of resin-bonded bridges.

TECHNIQUE

Online Figure 21-18, A and B, illustrates a typical case of congenitally missing lateral incisors in which tooth contours contraindicated the use of resin-retained bridges with metal retainers. Central incisors are very translucent, and the mesial contours of canines are deficient (see Online Fig. 21-18, C and E). After assessing centric and functional occlusions, it was determined that all-porcelain pontics could be placed without subjecting them to heavy occlusal forces. At the first appointment, the involved abutments are cleaned with flour of pumice, and an accurate shade selection is made, noting any desired color gradients or characterizations.

No preparation of the teeth is recommended, unless the proximal surfaces of the abutment teeth adjacent to the edentulous space are markedly convex. In such cases, slight flattening of the proximal surfaces with a diamond instrument facilitates closer adaptation of the pontic to the abutment teeth, increasing strength of the connectors. Otherwise, no retentive features are recommended for the preparation in the abutment teeth; the connector areas are entirely made of composite.

Bridge connectors composed of porcelain are subject to eventual fatigue fracture, after which repair is made more difficult. Studies show that “veneer bridges” (i.e., all-porcelain pontics retained by adjacent etched porcelain veneers), in particular, are the weakest design of all and should be avoided.¹¹ These types of bridges not only provide little bond strength to the pontic but also needlessly cover adjacent, healthy facial tooth surfaces. All-porcelain pontics (composite used for bonding to the abutment teeth) are similar to extracted natural tooth pontics in this regard. Those that have connector areas consisting of the design feature allow for easy repair and

replacement of the composite connector should a fracture in this area be encountered.

If high-strength ceramics that are totally immune to crack propagation and cohesive fracture are developed, retentive features prepared in the adjacent abutment teeth may be desired. These features, prepared in enamel, would consist of proximal grooves or boxes, depending on the faciolingual dimension of the proximal surfaces. In the absence of such totally fracture-resistant ceramics, however, all-porcelain pontics are best placed with composite connectors for ease of repair and replacement.

An elastomeric impression is made, and a working cast is generated from it. A modified ridge lap pontic tip design as previously described (see Online Fig. 21-6, B) is recommended. An occlusal bite registration should be made and forwarded to the laboratory so that the occlusal relationship can be considered during fabrication of all-porcelain pontics. The proximal surfaces of the pontics are etched with hydrofluoric acid. The area etched must include all areas anticipated for bonding to the composite-bonding medium. The etched proximal surfaces should extend just beyond the lingual line angles so that additional composite can be placed in the lingual embrasure areas for additional connector strength.

At the subsequent appointment, teeth are isolated with cotton rolls. A 2 × 2 inch (5 × 5 cm) cotton gauze is placed across the back of the patient’s mouth to act as a protective shield should the pontic be inadvertently dropped. A rubber dam is not recommended for this procedure because it precludes accurate assessment of the adaptation of the pontic tip to the residual ridge.

Before the teeth dehydrate, the position of each pontic is tested in the edentulous space to assess the shade and relationship of the pontic tip to the residual ridge. The pontic tip should contact the residual ridge passively with no blanching of the underlying tissue evident. Spaces of approximately 0.3 to 0.5 mm should exist between the pontic and the abutment teeth because stronger connectors are provided by the additional bulk of composite material. Care must be taken not to allow contamination of the etched pontic from saliva to occur during the try-in phase. If saliva contamination occurs, the etched proximal surfaces of the pontic must be cleaned thoroughly with alcohol and dried. After try-in, all etched proximal surfaces of the porcelain pontics are primed with a suitable silane-coupling agent (see the manufacturer’s instructions for the specific technique). The pontics are now ready for bonding.

The involved proximal enamel surfaces of the abutment teeth are roughened with a coarse, flame-shaped diamond instrument. Thereafter, all of the prepared (i.e., roughened) enamel surfaces should be acid-etched, rinsed, and dried. Care must be taken to maintain clean, dry, uncontaminated etched surfaces until the pontic is positioned and bonded. The abutment teeth are now ready for bonding.

A light-cured composite is preferred for bonding all-porcelain pontics because the extended working time allows the operator to contour the connectors initially before polymerization. The dentist applies the adhesive to the etched surfaces of the porcelain pontic and the abutment teeth and lightly blows with air to remove the excess. A 20-second application of light from the light-curing unit is used to polymerize the bonding agent on each etched surface.



Online Fig. 21-18 All-porcelain pontics. **A** and **B**, Patient with congenitally missing lateral incisors. **C** and **D**, Right side before and after treatment. **E** and **F**, Left side before and after placement of all-porcelain pontic. **G**, Lingual view of completed bridges. **H**, Facial view of all-porcelain pontics.

A small amount of composite material is placed on the proximal contact areas of the natural tooth pontic, and the pontic is inserted carefully into the proper position in the edentulous space. A stent, or index, made from bite registration material or fast-setting plaster can be used to position the pontic, if desired. Positioning by hand is recommended, however, so that optimal gingival pressure can be maintained for best tissue adaptation. The dentist shapes the excess composite extruding from the connector areas around the contact areas with an explorer tip or small plugger end of a composite instrument. After final verification that the pontic position is correct, the composite is polymerized with light for a minimum of 40 to 60 seconds each from facial and lingual directions (for a total of 80–120 seconds).

Additional composite is applied in the proximal areas (more material is added on the lingual surface than on the facial surface), contoured, and polymerized. Adequate gingival embrasures must be maintained to facilitate flossing and ensure good gingival health. After sufficient material has been added and polymerized, the dentist shapes and smooths the embrasure areas with carbide finishing burs, fine diamonds, and polishing disks. Facial embrasures are defined for esthetics, but lingual embrasures are closed with composite to strengthen the connectors (see Online Fig. 21-18, D, F, and G).

The dentist evaluates the occlusion centric contacts and functional movements. Heavy contacts on the pontic or the connector areas must be adjusted. The finished bridges (immediately after bonding) are illustrated in Online Figure 21-18, D and F through H. As with all resin-bonded bridges, patients must be advised to avoid biting into hard foods or objects to reduce the risk for dislodgment. Also, as noted

earlier, the patient must be advised, as part of informed consent, that although the chances are remote, the potential for dislodgment and the risk of swallowing or aspirating the pontic do exist. This possibility exists for all resin-bonded bridges, and patients must be warned of this hazard, even though the risk is minimal.

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Direct Gold Restorations

Gregory E. Smith

Direct Golds and Principles of Manipulation

Several types of dental restorative materials are currently available. Generally, they are grouped into categories such as amalgam, cast gold, tooth-colored material, dental porcelain, porcelain-fused-to-metal (PFM), and direct gold. Direct gold is a gold restorative material that is manufactured for compaction directly into prepared cavities. Two types of direct gold are manufactured for dental use: gold foil and powdered gold. These gold materials differ in their metallurgic structure.

Pure gold has been in use in dentistry in the United States for more than 100 years.¹⁻⁶ Various techniques have been advanced for its use in the restoration of teeth. It is generally agreed that this noble metal is a superior restorative material for treatment of many small lesions and defects in teeth, given sound pulpal and periodontal health. Success is achieved with direct gold restorations if meticulous care is given to an exacting technique in tooth preparation design and material manipulation. Direct gold restorations can last for a lifetime if attention is paid to details of restorative technique and to proper home care. The longevity of direct gold restorations is a result of the superb biocompatibility of gold with the oral environment and its excellent marginal integrity.

This chapter discusses the various forms of direct gold presently available and explains the principles required for their manipulation. The principles of tooth preparation are reviewed as they are applied to direct gold restorations. Class I, V, and III preparations and their restoration are considered in detail.

Materials and Manufacture

Several physical types of direct-filling gold have been produced.⁷ All are “compactable” in that they are inserted into tooth preparations under force and compacted or condensed into preparation line and point angles and against preparation walls.

Gold foil is manufactured by beating pure gold into thin sheets. The gold foil is cut into 4 × 4 inch (10 × 10 cm) sheets and sold in books of sheets, separated by pages of thin paper. The books contain $\frac{1}{10}$ oz or $\frac{1}{20}$ oz of gold. The sheet of foil that weighs 4 g is termed No. 4 foil; the sheet weighing 3 g is

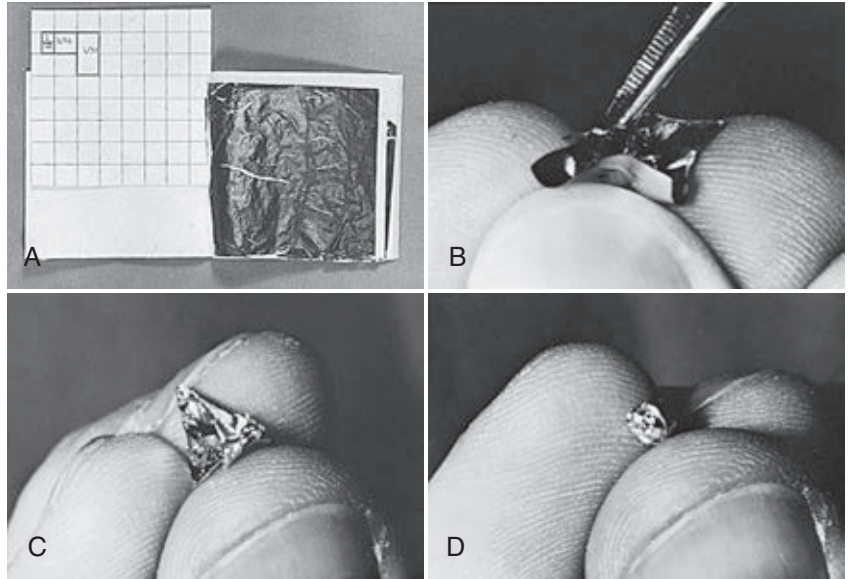
termed No. 3 foil; and the sheet weighing 2 g is termed No. 2 foil. Because the 4 × 4 inch sheets are too large to be used in restorative procedures, they are rolled into cylinders or pellets before insertion into tooth preparations. (The gold foil referred to in the restorative sections of this chapter is in pellet form.)

Pellets of gold foil are generally rolled from $\frac{1}{32}$ -inch, $\frac{1}{43}$ -inch, $\frac{1}{64}$ -inch, or $\frac{1}{128}$ -inch sections cut from a No. 4 sheet of foil. The book of foil is marked and cut into squares or rectangles (Online Fig. 22-1, A). Each piece is placed on clean fingertips, and the corners are tucked into the center (see Online Fig. 22-1, B and C), and then the foil is lightly rolled into pellet form (see Online Fig. 22-1, D). In addition, cylinders of gold foil may be rolled from the segments of a sheet (see Online Fig. 22-1, A). After pellets of gold are rolled, they may be conveniently stored in a gold foil box (Online Fig. 22-2), which is divided into labeled sections for various sizes of pellets. Cylinders of foil and selected sizes of other types of gold also may be stored in the box. Preferential contamination is suggested by placing a damp cotton pellet dipped into 18% ammonia into each section of the box. This serves to prevent deleterious oxides from forming on the gold until it is used.

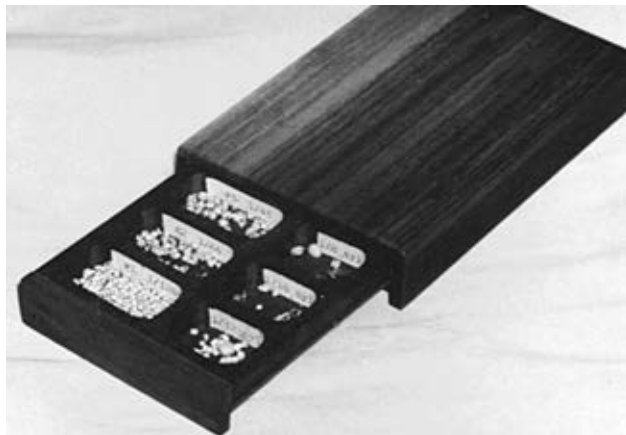
Powdered gold is made by a combination of chemical precipitation and atomization, with an average particle size of 15 mm (Online Fig. 22-3, A).⁸ The atomized particles are mixed together in wax, cut into pieces, and wrapped in No. 4 or No. 3 foil (see Online Fig. 22-3, B). Several sizes of these pellets are available. This product is marketed as Williams E-Z Gold (Ivoclar-Williams, Amherst, NY).

Cohesion and Degassing

Direct gold is inserted into tooth preparations under force. The purpose of the force is to weld the gold into restorations containing minimal porosity or internal void spaces.⁹⁻¹¹ Welding occurs because pure gold with an absolutely clean surface coheres as a result of metallic bonding. As the gold is forced and compressed into a tooth preparation, succeeding increments cohere to those previously placed. For successful welding to occur during restoration, the gold must be in a cohesive state before compaction, and a suitable, biologically compatible compacting force must be delivered.



Online Fig. 22-1 **A**, 4 × 4 inch book of foil marked for cutting and rolling into pellets of various sizes. **B** and **C**, Corners of foil piece are tucked into center. **D**, Foil is rolled into a completed pellet. (**A**, Courtesy of Terkla and Cantwell.)



Online Fig. 22-2 Gold foil box. Compartments are labeled to show pellet size.

Direct gold may be either cohesive or noncohesive. It is noncohesive in the presence of surface impurities or wax, which prevents one increment of gold from cohering to another. The manufacturer supplies books of gold foil or pre-rolled cylinders in a cohesive or noncohesive state. E-Z Gold pellets are supplied with a wax coating that must be burned off before compaction.

Because gold attracts gases that render it noncohesive, such gases must be removed from the surface of the gold before dental compaction. This process usually is referred to as *degassing* or *annealing* and is accomplished by application of heat. The term *degassing* is preferable because the desired result is to remove residual surface contamination (although further annealing, resulting in additional internal stress relief or recrystallization, also may occur in this process). All direct-filling gold products are degassed immediately before use except when noncohesive foil is specifically desired. Underheating during degassing should be avoided because it fails to render the gold surface pure. Over-heating also should be avoided because it may cause the gold to become brittle or

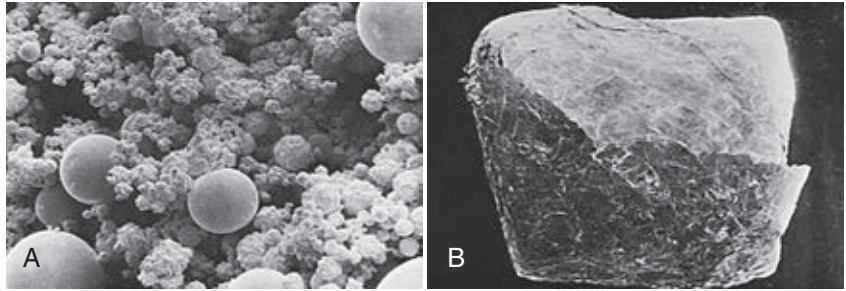
melt and render it unusable. Degassing is accomplished by heating the gold foil on a mica tray over a flame or on an electric annealer or by heating each piece of gold over a pure ethanol flame (Online Fig. 22-4).

The advantage of the technique involving use of the pure ethanol flame is that each piece of gold is selected and heated just before insertion, and waste of gold is avoided. A careful technique is needed to degas an increment of gold in the flame correctly. The gold is passed into the blue inner core of the flame on the tip of a foil-passing instrument and held just until the gold becomes dull red, and then the instrument is withdrawn from the flame. After a few seconds are allowed for cooling, the gold is placed in the preparation. Although any of the three degassing procedures is satisfactory for gold foil, this is not the case for E-Z Gold. The E-Z Gold pellet must be heated $\frac{1}{2}$ to 1 inch above the ethanol flame until a bright flame occurs (caused by ignition of the wax) and the pellet becomes dull red for 2 to 3 seconds, then it is withdrawn from above the flame.

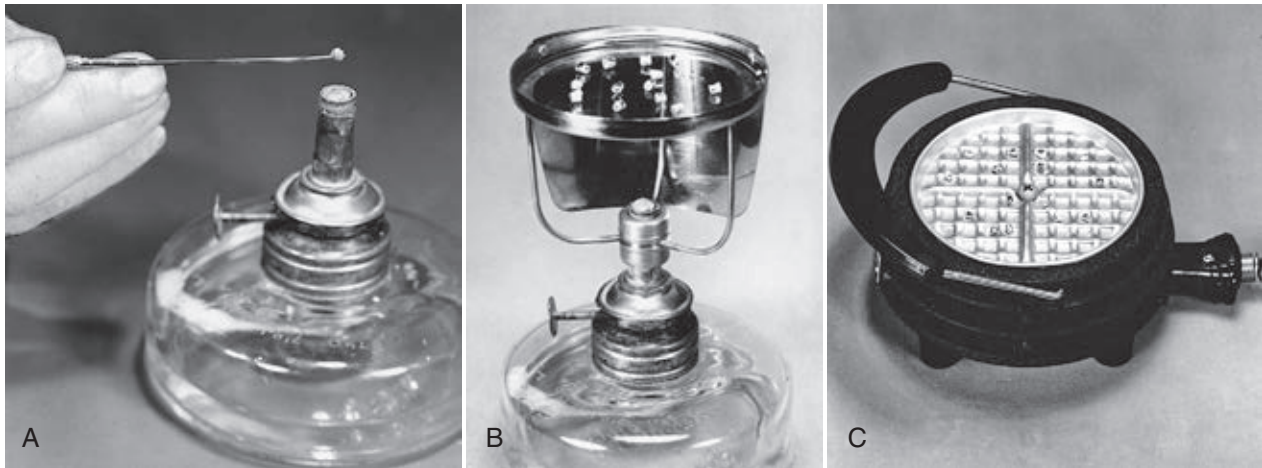
Principles of Compaction

Direct-filling gold must be compacted during insertion into tooth preparations.¹² With the exception of E-Z Gold, the compaction takes the form of malleting forces that are delivered either by a hand mallet used by the assistant or by an Electro-Mallet (McShirley Products, Glendale, CA) or a pneumatic mallet used by the dentist. E-Z Gold, because of its powdered form, may be compacted by heavy hand pressure delivered in a rocking motion with specially designed hand condensers.^{13,14} Successful malleting of the gold foil may be achieved with any of the currently available equipment. Some operators prefer the Electro-Mallet or the pneumatic mallet because a dental assistant is not required for the procedure.

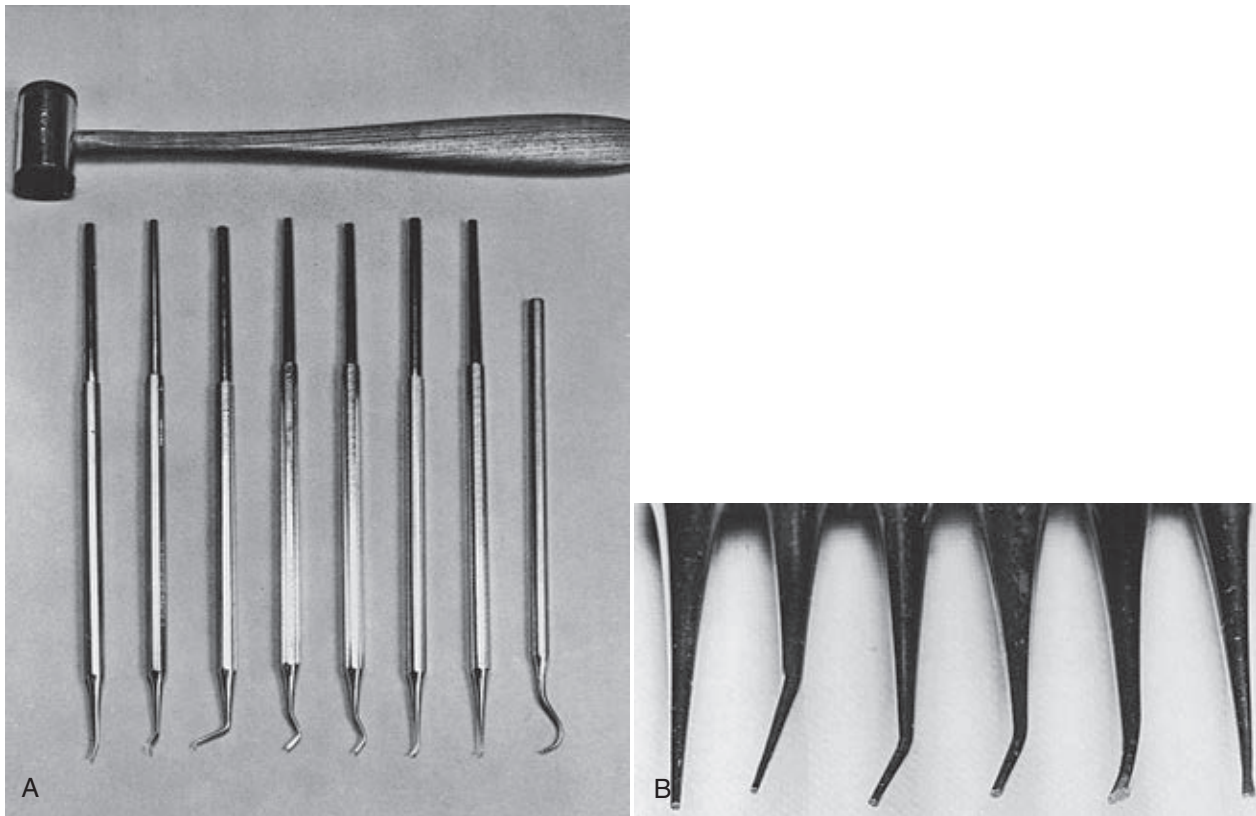
A technique preferred by many clinicians uses a hand mallet to deliver light blows to a condenser held by the dentist (Online Fig. 22-5, A). This technique allows great control of malleting forces when variations are called for, and it allows for rapid change in condenser nibs, or tips, when a multitude



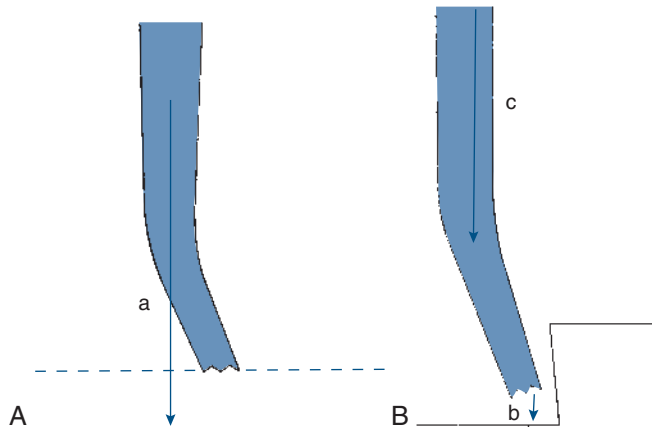
Online Fig. 22-3 Scanning electron micrographs of direct-filling golds. **A**, Spheres of E-Z Gold. **B**, Wrapped E-Z pellet that contains spheres. (Courtesy of Ivoclar-Williams Company, Inc., Amherst, NY.)



Online Fig. 22-4 **A**, Pellet of gold foil is degassed in pure ethanol flame. **B**, Mica tray mounted over alcohol lamp for degassing several increments of gold simultaneously. **C**, Gold foil degassed on an electric annealer. (Courtesy of Terkla and Cantwell.)



Online Fig. 22-5 **A**, Hand mallet and condensers used for hand mallet compaction of direct gold. **B**, Selection of variously shaped nibs. Left to right, Three round-faced nibs, oblique-faced nib, foot condenser, and rounded rectangular nib. (A, Courtesy of Terkla and Cantwell.)



Online Fig. 22-6 **A**, Oblique-faced condenser with the nib face established perpendicular to long axis of handle and perpendicular to line of force (a). **B**, Conventional monangle condenser; the nib face is not perpendicular to line of force (b); the condenser nib face is established perpendicular to end portion of shank rather than perpendicular to handle (c).

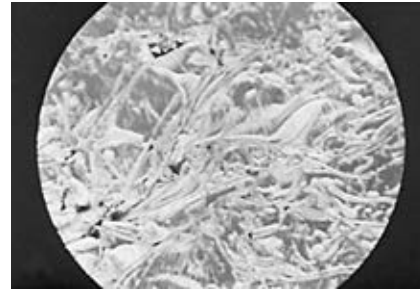
of condensers is required. In any case, a suitable condenser must be stepped over the gold systematically to achieve a dense, well-compacted restoration (see [Online Fig. 22-8](#)).

Condensers are designed to deliver forces of compaction to direct gold. Condensers used in the handpieces of the Electro-Mallet or pneumatic mallet consist of a nib, or working tip, and a short shank (approximately 1 inch [2.5 cm] in length) that fits into the malleting handpiece. Condensers used with the hand mallet are longer (approximately 6 inches [15 cm]) and have a blunt-ended handle that receives light blows from the hand mallet.

Condenser nibs are available in several shapes and sizes (see [Online Fig. 22-5, B](#)). All have pyramidal serrations on the nib faces to prevent slipping on the gold. Condensers described in this chapter are (1) the round condensers, 0.4 to 0.55 mm in diameter; (2) the Varney foot condenser, which has a rectangular face that is approximately 1 to 1.3 mm, and (3) the parallelogram condensers, which are used only for hand pressure compaction and have nib faces that measure approximately 0.5 to 1 mm.

Condenser shanks may be straight, monangled, or offset, and their nib faces may be cut perpendicular to the long axis of the handle or perpendicular to the end portion of the shank ([Online Fig. 22-6](#)). The smaller the nib face size (i.e., area), the greater the pounds per square inch delivered (given a constant malleting force). If the nib diameter is reduced by half, the effective compaction force in pounds per square inch is four times greater (because the area of a circle is proportional to the square of the diameter). For most gold, the 0.4- to 0.55-mm diameter nibs are suitable. Smaller condensers tend to punch holes in the gold, whereas larger ones are less effective in forcing the gold into angles in the tooth preparation.

Two fundamental principles involved in compaction of cohesive gold are to (1) weld the gold into a cohesive mass and (2) wedge as much gold as possible into the tooth preparation.¹⁵ Welding takes place primarily as a result of the coherence of the noble metal to itself. Wedging results from careful compacting technique. Regardless of the technique used, some



Online Fig. 22-7 Compacted gold foil. Linear channels are evident between creases in the foil pellet. Dark spots are void spaces in the compacted mass.

bridging occurs, resulting in void spaces not only in the compacted gold but also along the preparation walls. Success depends on minimizing these voids, particularly on the surface of the restoration and at the cavosurface interface, where leakage to the internal aspects of the restoration may begin. Gold foil compacts readily because of its thin form and produces a mass with isolated linear channels of microporosity ([Online Fig. 22-7](#)). Because the thin folds of the gold pellet weld to each other, the remaining channels of microporosity do not appear to be entirely confluent with one another.

It is recommended that compaction of E-Z Gold be done by hand pressure. As compaction is performed, the bag of atomized gold is opened, and the spheres of gold powder move over one another and against the preparation walls. Heavy and methodic hand pressure with the condensers is required to compact this form of gold effectively.

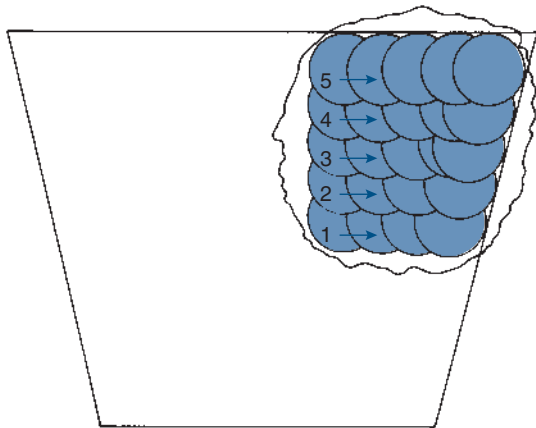
Compaction Technique for Gold Foil

Compaction begins when a piece of gold is placed in a tooth preparation. The gold is first pressed into place by hand, then a condenser of suitable size is used to begin malleting in the center of the mass (often this is done while this first increment is held in position with a holding instrument). Each succeeding step of the condenser overlaps (by half) the previous one as the condenser is moved toward the periphery ([Online Fig. 22-8](#)). The gold moves under the nib face of the condenser, effecting compaction as malleting proceeds.

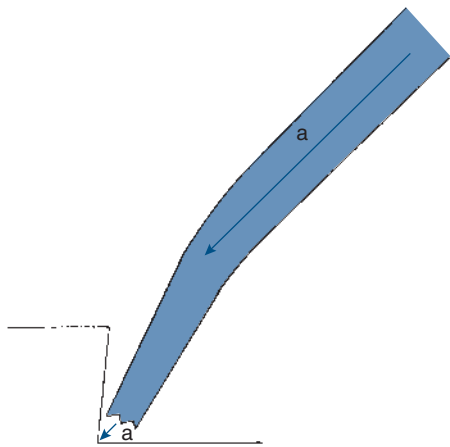
The most efficient compaction occurs directly under the nib face.¹⁵ Some compaction also occurs by lateral movement of the gold against surrounding preparation walls. The result of compaction is to remove most of the void space from within each increment of gold, to compact the gold into line and point angles and against walls, and to attach it to any previously placed gold via the process of cohesion.¹⁶

The line of force is important when any gold is compacted. The line of force is the direction through which the force is delivered (i.e., the direction in which the condenser is aimed) ([Online Fig. 22-9](#)). Specific instructions regarding line of force are given in subsequent sections as they relate to the restorations.

Research has shown that a biologically acceptable pulpal response occurs after proper direct gold procedures.¹⁷ Care is required when condensing forces are applied to preclude pulpal irritation. The Electro-Mallet is an acceptable condenser if the manufacturer's instructions for mallet intensity



Online Fig. 22-8 Diagrammatic order of compaction for increment of direct-filling gold. Condensers are moved across surface of gold in an orderly stepping motion. Each succeeding step of the nib overlaps the previous one by at least half of the nib face diameter. Condensation begins at position 1 and moves to the right, then resumes at 2 and repeats movement to the right. Finally, it continues in rows 3, 4, and 5.



Online Fig. 22-9 Line of force (a) remains parallel with the shaft or handle of the condenser, regardless of any angles in the shank of the instrument.

are followed. Correct hand-malleting technique requires a light, bouncing application of the mallet to the condenser, rather than delivery of heavy blows.

Compaction Technique for E-Z Gold

Using an amalgam condenser or a gold foil condenser, the first pellet of E-Z Gold is pressed into the depth of the tooth preparation and tamped into position. A small condenser is selected to thrust and wedge the gold into opposing line angles and against opposing walls, to secure the mass in the preparation. Additional pellets are added (one at a time, banking against the preparation walls) until the entire preparation is filled. To avoid creation of large void spaces in the restoration, a dense, fully condensed surface is obtained with each pellet before subsequent pellets are added.

Principles of Tooth Preparation for Direct Gold Restorations

Fundamentals of Tooth Preparation

The principles of tooth preparation for all direct gold restorations demand meticulous attention to detail for success. Failure to give attention to outline form may result in an unsightly restoration or, at the least, one in which cavosurface deficiencies are immediately obvious. Poor resistance form can result in tooth fracture; inadequate retention form may result in a loose restoration that is frustrating to the dentist. Lack of detailed convenience form may render an otherwise excellent tooth preparation unrestorable. The preparation must be smoothed and debrided to permit the first increments of gold to be stabilized.

The margins in outline form must not be ragged. They are established on sound areas of the tooth that can be finished and polished. The outline must include all structural defects associated with the lesion. The marginal outline must be designed to be esthetically pleasing because the final restoration may be visible.

Resistance form is established by orienting preparation walls to support the integrity of the tooth, such as a pulpal wall that is flat and perpendicular to occlusal forces. All enamel must be supported by sound dentin. Optimally placed axial or pulpal walls promote the integrity of the restored tooth, providing a suitable thickness of remaining dentin.

The retention form is established by parallelism of some walls and by strategically placed converging walls (as described in detail for each tooth preparation). In addition, walls must be smooth and flat, where possible (to provide resistance to loosening of the gold during compaction), and internal line angles must be sharp (to resist movement). Internal form includes an initial depth into dentin, ranging from 0.5 mm from the dentinoenamel junction (DEJ) in class I preparations to 0.75 mm from cementum in Class V preparations.

Optimal convenience form requires suitable access and a dry field provided by the rubber dam. Access additionally may require the use of a gingival retractor for Class V restorations or a separator to provide a minimal amount of separation (0.5 mm maximum) between anterior teeth for Class III restorations. Sharp internal line and point angles are created in dentin to allow convenient “starting” gold foil as compaction begins. Rounded form is permitted when E-Z Gold is used to begin the restorative phase. Removal of remaining carious dentin, final planing of cavosurface margins, and debridement complete the tooth preparation for direct gold.

Indications and Contraindications

Class I direct gold restorations are one option for the treatment of small carious lesions in pits and fissures of most posterior teeth and the lingual surfaces of anterior teeth. Direct gold also is indicated for treatment of small, cavitated Class V carious lesions or for the restoration, when indicated, of abraded, eroded, or abfraction areas on the facial surfaces of teeth (although access to the molars is a limiting factor). Class III direct gold restorations can be used on the proximal surfaces of anterior teeth where the lesions are small enough to be treated with esthetically pleasing results. Class II direct gold restorations are an option for restoration of small

cavitated proximal surface carious lesions in posterior teeth in which marginal ridges are not subjected to heavy occlusal forces (e.g., the mesial or distal surfaces of mandibular first premolars and the mesial surface of some maxillary premolars). Class VI direct gold restorations may be used on the incisal edges or cusp tips. A defective margin of an otherwise acceptable cast gold restoration also may be repaired with direct gold.

Direct gold restorations are contraindicated in some patients whose teeth have very large pulp chambers, in patients with severely periodontally weakened teeth with questionable prognosis, in patients for whom economics is a severely limiting factor, and in handicapped patients who are unable to sit for the long dental appointments required for this procedure. Root canal–filled teeth are generally not restored with direct gold because these teeth are brittle, although in some cases gold may be the material of choice to close access preparations (for root canal therapy) in cast gold restorations.

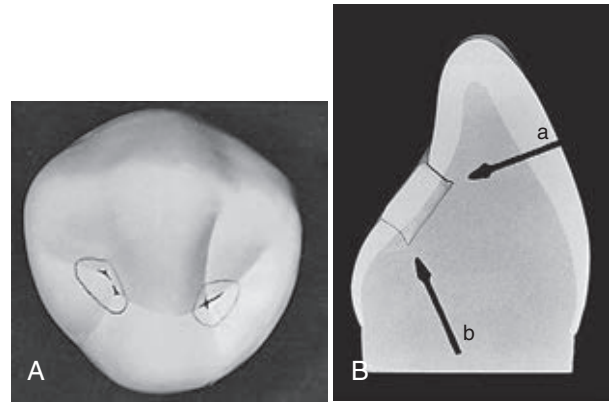
Tooth Preparations and Restorations

This section presents the preparation and the restoration of Class I, V, and III lesions. The preparations described may be restored entirely with pellets of gold foil, or E-Z Gold may be used. If powdered gold is selected, heavy hand pressure compaction may be substituted for hand mallet or automatic mallet techniques. Class I and V E-Z Gold restorations may be veneered with gold foil pellets, if desired. The Class III tooth preparation discussed in this chapter is recommended by Ferrier, and only pellets of gold foil are used for the restoration. All tooth preparations and restorative procedures are accomplished after a suitable field of operation has been achieved (usually by application of rubber dam).

Class I Tooth Preparation and Restoration Tooth Preparation Design

The marginal outline form for the Class I tooth preparation for compacted gold is extended to include the lesion on the tooth surface treated and any fissured enamel. The preparation outline may be a simple circular design for a pit defect, or it may be oblong, triangular, or a more extensive form (if needed to treat a defective fissure) (Online Fig. 22-10, A). Preparation margins are placed beyond the extent of pits and fissures. All noncoalesced enamel and structural defects are removed; the outline is kept as small as possible, consistent with provision of suitable access for instrumentation and for manipulation of gold.

For Class I tooth preparations, the external walls of the preparation are parallel to each other. In extensive occlusal preparations, the mesial or distal wall (or both) may diverge slightly occlusally, however, to avoid undermining and weakening marginal ridges. The pulpal wall is of uniform depth, parallel with the plane of the surface treated, and established at 0.5 mm into dentin. The pulpal wall meets the external walls at a slightly rounded angle created by the shape of the bur. Small undercuts may be placed in dentin if additional retentive features are required to provide convenience form in beginning the compaction of gold (see Online Fig. 22-10, B). Undercuts, when desired, are placed facially and lingually in



Online Fig. 22-10 **A**, Typical Class I occlusal marginal outlines for pit restorations with direct gold. **B**, Cross-section of model of lingual Class I preparation on maxillary incisor. Undercuts (a and b) are placed in dentin incisally and gingivally for additional retention.

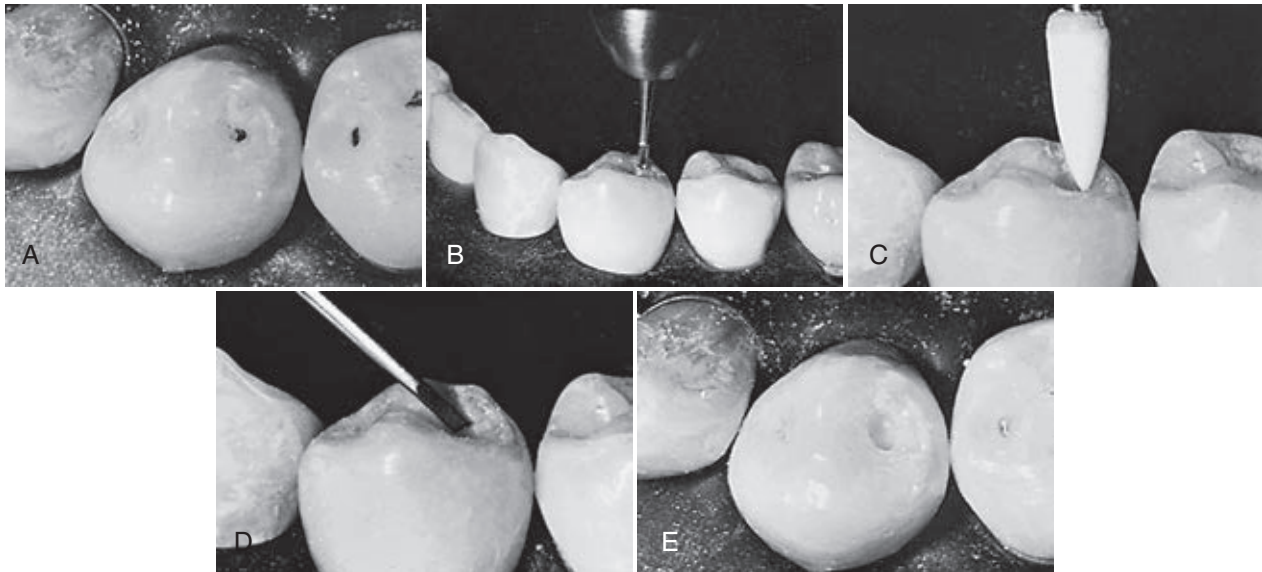
posterior teeth (or incisally and gingivally on the lingual surface of incisors) at the level of the ideal pulpal floor position. These undercut line angles must not undermine marginal ridges. A slight cavosurface bevel may be placed to (1) create a 30- to 40-degree metal margin for ease in finishing the gold and (2) remove remaining rough enamel. The bevel is not greater than 0.2 mm in width and is placed with a white rotary stone or suitable finishing bur.

Instrumentation

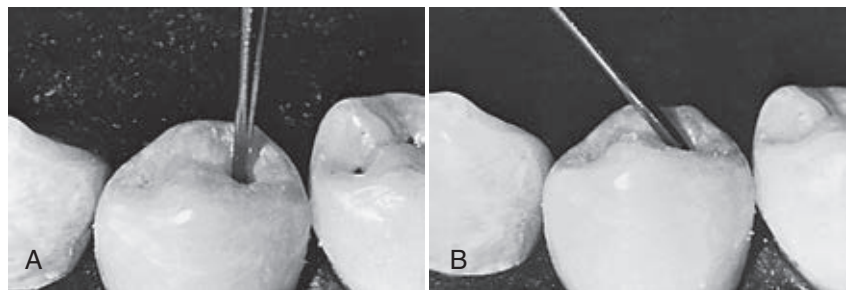
For description and illustration, the preparation of a carious pit on the mandibular first premolar is presented (Online Fig. 22-11, A). By use of a high-speed handpiece with air-water spray, the No. 330 or No. 329 bur is aligned, and the outline form (which includes the limited initial depth) is established (see Online Fig. 22-11, B). When the preparation is extensive because of the inclusion of fissured enamel, a small hoe (6½–2½–9) may be used to complete the desired degree of flatness of the pulpal wall. With a No. 33½ bur at low speed, small retentive undercuts are prepared into the dentinal portion of the external walls at the initial pulpal wall depth; these also may be prepared using a 6½-(90)-2½-9 angle-former chisel. Round burs of suitable size are used to remove any infected carious dentin that remains on the pulpal wall. The preparation is completed by finishing the cavosurface with an angle former, a small finishing bur (e.g., No. 7802), or a flame-shaped white stone (see Online Fig. 22-11, C through E).

Restoration

The restorative phase begins with the insertion of a pellet of E-Z Gold or gold foil. The gold is first degassed in the alcohol flame, cooled in air for a few moments, and inserted into the preparation with the passing instrument. The gold is pressed into place with the nib of a small round condenser. In larger preparations, a pair of condensers is used for this initial stabilization of the gold. Next, compaction of the gold begins with a line of force directed against the pulpal wall (Online Fig. 22-12, A). Hand pressure is used for E-Z Gold; malleting is used for gold foil. The gold is compacted into the pulpal line angles and against the external walls, and the line of force is



Online Fig. 22-11 Class I preparation for direct gold. **A**, Preoperative view of pit lesion. **B**, No. 330 bur is aligned properly for occlusal preparation. **C**, Occlusal cavosurface bevel is prepared with white stone. **D**, The bevel may be placed with an angle former. **E**, Completed tooth preparation.



Online Fig. 22-12 **A**, Compaction forces are delivered by the condenser held at 90-degree angle to the pulpal wall. **B**, Gold is condensed against the external preparation walls.

changed to a 45-degree angle to the pulpal and respective external walls (to compact the gold best against the internal walls) (see [Online Fig. 22-12, B](#)). Additional increments of gold are added, and the procedure is repeated until the preparation is about three quarters full of compacted gold. If E-Z Gold is to be the final restoration surface, compaction is continued until the restoration is slightly overfilled.

If gold foil is selected to veneer this restoration, pellets of suitable size are selected; in larger preparations, large pellets are convenient, whereas for small pit preparations, the operator should begin with $\frac{1}{64}$ -size pellets ([Online Fig. 22-13](#)). The pellet is degassed and carried to the preparation. First, hand pressure compaction is used to secure the pellet against the compacted E-Z Gold and spread it over the surface; next, mallet compaction is used. Likewise, each succeeding pellet is hand compacted, and then is compacted with the mallet. The condenser point is systematically stepped over the gold twice as malleting proceeds. Generally, the line of force is perpendicular to the pulpal floor in the center of the mass and at a 45-degree angle to the pulpal floor as the external walls are reached. At this stage and during all building of the restoration, the compacted surface should be saucer shaped, with the compaction of gold on the external walls slightly ahead of the center. The surface should never be convex in the center



Online Fig. 22-13 Placement of pellet of gold foil and compaction into tooth preparation.

because this may result in voids in the gold and poor adaptation of the gold along the external walls when the condenser nib is “crowded out” along the wall by the center convexity. The operator continues building the restoration until the cavosurface margin is covered with foil ([Online Fig. 22-14](#)). One needs to exercise extreme care that gold is always present between the condenser face and the cavosurface margin; otherwise the condenser may injure (i.e., fracture) the enamel margin. The central area of the restoration’s surface is filled in

to the desired level. Tooth surface contour of the gold is created to simulate the final anatomic form, and a slight excess of gold is compacted on the surface to allow for the finishing and polishing procedures.

The first step in the finishing procedure is to burnish the gold (Online Fig. 22-15, A). A flat beaver-tail burnisher is used with heavy hand pressure to harden the surface gold. A cleoid-discoid carver is used to continue the burnishing process and remove excess gold on the cavosurface margin. The cleoid, always directed so that a portion of the working edge is over or resting on enamel adjacent to or near the margins, is pulled from gold to tooth across the surface. This is done to smooth the surface and trim away excess gold (see Online Fig. 22-15, B). If considerable excess gold has been compacted, a green stone may be necessary to remove the excess in Class I restorations. Care must be taken at this stage to avoid abrading the surface enamel. After use of the cleoid-discoid, a small round finishing bur (No. 9004) is used to begin polishing (see Online Fig. 22-15, C). It is followed by the application of flour of pumice and tin oxide or white rouge (see Online Fig. 22-15, D). These powdered abrasives are applied dry, with a webless, soft rubber cup in a low-speed handpiece. Care is taken to use light pressure. Gentle blasts of air cool the surface during polishing. The completed restoration is illustrated in Online Figure 22-16.

Class V Tooth Preparation and Restoration Operating Field

As with all direct gold restorations, the rubber dam must be in place to provide a suitable, dry field for a Class V restoration. For lesions near the gingiva or that extend into the gingival sulcus, it is necessary to provide appropriate access to the lesion by placing a No. 212 retainer or gingival retractor. The punching of the rubber dam is modified to provide ample rubber between the teeth and to provide enough rubber for coverage and retraction of the soft tissue on the facial side of the tooth. The hole for the tooth to be treated is punched 1 mm facial of its normal position, and an extra 1 mm of dam is left between the hole for the treated tooth and the holes for the immediately adjacent teeth.

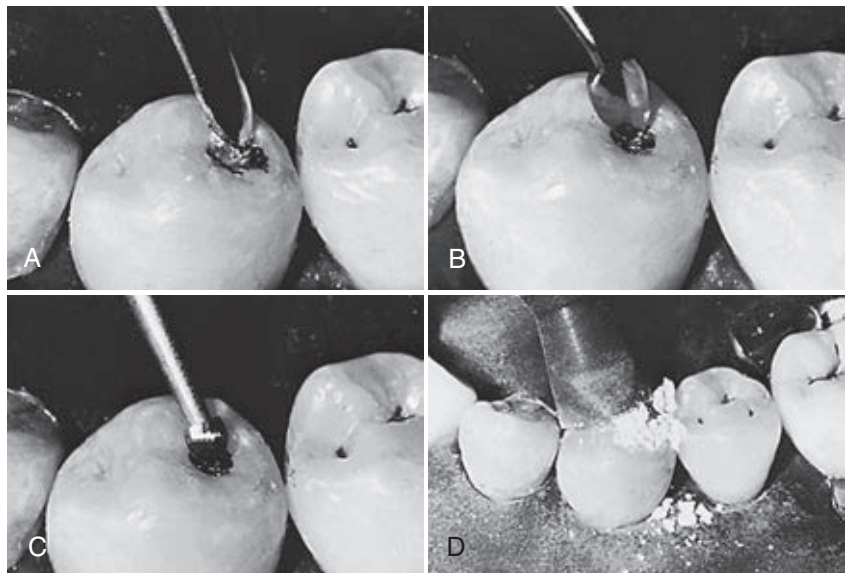
Several modifications may be made to the No. 212 retainer to facilitate its use. If the notches that are engaged by the retainer forceps are shallow, they may be deepened slightly with a large, carbide fissure bur to provide a more secure lock for the forceps (Online Fig. 22-17, A). If the tips of the retainer jaws are very sharp, they may be slightly rounded with a garnet disk, then polished to avoid scratching cementum during placement. For application to narrow teeth (e.g., mandibular incisors), the facial and lingual jaws may be narrowed by grinding with a heatless stone or carborundum disk, after which they are polished with a rubber wheel. To expedite placement on rotated teeth, the jaws may be modified by



Online Fig. 22-14 Compaction of gold foil has proceeded sufficiently to cover all the cavosurface margins.

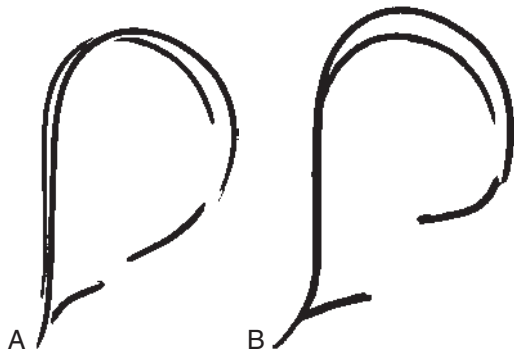
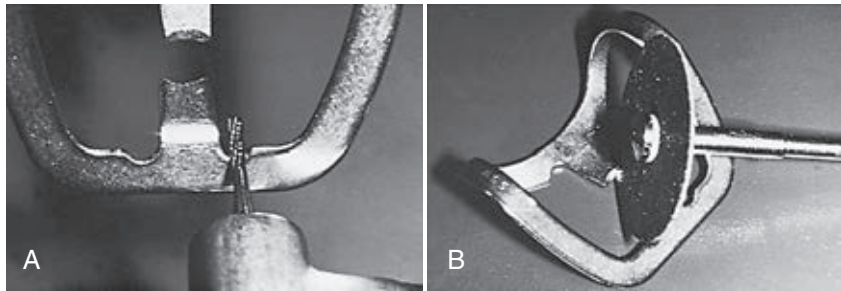


Online Fig. 22-16 Completed restoration.



Online Fig. 22-15 Steps in finishing Class I direct gold restoration. **A**, Burnisher work-hardens the surface gold. **B**, The cleoid-discoid instrument removes the excess gold from the cavosurface margins. **C**, A No. 9004 bur is used to begin the polishing phase. **D**, Polishing abrasives are applied with a rubber cup.

Online Fig. 22-17 **A**, Notches are deepened for secure holding of the No. 212 retainer. **B**, Jaws may be modified with a disk to facilitate retainer placement on rotated teeth.



Online Fig. 22-18 **A**, Drawing of a No. 212 retainer as received from the manufacturer. **B**, Modified facial and lingual jaws.

grinding suitable contour to the tip edge (see [Online Fig. 22-17, B](#)). The jaws may be bent for use on teeth where gingival access to lesions is difficult. This is done by heating the jaws to a cherry-red color in a flame, then grasping the entire facial jaw with suitable pliers and slightly bending the jaw apically. The procedure is repeated for the lingual jaw, bending it slightly occlusally ([Online Fig. 22-18](#)).

The No. 212 retainer must be applied carefully to avoid damage to soft or hard tissue. The retainer is secured in the retainer forceps and carried to the mouth after the rubber dam has been placed. The lingual jaw is positioned just apical to the lingual height of contour, and the index finger is placed against the jaw to prevent its movement. The retainer is rotated faciogingivally with the forceps, while the thumb retracts the dam; the facial jaw is set against the tooth ([Online Fig. 22-19, A](#)). Next, a ball burnisher is placed into one of the retainer notches and used to move the facial jaw gingivally (without scraping the jaw against the tooth) to the final position (i.e., 0.5–1 mm apical of the expected gingival margin) (see [Online Fig. 22-19, B](#)). Gentle pressure is used to position the facial jaw so that only the free gingiva is retracted, and the epithelial attachment is not harmed. The retainer is supported and locked into this desired position with the compound, which is softened, molded by the fingers, and placed between the bows and the gingival embrasures (see [Online Fig. 22-19, C](#)). The compound also serves to distribute compaction forces among all the teeth included in the retainer application.

Tooth Preparation Design

The typical Class V tooth preparation for restoration with direct gold is trapezoidal ([Online Figs. 22-20, 22-21, and](#)

[22-22](#)). This outline form is created to satisfy esthetic needs and the requirements for the retention and convenience forms in the treatment of lesions in the gingival third of the clinical crowns of teeth. The straight occlusal margin improves the esthetic result, and by virtue of its straight design, excess gold is readily discerned and removed in the final stages of the restorative process. The gingival outline is shorter than the occlusal route because the tooth narrows in the gingival area. In addition, it is prepared parallel with the occlusal margin for easy identification in the finishing phases. The mesial and distal margins connect the gingival margin to the occlusal margin.

The occlusal margin is straight and parallel with the occlusal plane of the teeth in the arch (see [Online Fig. 22-20 and 5-21](#)); it is extended occlusally to include the lesion. (When several adjacent teeth are restored, some additional extension is permissible to create a uniform level that may be more esthetically pleasing.) Often, the mesiodistal extension to the line angles of the tooth places the junction of the occlusal and mesial and distal margins gingival to the crest of the free gingiva, rendering the most esthetic result. The gingival margin is also straight, parallel with the occlusal margin, placed only far enough apically to include the lesion, and extends mesiodistally to the line angles of the tooth.

The mesial and distal margins are parallel to the proximal line angles of the tooth (see [Online Fig. 22-22, A](#)) and usually are positioned sufficiently mesially and distally to be covered by the free gingiva. The mesial and distal margins are straight lines that meet the occlusal margin in sharp, acute angles and meet the gingival margin in sharp, obtuse angles, both of which complete the trapezoidal form.

The depth of the axial wall varies with the position of the preparation on the tooth. The axial wall is approximately 1 mm deep in the occlusal half of the preparation. As the outline approaches the cervical line, the axial wall depth may decrease from 1 to 0.75 mm. The axial wall must be established in dentin, and occlusogingivally it should be relatively flat and parallel (approximately) with the facial surface of the tooth (see [Online Fig. 22-22, B](#)). Mesiodistally, the axial wall also is prepared approximately parallel with the surface contour of the tooth. This contour may create a slight mesiodistal curvature in the axial wall in convex contoured teeth and where the preparation is extensive proximally. Mesiodistal curvature of the axial wall prevents encroachment of the tooth preparation on the pulp. Excessive axial curvature results in a preparation that is either too shallow in the center or too deep at the proximal extensions, and it further complicates restoration by failing to provide a reasonably flat wall against which to begin compaction. A subaxial wall may be created within



Online Fig. 22-19 Placement of No. 212 retainer. **A**, Initial placement of facial jaw after first placing lingual jaw. **B**, Use of ball burnisher to carry the facial jaw to the final position. **C**, Retainer stabilized with compound to distribute compaction forces, prevent tipping, and to prevent either apical or occlusal movement of retainer.



Online Fig. 22-20 Facial view of Class V tooth preparation for direct gold. The occlusal and gingival margins are straight, parallel with each other, and extend mesially and distally to the respective mesiofacial and distofacial tooth crown line angles. The mesial and distal walls diverge facially and form obtuse angles with the axial wall. Line angles and point angles are sharp (see Online Fig. 22-22, B).



Online Fig. 22-21 Facio-occlusal view of design of gingival wall in Class V preparation for direct gold. The axiokingival line angle is acute and has been prepared at the expense of the gingival wall. This gingival margin is on cementum. If on enamel, the gingival cavosurface would be beveled slightly (see Online Fig. 22-26, E).

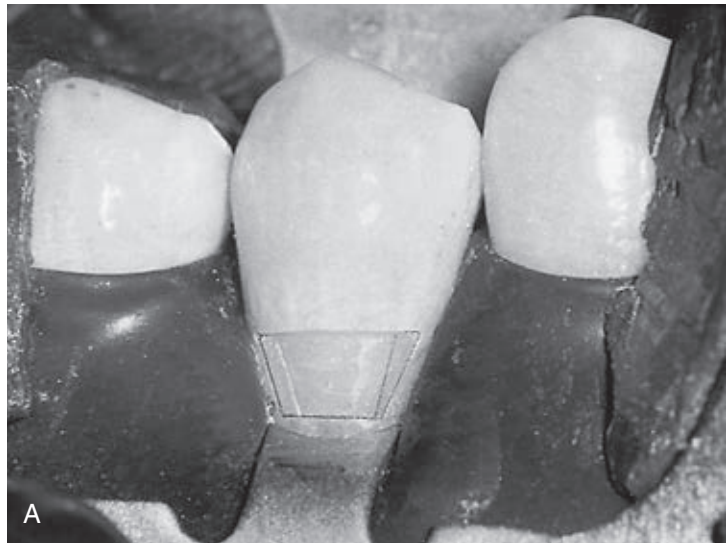
the axial wall to remove infected caries that has progressed deeper than the ideal axial wall placement.

The occlusoaxial internal line angle is a sharp right angle. The occlusal wall also forms a right angle with the external enamel surface, precluding undermining of the enamel. The gingivoaxial internal line angle is a sharp, acute angle, created at the expense of the gingival wall (see Online Fig. 22-22, B). The mesioaxial and distoaxial internal line angles are sharp, obtuse angles. These obtuse line angles are created to prevent the undermining of the mesial and distal enamel, although still providing some resistance to movement of the gold during compaction. They must never be acute angles.

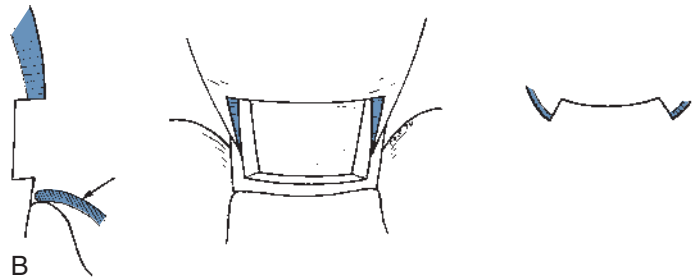
The mesial and distal prepared walls are flat and straight. They meet the occlusal wall in a sharp, acute line angle and meet the gingival wall in a sharp, obtuse line angle. The mesial and distal walls provide resistance for gold compaction, but they provide no retention.

The orientation of the gingival wall is the key to the retention form of the preparation. It is straight mesiodistally, meeting the mesial and distal walls in sharp line angles. Retention is provided by sloping the gingival wall internally to meet the axial wall in a sharply defined acute line angle. Retention is provided by the facial convergence of the occlusal and gingival walls. Gold wedged between these two walls is locked into the tooth. If the gingival margin is established on enamel, the cavosurface is beveled slightly to remove unsupported enamel (see Online Fig. 22-26, E). When placed on cementum, the gingival cavosurface is not beveled (see Online Fig. 22-24, B).

The outline of the preparation may be modified. In clinical situations demanding reduced display of gold, such as in anterior teeth, the incisal outline may be curved to follow the contour of soft tissue mesiodistally (Online Fig. 22-23). This modification is made only when required because preparation instrumentation and finishing of gold are more difficult than when a straight marginal outline is created. A similar modification may be made in the occlusal outline when caries extends more occlusally as the proximal extensions are reached. Also, the mesiodistal extension (i.e., dimension) of a preparation may be limited when caries is minimal, conserving intact tooth structure. When access requires, the gingival wall may be modified also to curve mesiodistally to include the gingival extent of advanced caries. The entire axial wall should not be extended pulpally to the depth of the lesion when deep cervical abrasion, abfraction, or erosion is treated; rather the axial wall is positioned normally, leaving a remaining V notch at its center to be restored with gold. When failing restorations are removed and restored with direct gold, the preparation



Online Fig. 22-22 A, Clinical Class V tooth preparation. Note the proper isolation of the operating field. This gingival margin is on cementum. **B**, Longitudinal section, facio-occlusal view, and cross-section. Line and point angles are sharp.



Online Fig. 22-23 Completed Class V gold restoration. Incisal margin curved to follow contour of gingival tissue for best esthetic result.

outline is partially dictated by the previous restoration ([Online Fig. 22-24](#)).

Instrumentation

The No. 33½ bur is used to establish the general outline form of the preparation. The end of the bur establishes the distal wall ([Online Fig. 22-25, A](#)); the side establishes the axial depth and the occlusal, gingival, and mesial walls (see [Online Fig. 22-25, B](#)). When access permits, the end of the bur may be

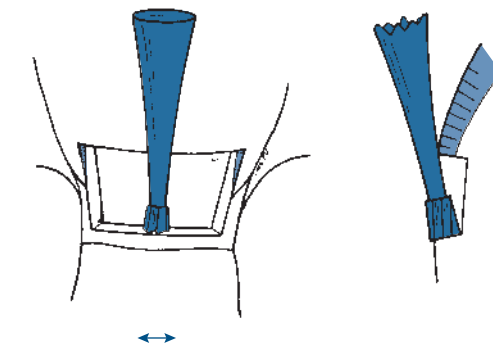
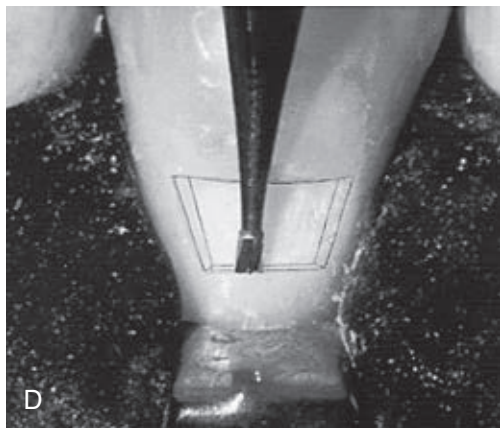
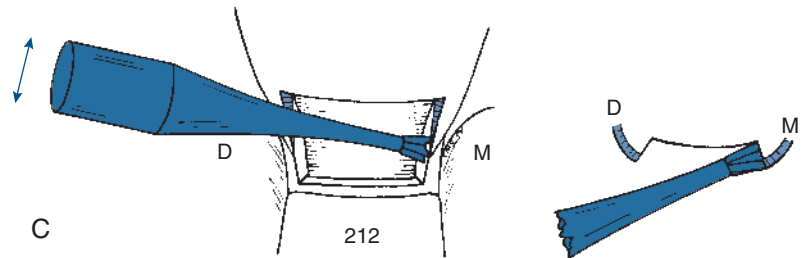
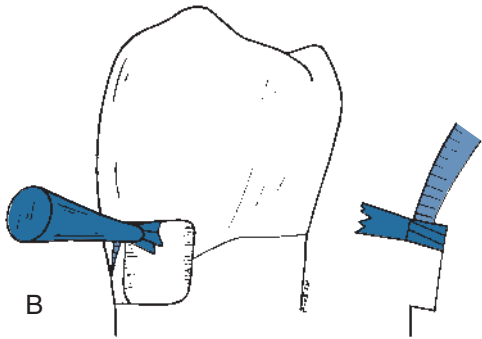
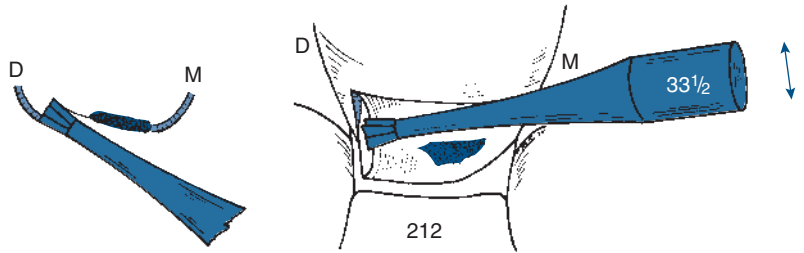
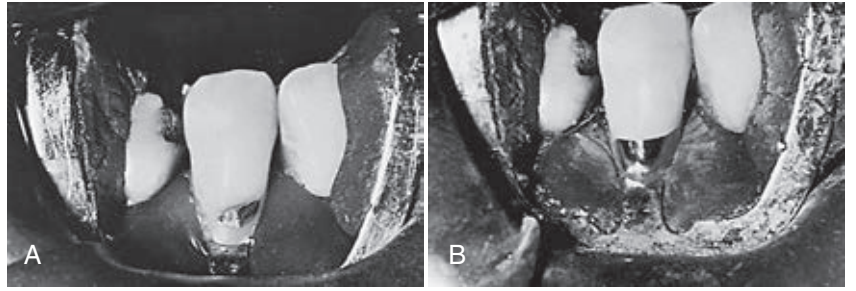
used to establish the mesial and gingival walls (see [Online Fig. 22-25, C and D](#)). The gingival and mesial walls may be prepared with the side of the bur if access so dictates (see [Online Fig. 22-25, E and F](#)). The end of the bur is used to place the axial wall in dentin (see [Online Fig. 22-25, G](#)).

The 6½-2½-9 hoe or the larger 10-4-8 hoe is useful for planing preparation walls, establishing sharp internal line angles ([Online Fig. 22-26, A](#)), and finishing margins. The Wedelstaedt chisel is used to finish the occlusal cavosurface margin (see [Online Fig. 22-26, B](#)) and may be used to plane the axial wall. The acute axi gingival angle is established with the 6½-2½-9 hoe, cutting from the cavosurface to the axial wall in a push-cut stroke (see [Online Fig. 22-26, C](#)). The chips of dentin produced at the axi gingival angle may be removed with the tip of an explorer (see [Online Fig. 22-26, D](#)) or the point of a 6½-(90)-2½-9 small angle former. Care must be taken not to gouge the axial wall. When its use is indicated, the gingival bevel is prepared with the Wedelstaedt chisel or a hoe (see [Online Fig. 22-26, E](#)).

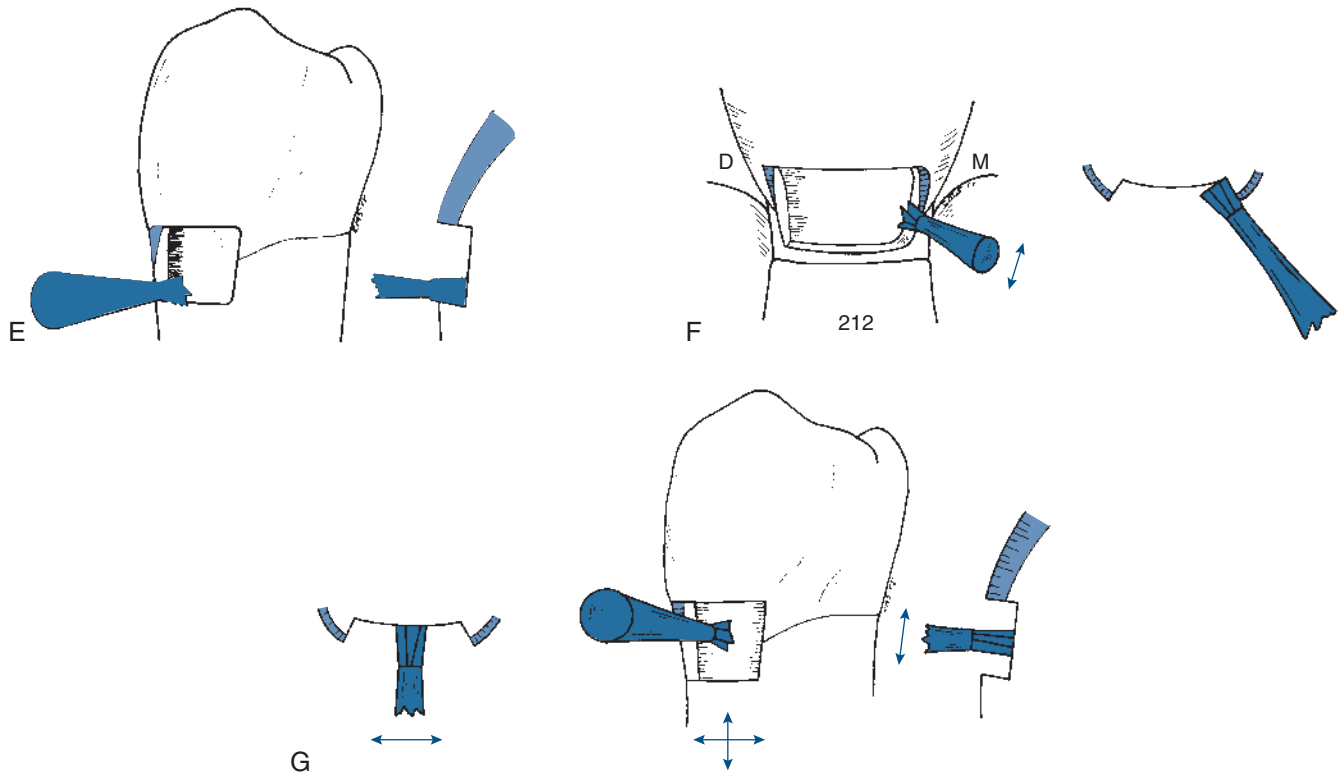
Restoration

Restoration of the Class V preparation begins with application of cavity varnish (if desired), after which a piece of degassed E-Z Gold is placed into the preparation. The gold is degassed in the alcohol flame and carried to its place in the preparation with the passing instrument. Parallelogram foil condensers or other suitable serrated condensers are used to force the gold firmly against the axial wall and to wedge it into the line angles. One instrument may be put aside (and the other is

Online Fig. 22-24 A, Failing Class V amalgam restoration. B, Replacement direct gold restoration.



Online Fig. 22-25 Use of No. 33½ bur in straight handpiece for initiating Class V preparation. A, The end of the bur is used to establish the distal wall. B, The side of the bur is used to establish the occlusal wall. C, The end of the bur prepares the mesial wall, if access permits. D, The end of the bur is used to establish the gingival wall, if access permits. The use of a No. 33½ bur in the straight handpiece for initiating Class V preparation.



Online Fig. 22-25, cont'd **E**, Preparation of the gingival wall with the side of the bur. **F**, Preparation of the mesial wall with the side of the bur. **G**, The end of the bur may be used to establish the initial axial wall depth in dentin.

used as a holding instrument to prevent movement of the entire piece of gold), and compaction can begin by delivering heavy compacting forces to the gold.

After stabilization of the gold, completion of compaction of the initial mass of gold begins in the center of the mass with a 0.5-mm-diameter, round, serrated condenser nib. Careful, methodical stepping of the gold proceeds outward toward the external walls (to wedge the gold in the tooth and remove internal voids). As soon as the gold is stabilized, a holding instrument is no longer necessary. As the walls are reached, a line of force of 45 degrees to the axial wall is used to drive the gold into the line angles and against the external walls. The entire surface of the gold is condensed twice to complete the compaction of the gold. Additional increments of E-Z Gold are added until the preparation is filled to at least half its depth. E-Z Gold pellets are used to complete the restoration, covering the margins first, and to complete compacting in the center of the facial surface. Pellets of gold foil also may be used to complete the outer one half of the restoration (Online Fig. 22-27).

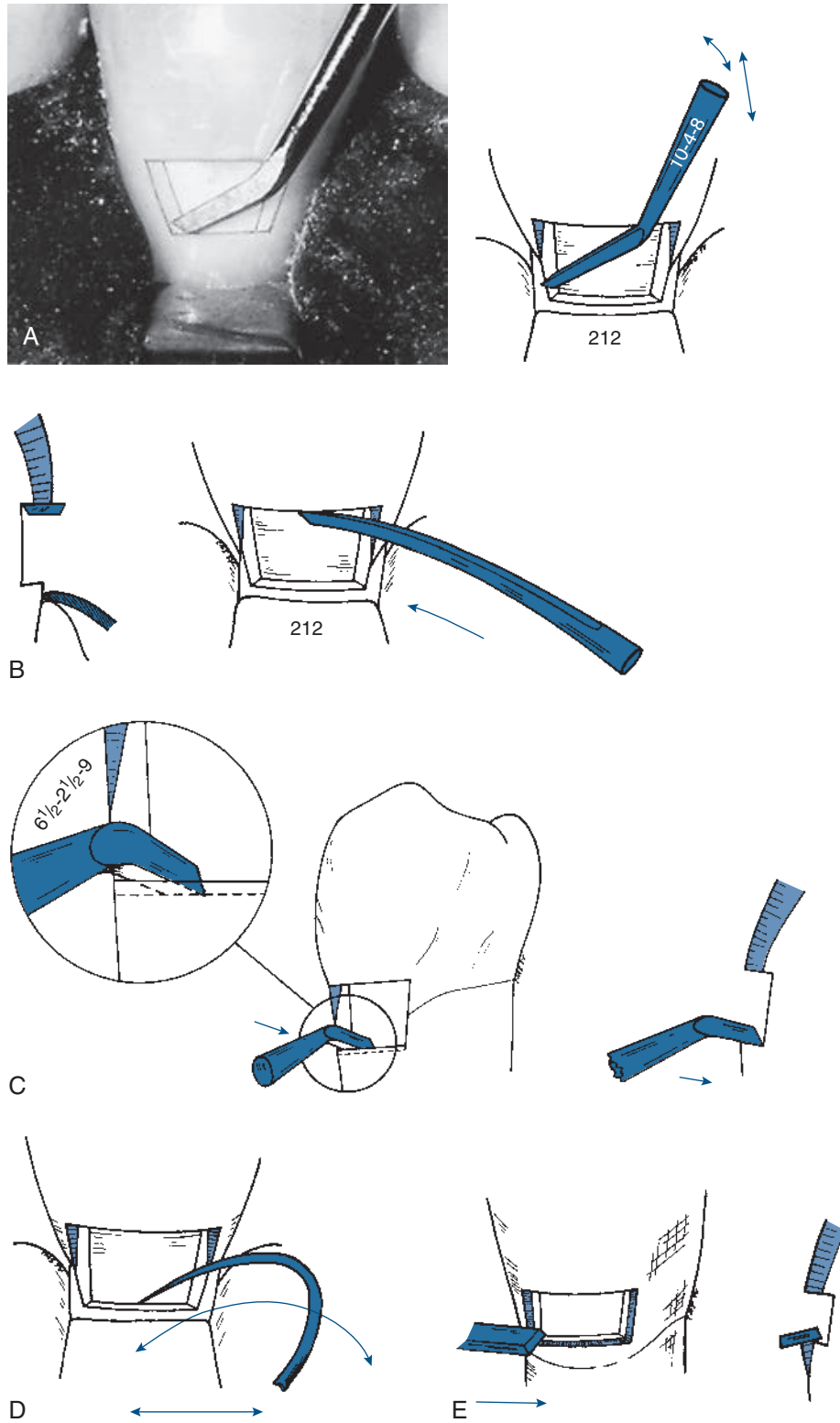
If gold foil is used for the outer half of the restoration, compaction proceeds with medium-sized pellets at the mesio-occlusal or disto-occlusal line angle and then across the occlusal wall. The entire wall and occlusal cavosurface margin are covered with compacted gold foil (see Online Fig. 22-27, A). To ensure that gold protects the margin from blows of the condenser face, care should be exercised when the condenser approaches any enamel margin. Next, the gingival, mesial, and distal walls are covered, which leaves the restoration concave (see Online Fig. 22-27, B). It is essential that all cavosurface

margins be covered at this time, before the final convex surface of the restoration is formed.

Medium and large pellets (sizes $\frac{1}{43}$ and $\frac{1}{32}$) are compacted in the center of the restoration to complete the formation of the appropriate contour. A slight excess contour is developed and is removed later when the gold is finished and polished. Any small remaining deficiencies in the surface contour are filled with small pellets. A Varney foot condenser (or other large condenser) is malleted over the entire surface to make it smooth and assist in detection of any poorly compacted areas (see Online Fig. 22-27, C).

Finishing begins with application of a beaver-tail burnisher to work-harden and smooth the surface (Online Fig. 22-28, A). Petroleum jelly may be applied to the dam to avoid abrasion from disks; it also may be applied to the disks. Gross excess contour, if any, is removed with a fine garnet disk applied with a Sproule or other suitable mandrel in a low-speed handpiece (see Online Fig. 22-28, B). Excess gold is removed from the cavosurface margins with the cleoid–discoid instrument (using pull-cut strokes) or the gold knife (using only push-and-cut strokes from the gold to the tooth) (see Online Fig. 22-28, C and D). When removing the excess gold over the gingival margin, care is exercised not to remove cementum or “ditch” the root surface (especially when using rotary instruments).

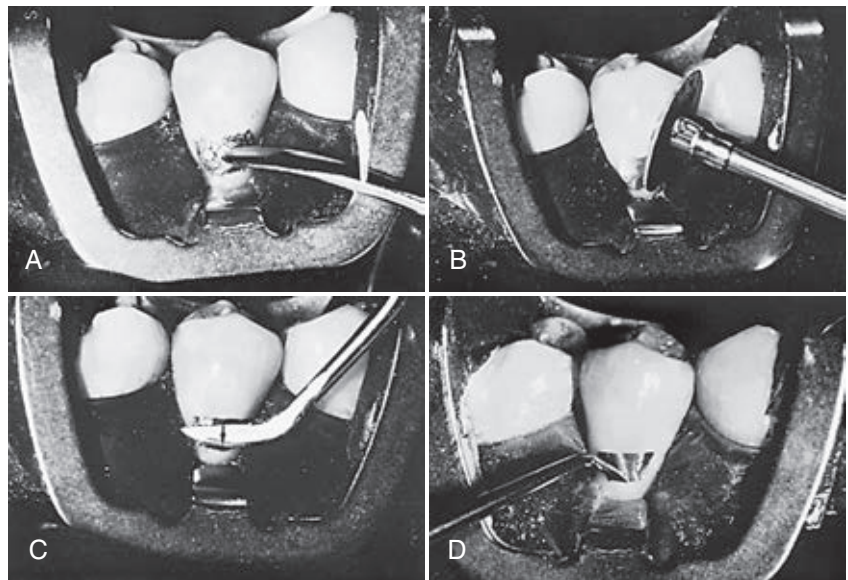
When the final contour has been obtained, cuttle disks may be used in decreasing abrasiveness (i.e., coarse to medium to fine) to ready the surface for final polishing. These disks and the cleoid are helpful in removing very fine fins of gold from margins. Polishing is performed with fine pumice followed by



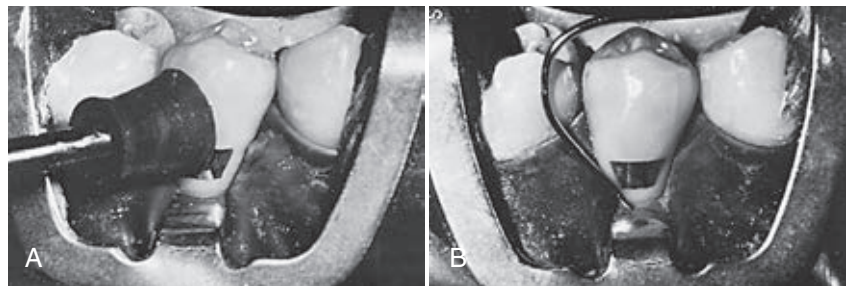
Online Fig. 22-26 Use of hand instruments in Class V tooth preparation. **A**, The small hoe planes the preparation walls. **B**, The Wedelstaedt chisel refines the occlusal wall and the margin. **C**, The small hoe creates an acute axiokingival line angle in dentin. **D**, The explorer is used to remove debris from the completed preparation. **E**, The chisel blade bevels the gingival cavosurface margin, when indicated. (**E**, From Howard WC, Moller RC: Atlas of operative dentistry, St. Louis, 1981, Mosby.)



Online Fig. 22-27 Completion of compaction where gold foil is used to overlay the E-Z Gold. **A**, Condensation of foil proceeds to cover the cavosurface margins. A slight excess of gold has been condensed over the mesial half of the occlusal cavosurface margin. **B**, All cavosurface margins are covered with a slight excess of gold. The restoration, at this stage of insertion, is concave. **C**, After additional foil pellets are compacted in the central area to form a convex restoration surface with slight excess, a foot condenser is used to confirm condensation.



Online Fig. 22-28 Finishing the Class V restoration. **A**, Burnisher work-hardens surface. **B**, A small, fine garnet disk removes the excess gold contour. **C**, The gold knife's secondary edge used with push-stroke (arrow) removes excess gold from the gingival margin. **D**, After final surfacing with a cuttle disk, any remaining marginal excess is removed with the cleoid carver.



Online Fig. 22-29 **A**, A soft-rubber cup is used to apply polishing abrasives. **B**, The explorer is used to remove any remaining polishing powder from site of completed restoration.

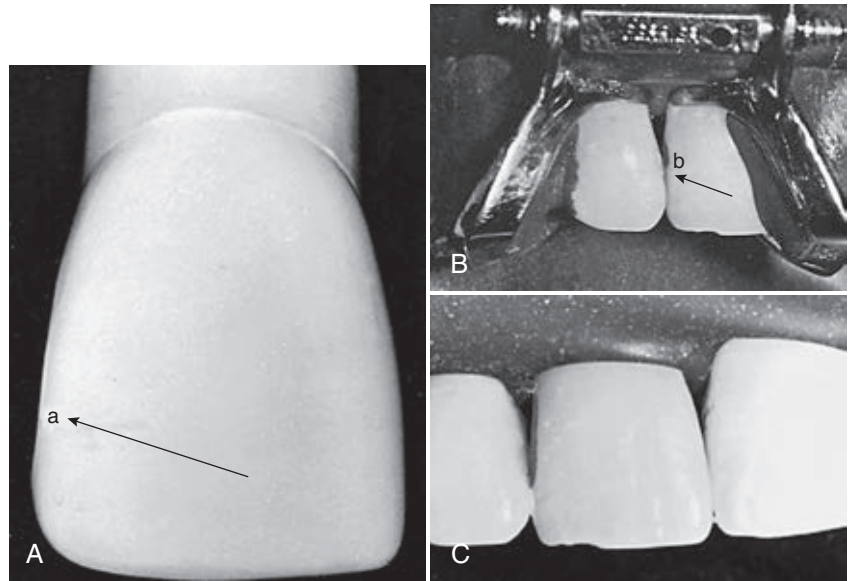
tin oxide or white rouge (applied with a soft, webless rubber cup). Care also is required at this stage to avoid ditching cementum with the polishing abrasive. The abrasives are used dry so that the field may be kept clean, and the exact position of the rubber cup can be seen at all times (Online Fig. 22-29).

After polishing has been completed, the No. 212 retainer and rubber dam are removed. Removal of the retainer is best accomplished with the forceps firmly locked into the notches on the retainer. The retainer jaws are opened from the tooth with the forceps and carefully removed occlusally (without

scratching the restoration or the surface enamel of the tooth). The gingival sulcus is rinsed and examined to ascertain that it is free of debris. Soft tissue is massaged gently before the patient is dismissed.

Class III Tooth Preparation and Restoration

Many styles of Class III preparations are advocated for use with direct gold. Some preparations are based on the lingual approach and are restored with E-Z Gold. Others may be



Online Fig. 22-30 Class III direct gold restoration. **A**, The model of the preparation shows the esthetic marginal outline (a). **B**, Central incisor (b) before distal preparation. **C**, Completed Class III restoration.

instrumented from either the facial or the lingual surface and use gold foil as the restorative material. The outline form selected must provide adequate access for placing the restoration and developing an acceptable esthetic result. The preparation design presented in subsequent sections was first described by Ferrier in the early years of the twentieth century and is still used today.¹⁸ It has the advantage of not only conserving the tooth structure but also providing access for compaction of gold foil directly against all preparation walls and cavosurface margins. This results in a dense, esthetically pleasing result (if careful attention is given to management of the outline design). This preparation is instrumented primarily from a facial approach, although lingual instrumentation may be used in maxillary teeth. The preparation may be modified for mandibular anterior teeth, the distal surface of maxillary canines, and the distal surface of some lateral incisors.

Tooth Preparation Design for Maxillary Incisors

The marginal outline is the most important. From a facial view, the gingival four fifths of the facial margin is straight and (generally) parallel with the contour of the tooth ([Online Fig. 22-30](#)). The facial margin forms a gentle curve in its incisal one fifth to blend with the incisal margin. When viewed from a proximofacial aspect, the facial outline follows the general contour of the adjacent tooth ([Online Fig. 22-31](#)) and meets the gingival outline in a slightly obtuse angle. This juncture may be curved slightly to enhance esthetics.

The gingival margin is crucial to the entire preparation. Its faciolingual length dictates the remainder of the preparation. Where possible, the gingival margin is established just apical to the crest of the free gingiva to enhance the esthetic result. It is straight faciolingually and is approximately at a right angle to the long axis of the tooth. It meets the facial margin in a sharply defined obtuse angle that may be rounded slightly (as previously described), and it meets the lingual margin in a sharply defined acute angle.

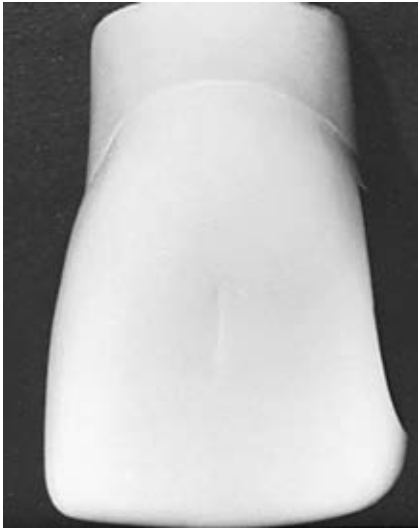


Online Fig. 22-31 Proximofacial view of Class III preparation.

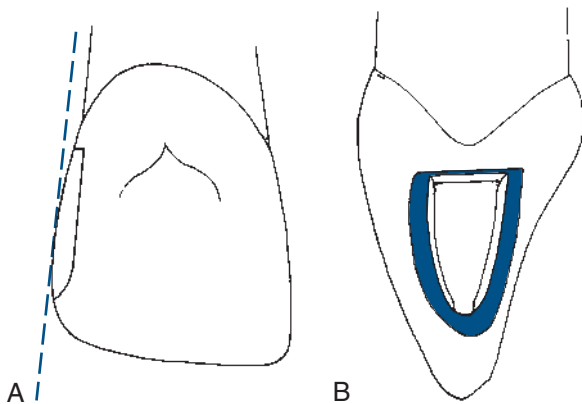
Viewed from the lingual aspect, the lingual margin generally parallels the long axis of the tooth ([Online Fig. 22-32](#)). It may diverge slightly proximally from the long axis, however, to parallel more nearly the proximal contour. It meets the gingival margin in a sharply defined angle that is nearly 90 degrees when viewed from the lingual aspect ([Online Fig. 22-33](#)), but it is acute when viewed from the proximal aspect. The lingual margin is straight in its gingival two thirds, but then it curves abruptly to meet the incisal margin.

The incisal margin is placed incisally to the contact area to provide access to the preparation; however, it is not extended enough to weaken the incisal angle of the tooth. It forms a smooth curve that connects the facial and lingual margins of the preparation.

To provide a suitable resistance form, the internal aspects of the preparation are precisely instrumented. The gingival



Online Fig. 22-32 Lingual view of Class III preparation.

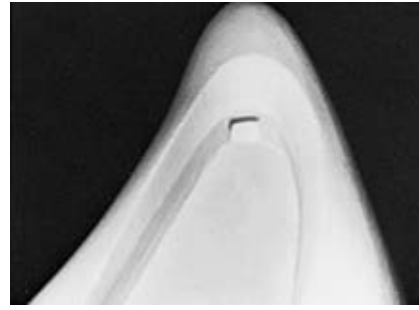


Online Fig. 22-33 Lingual marginal outline of Class III preparation. **A**, View of lingual outline. Note the sharp linguogingival angle. **B**, Proximal view of preparation. Note that the linguogingival angle is sharp and acute in this view. (A, From *Stibbs GD: Direct golds in dental restorative therapy*. Oper Dent 5:107, 1980.)

wall is flat faciolingually. The axial wall is flat faciolingually and incisogingivally, and it is established 0.5 mm into dentin. The resistance form also is created by establishing sharp, obtuse axiofacial and axiolingual line angles in dentin. The facial and lingual walls diverge only enough to remove undermined enamel, and yet they provide firm, flat walls against which the gold can be compacted.

As in the Class V restoration, retention form is provided only between the gingival and incisal walls. In the Class III preparation, the dentinal portion of the gingival wall (as in the Class V gingival wall) slopes apically inward to create an acute axiogingival line angle. In the Class III preparation, the incisal portion is undercut (Online Fig. 22-34). This undercut is placed in dentin, facioincisally, to create a mechanical lock between the incisal and gingival walls. This increased retention form in the Class III preparation is required because of the length of the preparation incisogingivally and because of the difficulty of access in compacting the gold.

Provision for the convenience form is made by the abrupt incisolingual curve (which permits introduction of a



Online Fig. 22-34 View of incisal retention in Class III preparation. The undercut is placed in dentin but does not undermine enamel.

condenser directed toward the gingival wall), by adequate clearance of all margins from the adjacent tooth, and by placement of sharp internal point angles suitable for beginning compaction of gold. The facio-axio-gingival and linguo-axio-gingival point angles may be enlarged slightly to assist in initial stages of foil compaction, if desired.¹⁹

The finishing of enamel walls requires placement of a facio-inciso-lingual cavosurface bevel, which determines the final marginal outline. This bevel is made with hand instruments and is established totally in enamel. It is designed to create maximum convenience form, to remove all surface irregularities and any unsupported enamel, and to establish a more esthetically pleasing result (Online Fig. 22-35; see also Online Fig. 22-30).

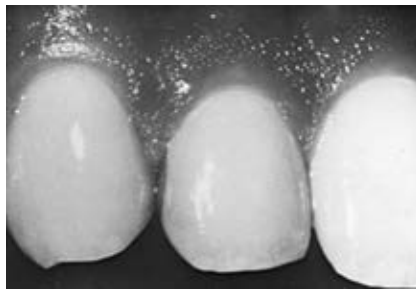
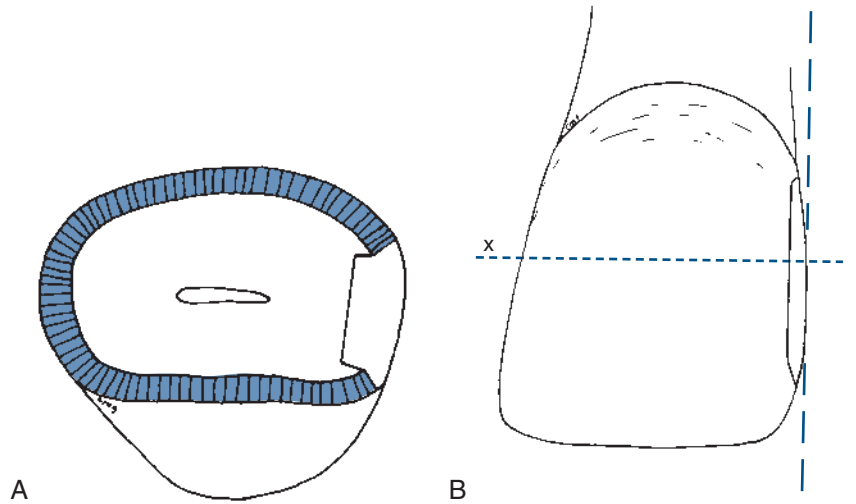
Modifications of Class III Preparations

The distal surface of maxillary canines may require a modification in preparation design for convenience in gold compaction. Because a highly convex surface is generally present, it is often desirable to create a “straight-line preparation” in which the facial outline appears as a slice. This modification provides clearance from the mesial marginal ridge of the first premolar and provides considerable convenience form to allow compaction of gold on the gingival wall directly from an incisal position. This type of preparation also is appropriate for the distal surface of highly contoured lateral incisors (Online Fig. 22-36).

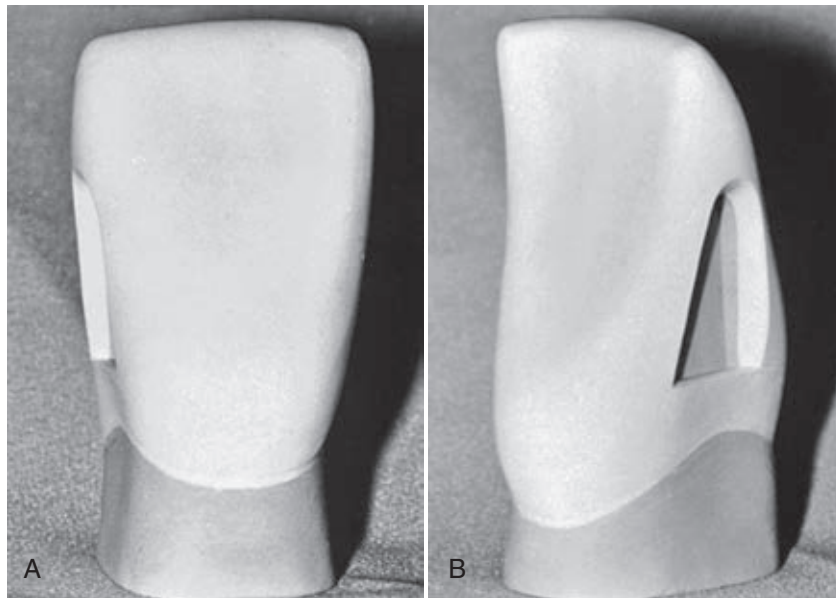
The mandibular incisors require a modified Class III preparation because of their small size and because access from a lingual position may be exceptionally difficult. The lingual wall is created in one plane, and extension of the lingual and the incisal walls is limited. The axiolingual line angle is a right or slightly obtuse angle. Care is taken to avoid lingual over-extension of the lingual wall because this can result in the removal of dentinal support for lingual enamel, rendering the preparation unrestorable by direct gold. The outline form is extended lingually only far enough to include the lesion and to allow access for finishing of the gold. Incisal extension is restricted because the proximal contact area between mandibular incisors is often near the incisal angle. Extension incisally past the contact may weaken this critical area of the tooth; a mechanical separator may be necessary to obtain clearance between teeth. This provides access for tooth preparation and gold compaction. Facial extension is similar to the maxillary preparation (Online Fig. 22-37).

Internally, the incisal retentive angle for the mandibular Class III preparation is placed directly incisally, rather than

Online Fig. 22-35 Class III preparation internal form and facial marginal outline. **A**, Incisal view of cross-section of preparation in plane x shown in *B*. Facial and lingual cavosurface bevels are shown placed in enamel. **B**, Facial view of the facial marginal outline of the preparation. (From *Stibbs GD: Direct golds in dental restorative therapy. Oper Dent 5:107, 1980.*)



Online Fig. 22-36 Direct gold restoration of a clinical Class III preparation of straight-line design on the distal portion of the maxillary lateral incisor.



Online Fig. 22-37 Mandibular Class III preparation. **A**, Facial view. The facial margin is similar to that in the maxillary preparation. **B**, Linguoproximal view.

facioincisally as in maxillary teeth. This modification is made to conserve the thickness of the tooth structure at the facioincisal angle, where wear of mandibular anterior teeth frequently occurs. Lingual approach Class III restorations may be made using E-Z Gold. In such cases, the lingual “slot” type of preparation is made with rounded internal line angles.

Separation of Teeth

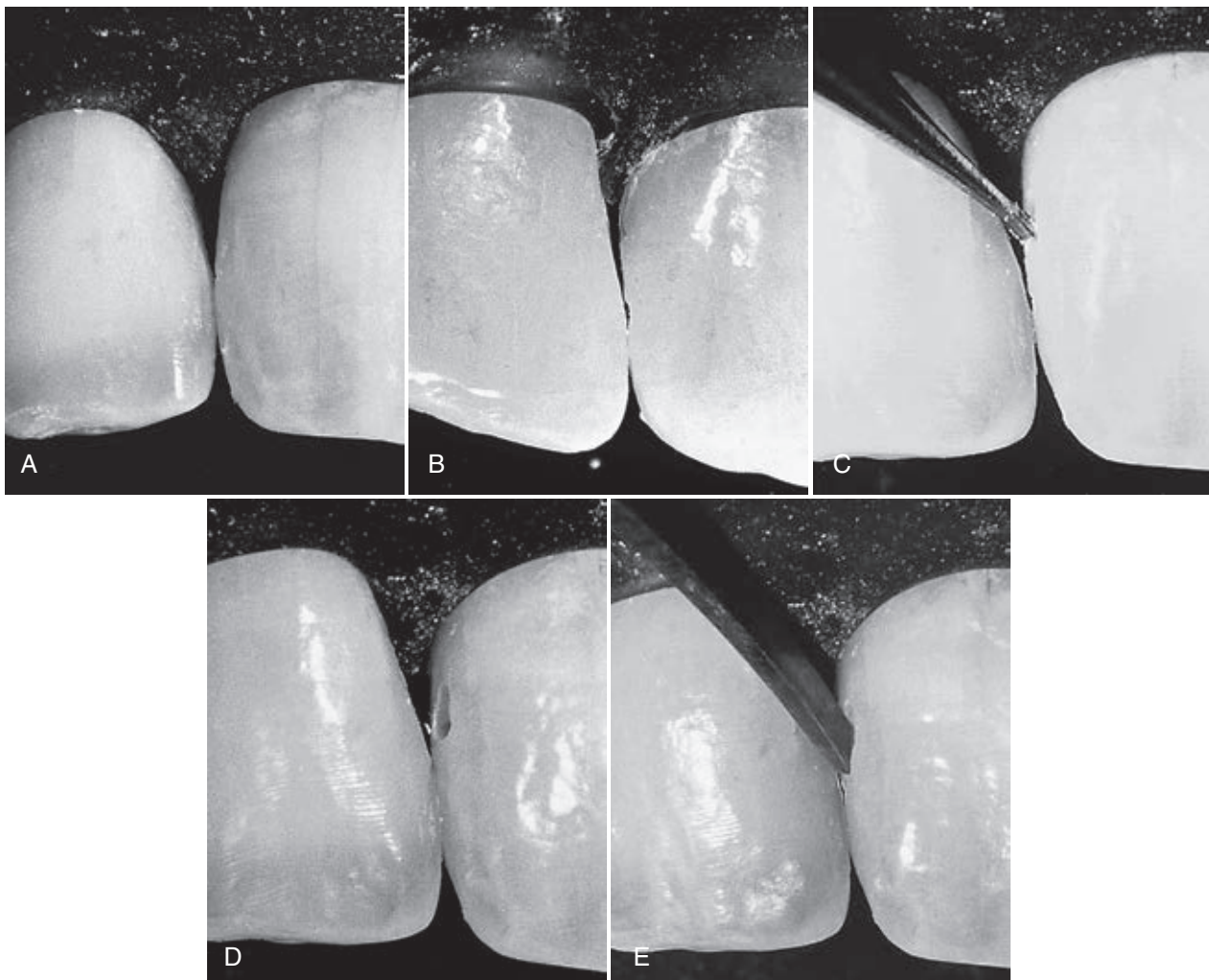
Separation of teeth frequently is needed for instrumentation or finishing procedures performed on Class III direct gold restorations. The Ferrier separator is a convenient instrument for accomplishing this separation. It is applied and stabilized with compound (similar to stabilization of a No. 212 retainer) (Online Fig. 22-38). The jackscrews of the separator are activated with the separator wrench to draw the teeth slightly apart, creating a maximum space of 0.25 to 0.5 mm. It is desirable to provide only this minimum separation and to remove the separator as soon as possible (preventing damage to periodontal structures).

Instrumentation

The No. 33½ bur (or a suitable Wedelstaedt chisel) is used to begin the preparation (Online Fig. 22-39). The bur is angled from the facial to position the gingival outline and the facial wall. A Wedelstaedt chisel establishes the lingual extension, and the No. 33½ bur defines the linguogingival line angle.



Online Fig. 22-38 Separator placed before clinical Class III preparation for the mandibular incisor.



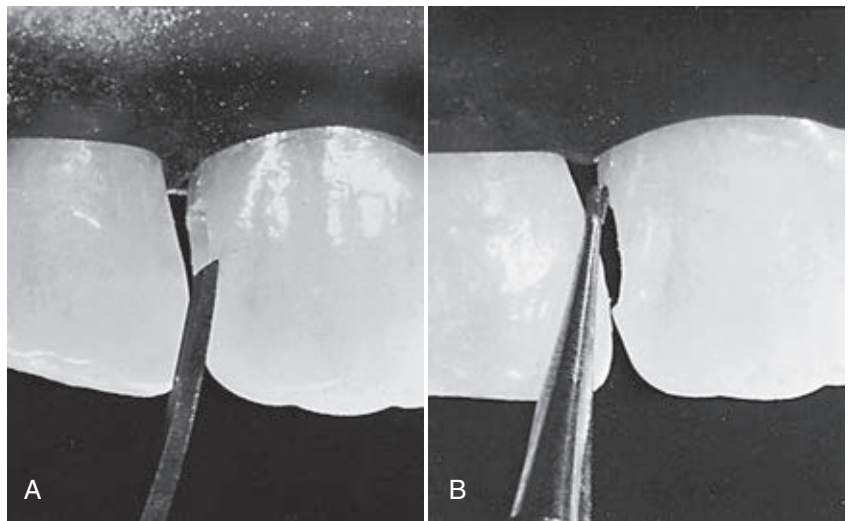
Online Fig. 22-39 A, Preoperative view of the extracted maxillary central incisor that has been mounted in dentiform. Distal surface to be treated with Class III cavity preparation and restoration of compacted gold. B, Preoperative lingual view. C, Facial approach initial entry is made with No. 33½ bur. D, Initial bur entry. E, The Wedelstaedt chisel begins to establish the facial outline form.

(Online Fig. 22-40) and completes the gingival floor preparation. The outline form is completed by beveling the cavosurface areas with a Wedelstaedt chisel. Next, the dentinal part of the gingival, lingual, facial, and incisal walls is planed. A small hoe (i.e., 6½-2½-9) is used for the lingual and gingival walls (Online Fig. 22-41). An angle former is used to plane the facial dentinal wall (Online Fig. 22-42). An axial plane (i.e., 8-1-23) smooths the axial wall, and a bi-beveled hatchet (i.e., 3-2-28) establishes the incisal retentive angle with a chopping motion (Online Fig. 22-43). Small angle formers are used to complete the sharp facio-axio-gingival and linguo-axio-gingival point angles and the slightly acute axiokingival angle (Online Fig. 22-44). The point angles may be enlarged further with the No. 33S bur (i.e., end-cutting bur) for additional convenience form. The Wedelstaedt chisel may be used again

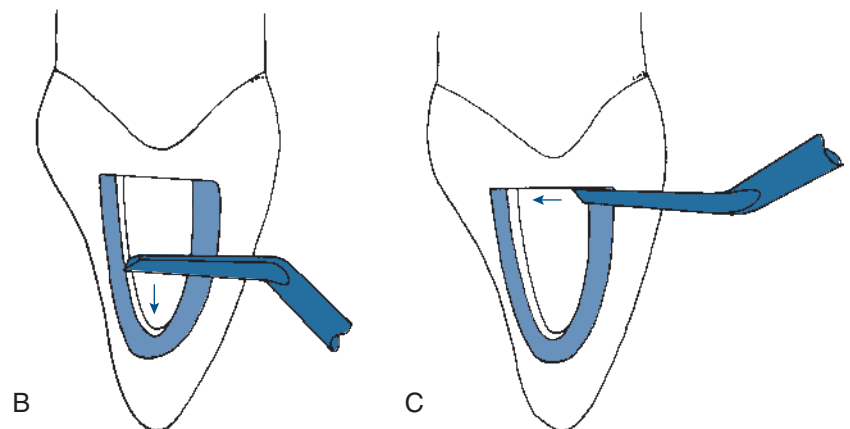
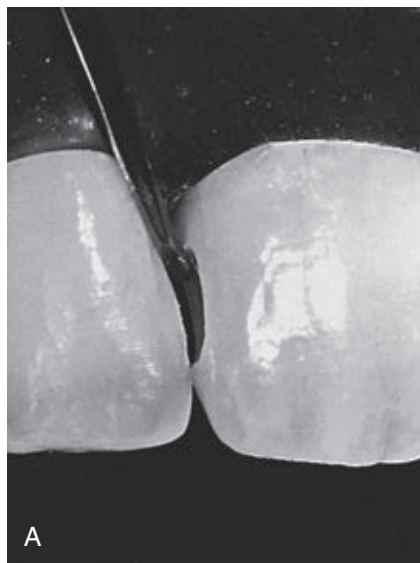
to complete the final planing of the cavosurface margins (Online Fig. 22-45).

Restoration

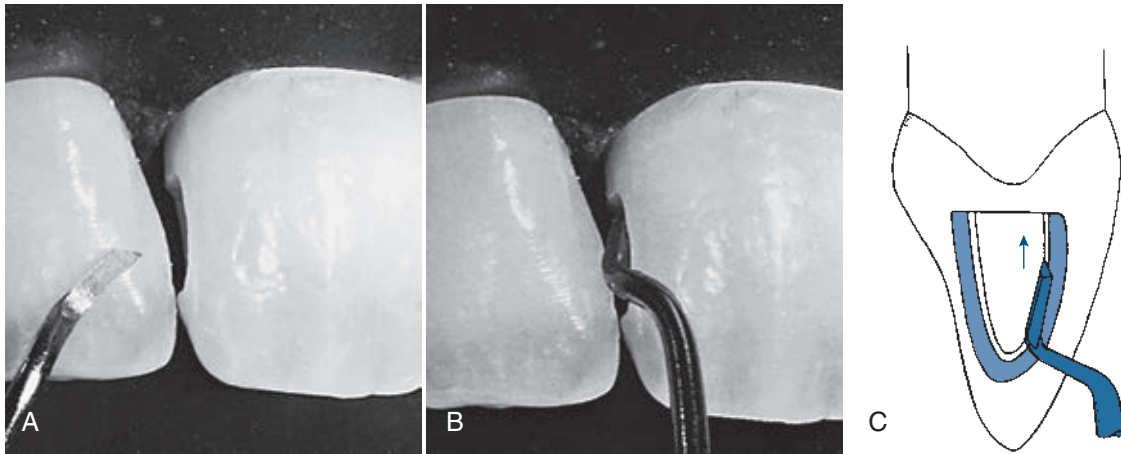
The separator is used to obtain a separation of 0.25 to 0.5 mm. Compaction of gold foil begins at the linguo-axio-gingival point angle (Online Fig. 22-46). A small (i.e., 0.4 mm) monangle condenser is used to compact the gold, which is held by a small holding instrument. Pellets size ¼ or ⅛ are used in the beginning of the restorative phase. The line of force is directed over the facial surface of the adjacent tooth and into the linguo-axio-gingival point angle (see Online Fig. 22-46, B). As soon as ample gold has been compacted into the linguo-axio-gingival area to cover the linguo-axio-gingival shoulder, compaction



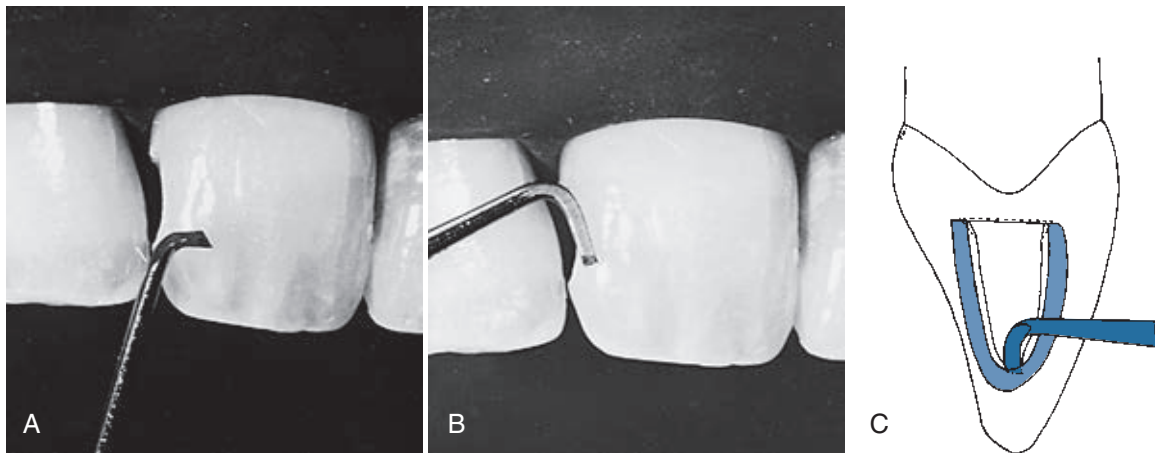
Online Fig. 22-40 Lingual view of preparation instrumentation. **A**, The Wedelstaedt chisel planing the lingual enamel wall. **B**, An inverted cone bur is used to establish the sharp linguo-axio-gingival shoulder.



Online Fig. 22-41 Use of small hoe facial approach in tooth preparation. **A**, The hoe planes the lingual dentinal wall from the incisal aspect to the gingival aspect. **B**, The hoe also planes this wall from the gingival aspect to the incisal aspect (arrow). **C**, The hoe planes the gingival cavosurface (arrow). See Online Figure 5-44, D, for the direction of the enamel portion of the gingival wall for a strong margin (full-length enamel rods).



Online Fig. 22-42 Use of the angle former to plane the facial dental wall. **A**, Angle former before placement in the preparation. **B**, Angle former in the preparation. **C**, The angle former is directed apically (arrow) to plane the facial dental wall.



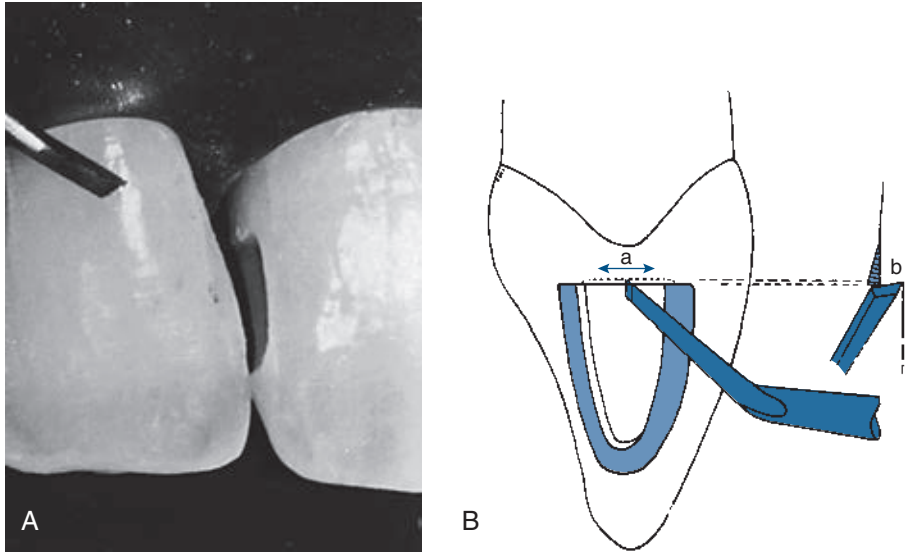
Online Fig. 22-43 **A**, Axial plane before placement in the preparation. **B**, Bi-beveled hatchet before placement in the preparation. **C**, The bi-beveled hatchet is used to establish the incisal retentive angle.

continues across the gingival wall (Online Fig. 22-47) and into the faciogingival angle. The offset condenser (with a faciogingival line of force) is used to fill the facio-axio-gingival point angle (Online Fig. 22-48). Compaction of gold at the linguogingival area is confirmed with the oblique-faced monangle condenser (i.e., 0.5 mm) from the linguoincisor position (Online Fig. 22-49). Failure to provide dense gold in this linguogingival area at this stage may result in a void at the linguogingival angle and subsequently may lead to restoration failure.

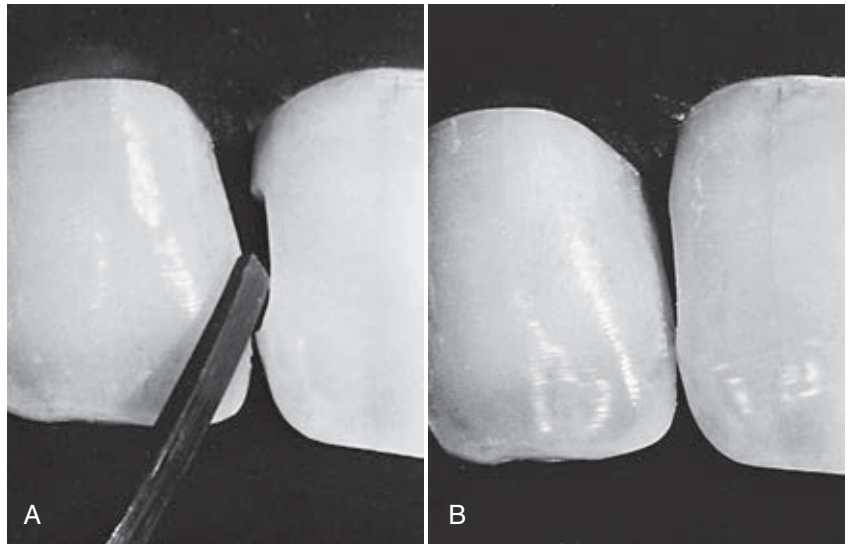
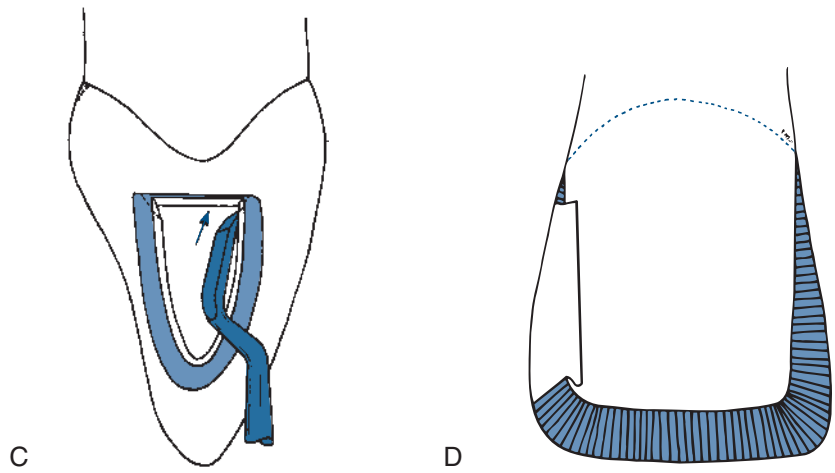
The bulk of the restoration is compacted with $\frac{1}{43}$ - or $\frac{1}{32}$ -sized pellets, mainly from a facial (occasionally from a lingual) direction (Online Fig. 22-50). The line of force is maintained in an axiogingival direction with the 0.5-mm monangle or oblique-faced monangle condenser (see Online Fig. 22-50, B). This requires that the incisal surface of the growing restoration always slope apically, with the gold on the axial wall ahead of the proximal surface of the restoration. During the compaction procedure, the vector of the line of force always should be toward the internal portion of the preparation to prevent dislodgment of the restoration.

The next step is the restoration of the incisal portion of the preparation, referred to as “making the turn.” It is accomplished in three phases. First, sufficient gold is built up on the lingual wall so that the gold is near the incisal angle (Online Fig. 22-51). Second, the incisal area is filled by compacting $\frac{1}{28}$ -size pellets with the right-angle hand condenser (Online Fig. 22-52). Third, pellets of foil are compacted into the incisor and incisal areas with the offset condenser. This fills the incisal portion, making a complete turn from lingual to facial (Online Fig. 22-53, A). The entire incisal cavosurface is covered with gold (see Online Fig. 22-53, B).

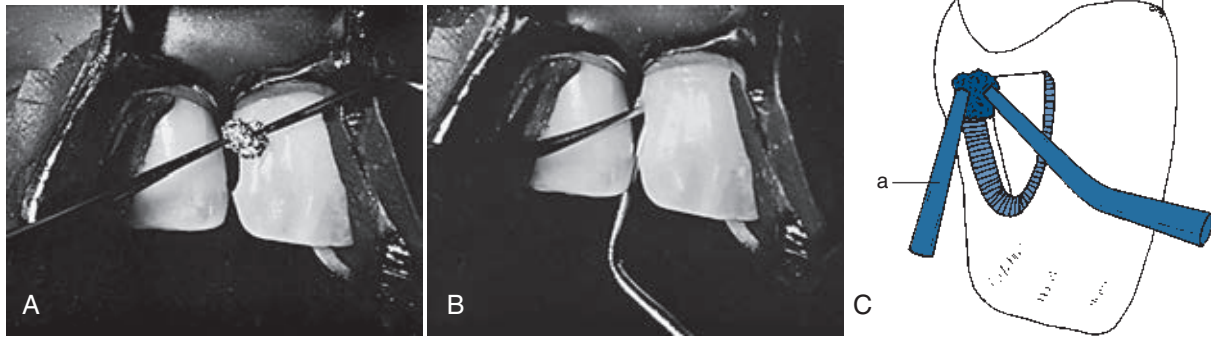
Additional gold compaction finishes the facial one third of the restoration, and then the Varney foot condenser is used to “after-condense” over the contour of the restoration. More separation is generated by slight activation of the separator, before finishing and polishing the restoration. A sharp, gold foil knife is used to remove excess in the contact area, permitting a fine finishing strip or steel matrix strip to pass through. A pull-cut Shooshan file or gold knife may facilitate removal of excess gold facially (Online Fig. 22-54). Initial contouring of the contact area is performed with long, extra-narrow,



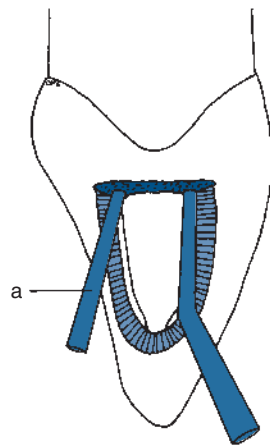
Online Fig. 22-44 A, Angle former before use in the preparation. B, The angle former is moved faciolingually (a) to establish an acute axiogingival line angle (b). C, The offset angle former thrust facioingivally establishes an acute facio-axio-gingival point angle. D, Completed incisal, gingivoaxial retention form. (D, From Stibbs GD: *Direct golds in dental restorative therapy*. Oper Dent 5:107, 1980.)



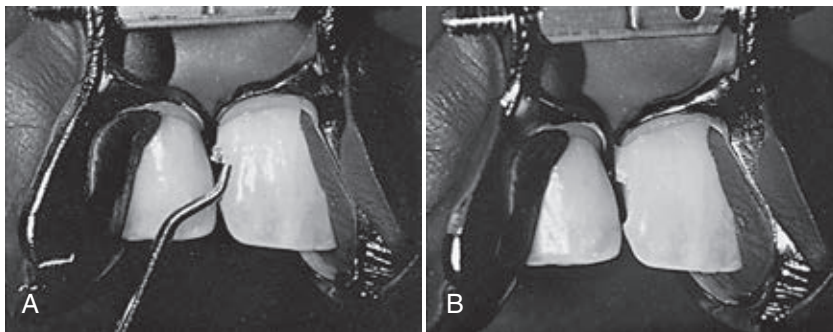
Online Fig. 22-45 A, The Wedelstaedt chisel may be used again to plane margins. B, Completed facial margin of Class III tooth preparation viewed from the facial position.



Online Fig. 22-46 **A**, The first pellet of the gold foil is placed from the facial aspect into the preparation. Note the separation of teeth by 0.25 to 0.5 mm. **B**, Compaction of the pellet into the linguo-axio-gingival point angle. The line of force is directed linguo-axio-gingivally, while the holding instrument is placed from the lingual position. **C**, The holding instrument (a) prevents dislodgment of foil during compaction.



Online Fig. 22-47 The holding instrument (a) remains in position as the gold foil is condensed across the gingival wall toward the facial portion of the preparation.

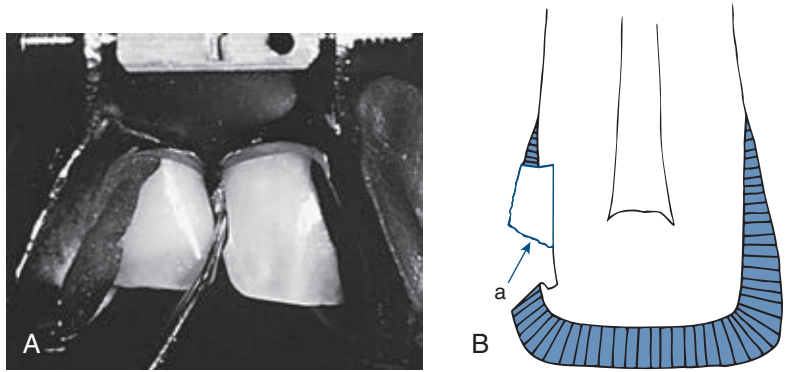


Online Fig. 22-48 **A**, Offset condenser before placement in the cavity preparation. **B**, Compacted gold foil covering the gingival wall and the cavosurface.

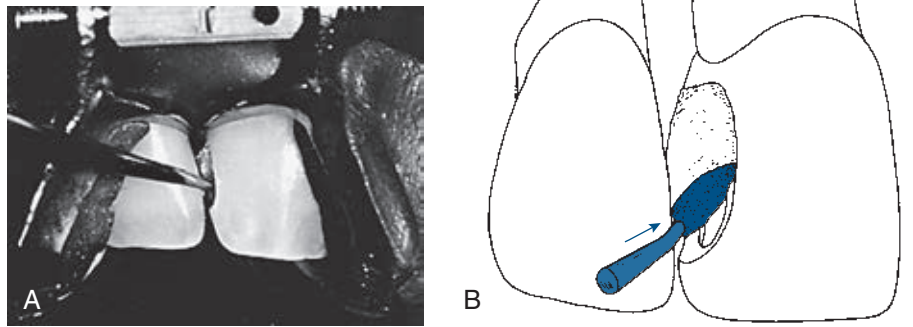


Online Fig. 22-49 Lingual view. The monangle condenser confirms compaction of gold at the linguogingival aspect of the restoration.

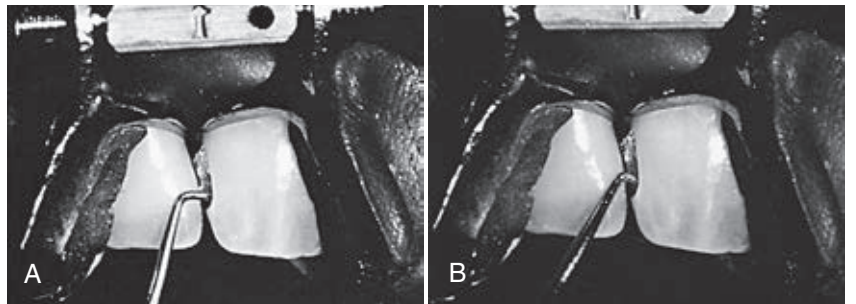
Online Fig. 22-50 **A**, The monangle condenser is used to build the bulk of gold in the gingival half of the preparation. **B**, Gingival half of the restoration in longitudinal section. The line of force (*a*) is directed axiokingivally during compaction of gold to prevent dislodgment of the restoration.



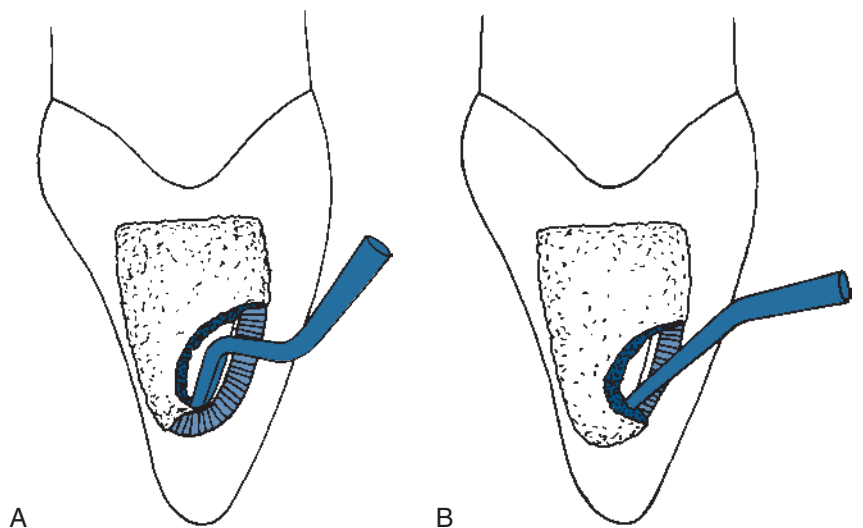
Online Fig. 22-51 **A**, The condenser is directed over the facial surface of the adjacent tooth, while the gold is built toward the incisal aspect. **B**, The gold is compacted from the facioincisal aspect to cover the lingual cavosurface; however, compaction direction must continue to have a major vector (*arrow*) toward the axial wall to prevent dislodgment. At this stage, the compacted foil on the axial wall must be well ahead (incisally) of the “growing” proximal surface.



Online Fig. 22-52 **A**, The right-angle hand condenser begins to press the gold into the incisal retention. **B**, This condenser forces the gold deeply into the incisal retentive undercut.



Online Fig. 22-53 Completing the compaction of gold into the incisal region of the preparation. **A**, The offset bayonet condenser condenses the gold into the incisal retention with mallet compaction. **B**, The incisal cavosurface is restored with gold foil condensed with the small monangle condenser.





Online Fig. 22-54 A sharp, thin-bladed gold knife removes excess gold from the facial surface.



Online Fig. 22-55 Fine cuttle finishing strips polish the proximal surface of the gold foil restoration.



Online Fig. 22-56 Completed maxillary Class III gold foil restoration.

extra-fine cuttle finishing strips, to gain access to the proximal surface. Next, a wide, medium cuttle strip may be used for rapid removal of excess gold. Final contouring continues with the medium and fine, narrow strips. Finishing is performed with the extra-narrow, extra-fine cuttle strip (Online Fig. 22-55). Care is taken to finish only the facial or lingual areas with the strip and to avoid flattening the contact area. The gold knife or cleoid–discoid instrument can be used to remove the final excess gold from the cavosurface margins. The separator is then removed. Final polishing is accomplished with a worn, extra-fine cuttle strip. Polishing powder may be used. Omitting this step results in a satin finish that is less



Online Fig. 22-57 Completed mandibular Class III gold foil restoration of the lesion in Online Figure 5-38.

reflective of light and perhaps more esthetically pleasing (Online Fig. 22-56).

Summary

Direct-filling gold is useful in restorative dentistry. If carefully manipulated by a dentist, this restorative material may provide lifetime service to patients and promote their oral health (Online Fig. 22-57). Direct-filling gold contributes to the art and the science of restorative dentistry.

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Additional Information on Instruments and Equipment for Tooth Preparation

Terrence E. Donovan, R. Scott Eidson

Sharpening Hand Instruments

Selecting the proper hand cutting instrument and using the proper instrument grasp mean little if the instruments are not sharp. Instruments with dull cutting edges cause more pain to the patient, prolong operating time, are more difficult to control, and reduce quality and precision in tooth preparation. It is essential that all cutting instruments be sharp. Re-sharpening requires little time and is rewarding. The dentist or the assistant should regularly test the instruments for sharpness, and when indicated, the hand instruments should be sharpened before they are placed in the tray setup, thus preventing delays in starting or completing an operation (see the section on sharpness test below).

Many types of sharpening equipment exist, including stationary sharpening stones, mechanical sharpeners, and stones that are used in the handpiece. One type or design usually does not accommodate the full variety of dental instruments with their various shapes of cutting edges. For efficient and effective sharpening, the dentist must seek out the most suitable equipment.

Stationary Sharpening Stones

The most frequently used sharpening equipment consists of a block or stick of abrasive material called *stone*. The stone is supported on a firm surface, and the instrument is oriented and held by hand while being stroked against the stone surface. Stationary stones are often called *oilstones* because of the common practice of applying a coating of oil on them as an aid to the sharpening process. Sharpening stones are available in a variety of grits, shapes, and materials.

Stationary oilstones are available in coarse, medium, and fine grits. Only a fine-grit stone is suitable for the final sharpening of dental instruments to be used for tooth preparation. Coarse and medium grits may be used for initial reshaping of a badly damaged instrument or for sharpening other dental equipment

such as bench knives. Coarser stones cut more rapidly but produce a rougher surface. If the use of two or more grits is required, the coarser one is used as little as needed for reshaping, and then the final sharpening is done with a fine stone.

Stationary stones can be obtained in various shapes, including flat, grooved, cylindrical, and tapered. Flat stones are preferred for sharpening all instruments with straight cutting edges; other shapes are most useful for sharpening instruments with curved cutting edges. Cylindrical stones are used for sharpening instruments with concave edges, and tapered stones permit the use of a portion of the stone with a curvature matching that of the instrument.

Sharpening stones are made from any of several natural or synthetic materials. The normal manufacturing process for the synthetic materials involves pressing carefully sized particles of an abrasive into the desired shape and heating to form a solid. To maintain sharp edges on the particles, the process must result in a porous material. The properties of the stone depend on the volume and size of the pores and on the composition and size of the abrasive. Four types of materials are in common use for sharpening stones: Arkansas stone, silicon carbide (SiC), aluminum oxide, and diamond.

Arkansas stone is a naturally occurring mineral containing microcrystalline quartz and traditionally has been the preferred material for fine sharpening stones. It is semi-translucent, white or gray in color, and hard enough to sharpen steel, but not carbide instruments. Arkansas stones are available in hard and soft varieties. The hard stone, although it may cut more slowly, is preferable because the soft stone scratches and grooves easily, rendering it useless. These stones should be lubricated with light machine oil before being used. This assists in the fineness of sharpening, prevents clogging of the stone pores, and avoids the creation of heat, which alters the temper of the steel blade. An Arkansas stone should be covered with a thin film of oil when stored. During the sharpening of an instrument, the fine steel cuttings remain on the stone and tend to fill up the pores of the stone; when the stone appears

dirty, it should be wiped with a clean woolen cloth soaked in oil. If the stone is extremely dirty or difficult to clean, it may be wiped with a cloth soaked in alcohol.

SiC is widely used as an industrial abrasive. It is the most commonly used material for grinding wheels and “sandpapers” and for sharpening stones. It is hard enough to cut steel effectively, but not hard enough to sharpen carbide instruments. SiC stones are available in many shapes in coarse and medium grits, but not in fine grits. As a result, they are not as suitable as other materials for the final sharpening of dental instruments. SiC stones are normally of a dark color, often black or greenish black. These stones are moderately porous and require lubrication with a light oil to prevent clogging.

Aluminum oxide is increasingly used to manufacture sharpening stones. Aluminum oxide stones commonly are produced in various textures from different particle sizes of abrasive. Coarse and medium grit stones generally appear as speckled tan or brownish in color. Fine-grit stones are usually white, have superior properties, and are less porous so that they require less lubrication during use. Either water or light oil is adequate as a lubricant.

Diamond is the hardest available abrasive and is most effective for cutting and shaping hard materials. It is the only material routinely capable of sharpening carbide and steel instruments. Diamond hones are small blocks of metal with fine diamond particles impregnated in the surface. The diamonds are held in place by an electroplated layer of corrosion-resistant metal. Most hones include grooved and rounded surfaces and a straight surface and are adaptable for sharpening instruments with curved blades. These hones are nonporous, but the use of a lubricant extends the life of the hones. They may be cleaned with a mild detergent and a medium-bristle brush.

Mechanical Sharpeners

As high-speed rotary cutting instruments have been improved and their use has increased, the use of hand cutting instruments and the need for re-sharpening has decreased. As a result, some dental office personnel do not do enough hand sharpening to remain confident of their proficiency. Under such circumstances, the use of a powered mechanical sharpener is beneficial.

The Rx Honing Machine (Rx Honing Machine Corp, Mishawaka, IN) is an example of a mechanical sharpener (Online Fig. 23-1). This instrument moves a hone in a reciprocating motion at a slow speed, while the instrument is held at the appropriate angulation and supported by a rest. This is much easier than holding the instrument at the proper angulation while moving it relative to the hone. Interchangeable aluminum oxide hones of different shapes and coarseness are available to accommodate the various instrument sizes, shapes, and degrees of dullness. Restoration of the cutting edge is accomplished more easily and in less time than by other sharpening methods. This type of sharpener is also very versatile and, with available accessories, can fill almost all instrument sharpening needs.

Handpiece Sharpening Stones

Mounted SiC and aluminum oxide stones for use with straight and angle handpieces are available in various sizes and shapes



Online Fig. 23-1 **A**, The Rx Honing Machine shown is used as mechanical sharpener for many different types of dental instruments. It has two spindle drives, one clockwise and the other counterclockwise, to which can be mounted different types of disks and hones to polish and sharpen various types of dental instruments. **B**, The RX Honing Machine shown using a ceramic hone to sharpen a Black spoon dental instrument to extend the life of the instrument.

(see the section on other abrasive instruments). Those intended for use in straight handpieces, particularly the cylindrical instruments with straight-sided silhouettes, are more useful for sharpening hand instruments than are the smaller points intended for intraoral use in the angle handpieces. Because of their curved periphery, it is difficult to produce a flat surface using any of these instruments. These stones also may produce inconsistent results because of the speed variables and the usual lack of a rest or guide for the instrument. Satisfactory results can be obtained, however, with minimal practice, especially on instruments with curved blades.

Principles of Sharpening

Most operative hand cutting instruments can be sharpened successfully on either a stationary stone or the mechanical sharpener. The secret to easy and successful sharpening is to sharpen the instrument at the first sign of dullness and not wait until the edge is completely lost. If this procedure is

followed, a fine cutting edge is restored with a few strokes on a stationary stone or a light touch to the mechanical sharpener. At the same time, operating efficiency is not reduced by attempting to use an instrument that is getting progressively duller.

The choice of equipment used for sharpening is up to the dentist. In the use of any equipment, several basic principles of sharpening should be followed:

1. Sharpen instruments only after they have been cleaned and sterilized.
2. Establish the proper bevel angle (usually 45 degrees) and the desired angle of the cutting edge to the blade before placing the instrument against the stone, and maintain these angles while sharpening.
3. Use a light stroke or pressure against the stone to minimize frictional heat.
4. Use a rest or guide, whenever possible.
5. Remove as little metal from the blade as possible.
6. Lightly hone the unbeveled side of the blade after sharpening, to remove the fine bur that may have been created.
7. After sharpening, resterilize the instrument along with other items on the instrument tray setup.
8. Keep the sharpening stones clean and free of metal cuttings.

Mechanical Sharpening Techniques

When chisels, hatchets, hoes, angle formers, or gingival margin trimmers are sharpened on a reciprocating honing machine (i.e., sharpener), the blade is placed against the steady rest, and the proper angle of the cutting edge of the blade is established before starting the motor. Light pressure of the instrument against the reciprocating hone is maintained with a firm grasp on the instrument. A trace of metal debris on the face of a flat hone along the length of the cutting edge is an indication that the entire cutting edge is contacting the hone (see Fig. 23-1, B).

The mechanical sharpener is easily mastered with a little practice and is a quick method of sharpening hand instruments. Regardless of the type of mechanical sharpener used, the associated instructions for use should be thoroughly understood before attempting to sharpen any type of instrument.

Handpiece stones are used chiefly for instruments with curved blades, especially for the inside curve of such blades. The handpiece should be run at a low speed. The instrument is held lightly against the stone with a modified pen grasp, and whenever possible, the ring and little fingers of each hand should be touching each other to act as a rest or steadying force. When this method of sharpening is used, care must be exercised not to overheat the instrument being sharpened. The use of some form of lubricant or coolant is advisable. If oil is used, care should be exercised to ensure that oil is not thrown from the stone during sharpening, and the stone should be reserved for future sharpening only.

An instrument such as an amalgam knife or a gold knife has a wide blade with a narrow edge bevel, in contrast to the wide bevel of a chisel or hatchet. It is difficult to maintain the narrow edge bevel by using a mechanical sharpener or a handpiece stone. This type of instrument should be sharpened on a stationary stone.



Online Fig. 23-2 Sharpening an instrument. Maintaining the proper angle of bevel and angle of the cutting edge to the stone is aided by resting the fingertips on the stone.

Stationary Stone Sharpening Techniques

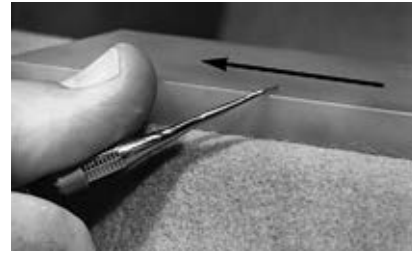
The stationary sharpening stone should be at least 2 inches wide and 5 inches long because a smaller stone is impractical. It also should be of medium grit for hand cutting instruments. Before the stone is used, a thin film of light oil should be placed on the working surface. In addition to establishing the proper 45-degree angle of the bevel and the cutting edge to the stone, several fundamental rules apply to using the stationary stone:

1. Lay the stone on a flat surface, and do not tilt the stone while sharpening.
2. Grasp the instrument firmly, usually with a modified pen grasp, so that it does not rotate or change angles while being sharpened.
3. To ensure stability during the sharpening strokes, use the ring and little finger as a rest, and guide along a flat surface or along the stone. This prevents rolling or dipping of the instrument, which results in a distorted and uneven bevel.
4. Use a light stroke to prevent the creation of heat and the scratching of the stone.
5. Use different areas of the stone's surface while sharpening because this helps prevent the formation of grooves on the stone that impair efficiency and accuracy of the sharpening procedure.

When sharpening chisels, hatchets, or hoes on the stationary stone, grasp the instrument with a modified pen grasp, place the blade perpendicular to the stone, and tilt the instrument to establish the correct bevel (Online Fig. 23-2). Establishing and maintaining this correct bevel is the most difficult part of sharpening on a stationary stone. One method that assists in establishing the proper bevel angle is to observe the oil on the stone while the instrument is tilted, in an effort to establish contact between the entire bevel and the stone. When oil is expressed evenly on all sides, the entire bevel is touching the stone, and the proper angle has been established to proceed with the sharpening strokes. If this alignment is altered during sharpening, discrepancies of the cutting edge and bevel result. Using the finger rests and guides as illustrated in Online Figure 23-2, the operator can slide the instrument back and forth along the stone. The motivating force should be from the shoulder so that the relationship of the hand to the plane of



Online Fig. 23-3 Sharpening the gingival margin trimmer. The palm-and-thumb grasp may be used while holding the stone in the opposite hand to establish a proper cutting edge angle.



Online Fig. 23-4 Sharpening an amalgam knife or a gold knife. The stone is placed at the edge of the table so that the blade may be tilted to form an acute angle with the stone. The arrow indicates the direction of the sharpening movement of the instrument along the stone.

the stone is not changed during the stroke. Another technique is to move the stone back and forth while maintaining a constant position of the instrument. The procedure for sharpening angle formers is essentially the same as that used for chisels, hatchets, or hoes except that allowance must be made for the angle of the cutting edge to the blade.

Gingival margin trimmers require more orientation of the cutting edge to the stone before sharpening than does a regular hatchet. The same principle of establishing the proper bevel angle and cutting edge angle is the criterion for instrument position before sharpening. It may be expedient to use a palm-and-thumb grasp when sharpening a trimmer with a 95- or 100-degree cutting edge angle (Online Fig. 23-3).

When single-bevel instruments are sharpened, a thin, rough ridge of distorted metal, called *bur* or *bur-edge*, collects on the unbeveled side of the blade. This bur is eliminated by a light stroke of the unbeveled side of the blade over the stone. This side of the blade is placed flat on the stone, and one short forward stroke is made. Burring can be kept to a minimum, however, if the direction of the sharpening stroke is against only the cutting edge of the blade, and the cutting edge does not contact the stone during the return stroke. The blade is touching the stone only on the forward sharpening stroke.

The amalgam knife or the gold knife has a thin blade tapering to the sharpened edge. A narrow edge bevel is present on both sides of the blade. In sharpening this instrument, only the edge bevels should be honed. If the entire side of the blade is worked each time, the thin blade soon disappears or becomes so thin that it fractures under the slightest pressure. To sharpen the amalgam knife or the gold knife, the blade is placed on the stone with the junction of the blade and shank immediately over the edge of the stone. The blade is tilted to form a small acute angle with the surface of the stone, and the stroke is straight along the stone and toward the edge of the blade only (Online Fig. 23-4). The sharpening is accomplished on both sides of the blade, with the stroke always toward the blade edge. This method produces the finest edge and eliminates any burs on the cutting edge.

The most difficult instruments to sharpen on a flat stone are the spoon excavators and discoid instruments. Only the rounded outside surface of the spoon can be honed satisfactorily on a flat stone, and this involves a rotary movement accompanied by a pull stroke to maintain the curvature of the edge. The spoon is placed on the far end of the stone and held so that the handle is pointing toward the operator. As the instrument is pulled along the stone toward the operator, the handle is rotated gradually away from the operator, until it is

pointing away from the operator at the end of the stroke. The instrument is picked up and placed at the far end of the stone, and the motion is repeated until the edge is honed. The stone may be placed on a flat surface or held in the hand for this procedure (Online Fig. 23-5). To hone the flat inside surface of the blade, a small cylindrical stone is passed back and forth over the surface (Online Fig. 23-6).

Other means of sharpening spoon excavators are achieved by using a grooved stone, mounted disks, or stones for use with a straight handpiece. A tendency exists, however, to remove too much metal when handpiece stones are used.

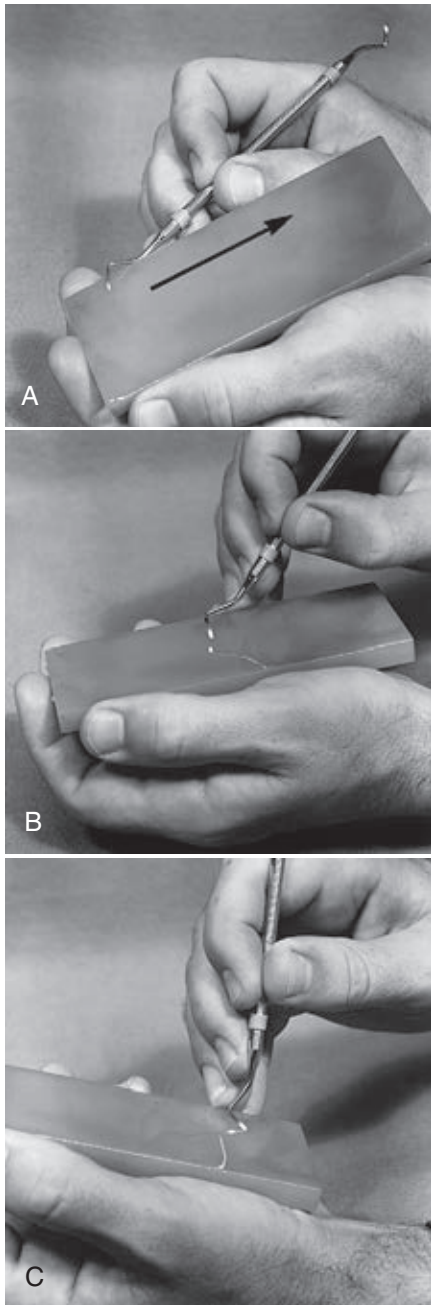
Sharpness Test

Sharpness of an instrument can be tested by lightly resting the cutting edge on a hard plastic surface. If the cutting edge digs in during an attempt to slide the instrument forward over the surface, the instrument is sharp. If it slides, the instrument is dull. Only very light pressure is exerted in testing for sharpness.

The principles and techniques previously discussed provide sufficient background for the operator to use proper methods in sharpening other instruments not discussed here. It cannot be overemphasized that sharp instruments are necessary for optimal operating procedures. It also has been found prudent to have multiple tray setups so that a substitute instrument is available, if necessary, or substitute sterile instruments should be available so that other sterile tray setups are not disrupted when instruments are borrowed.

Sterilization and Storage of Hand Cutting Instruments

Because hepatitis A and B viruses have been found in the saliva of infected persons, and evidence indicates that some dental personnel have acquired hepatitis B infections from patients, the importance of proper equipment and procedures for instrument sterilization must be emphasized. Sterilization in dental offices can be accomplished by autoclaving, dry-heat procedures, ethylene oxide equipment, and chemical vapor sterilizers. Boiling and chemical solutions (cold disinfection) do not sterilize instruments and should be considered as disinfection procedures only. The belief that only instruments that puncture or cut soft tissue or are exposed to blood should be sterilized and others only disinfected is no longer valid as a precaution against cross-infections. Aseptic techniques are



Online Fig. 23-5 Sharpening a spoon excavator. **A**, Beginning of the stroke. **B**, Continuation of the pull stroke while rotating the handle in a direction opposite the stroke. **C**, Completion of the stroke and the handle rotation. Finger guides are used during the entire stroke, which is in the direction indicated by the arrow.

presented in other subject areas and are not detailed here. Sterilization procedures for operative dentistry are presented in Online Chapter 19. Storage of any hand cutting instrument should be in a sterile, wrapped tray setup or in an individual sterile wrapping.

Effects of Sterilization

Methods of sterilization are sporicidal cold disinfection, boiling in water, autoclaving (steaming under pressure), use



Online Fig. 23-6 Use of a small cylindrical stone to hone the inside surface of spoon excavators and discoid–cleoid instruments. *Note:* Gloving is not illustrated in Figures 7-15 to 7-19 because sharpening is accomplished *after* sterilizing the washed instrument; after the instrument is sharpened, it is sterilized again.

of chemical vapor, and use of hot air (dry heat) (see Online Chapter 19 or details regarding acceptable methods of sterilization). Sterilizing carbon steel instruments by any of the first three methods causes discoloration, rust, and corrosion. Several methods for protecting against or minimizing these problems are available. One method used by manufacturers is to electroplate the instrument. This affords protection, except on the blade, where use and sharpening remove the plating. The plating also may pit or peel on the handle and shank under certain circumstances. A second method of protection is the use of rust inhibitors, which are soluble alkaline compounds. These usually are incorporated into commercial sporicidal cold disinfectant solutions, and special preparations are available for use in boiling water and autoclaves. The third method of minimizing the effect of moisture is to remove the instruments promptly at the end of the recommended sterilizing period, dry them thoroughly, and place them in the instrument cabinet or on the tray setup. Leaving instruments exposed to moisture for extended periods or overnight should be avoided.

Boiling in water and autoclaving for sterilization do not produce discoloration, rust, or corrosion of stainless steel instruments. Prolonged immersion in cold disinfectant solutions may, however, cause rusting. It is advisable to leave stainless steel instruments exposed to moisture only for the recommended time. Dry-heat sterilizers do not rust and corrode carbon steel instruments, but the high heat may reduce the hardness of the alloy, which would reduce the ability of the instruments to retain their sharp cutting edge. The choice of alloy in a hand instrument is left to the operator, but whichever alloy is selected to suit the immediate needs would soon prove unsatisfactory if proper manipulation and sterilization are not continually practiced.

Powered Cutting Equipment

Development of Rotary Equipment

The availability of some method of cutting and shaping of tooth structure and restorative materials is essential for the restoration of teeth. Although archeological evidence of dental treatment dates from 5000 B.C., little is known about the equipment and methods used then.¹ Early drills powered by hand are illustrated in [Online Figures 23-7 and 23-8](#). Much of the subsequent development leading to present powered



Online Fig. 23-7 Early straight hand drill for direct access preparations (circa 1800). The back end of the bur shank fits into a finger ring while the front end is rotated with the thumb and the forefinger.

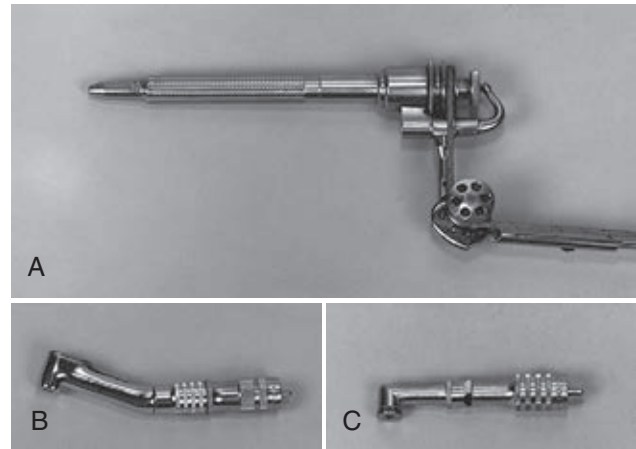


Online Fig. 23-8 Early angle hand drill for indirect access preparations (circa 1850). The bur is activated by squeezing the spring-loaded handle.

cutting equipment can be seen as a search for improved sources of energy and means for holding and controlling the cutting instrument. This search has culminated in the use of replaceable bladed or abrasive instruments held in a rotary handpiece, usually powered by compressed air.

A handpiece is a device for holding rotating instruments, transmitting power to them, and for positioning them intra-orally. Handpieces and associated cutting and polishing instruments developed as two basic types, straight and angle (Online Fig. 23-9). Most of the development of methods for preparing teeth has occurred within the last 100 years.² Effective equipment for the removal (or preparation) of enamel has been available only since 1947, when speeds of 10,000 rpm (revolutions per minute) were first used, along with newly marketed carbide burs and diamond instruments. Since 1953, continued improvements in the design and materials of construction for handpieces and instruments have resulted in equipment that is efficient and sterilizable, much to the credit of manufacturers and the profession alike. Online Table 23-1 summarizes some significant developments of rotary dental equipment.

One of the most significant advancements was the introduction of the electric motor as a power source in 1874. It was incorporated into a dental unit in 1914.³ The initial handpiece equipment and operating speeds (maximum of 5000 rpm) remained virtually unchanged until 1946 (Online Fig. 23-10).



Online Fig. 23-9 Conventional designs of handpieces. **A**, Belt-driven straight handpiece. **B**, Gear-driven angle handpiece that attaches to front end of the straight handpiece. **C**, Gear-driven angle handpiece designed for cleaning and polishing procedures.

Online Table 23-1 Evolution of Rotary Cutting Equipment in Dentistry

Date	Instrument	Speed (rpm)
1728	Hand-rotated instruments	300
1871	Foot engine	700
1874	Electric engine	1,000
1914	Dental unit	5,000
1942	Diamond cutting instruments	5,000
1946	Old units converted to increase speed	10,000
1947	Tungsten carbide burs	12,000
1953	Ball-bearing handpieces	25,000
1955	Water-turbine angle handpiece	50,000
1955	Belt-driven angle handpiece (Page-Chayes)	150,000
1957	Air-turbine angle handpiece	250,000
1961	Air-turbine straight handpiece	25,000
1962	Experimental air-bearing handpiece	800,000
1994	Contemporary air-turbine handpiece	300,000

rpm, revolutions per minute.

The steel burs used at the time could not cut enamel effectively, even when applied with great force. With steel burs, increased speed and power resulted only in increased heat and instrument wear. Further progress was delayed until the development of instruments that could cut enamel. Diamond cutting instruments were developed in Germany around 1935 but were scarce in the United States until after World War II. In a 10-year period, starting in late 1946, cutting techniques were revolutionized. Diamond instruments and tungsten carbide burs capable of cutting enamel were produced commercially. Both instruments performed best at the



Online Fig. 23-10 Typical equipment when an electric motor is used as the source of power: foot control with rheostat (w), belt-driven straight handpiece (x), three-piece adjustable extension arm (y), and electric motor (z).



Online Fig. 23-11 Page-Chayes handpiece (circa 1955). The first belt-driven angle handpiece to operate successfully at speeds greater than 100,000 rpm (revolutions per minute).

highest speeds available, and that prompted the development of higher-speed handpieces. Obtaining speeds of 10,000 to 15,000 rpm was a relatively simple matter of modifying existing equipment by enlarging the drive pulleys on the dental engine. By 1950, speeds of 60,000 rpm and greater had been attained by newly designed equipment employing speed-multiplying internal belt drives (Online Fig. 23-11).² They were found to be more effective for cutting tooth structure and for reducing perceived vibration.

The major breakthrough in the development of high-speed rotary equipment came with the introduction of contra-angled handpieces with internal turbine drives in the contra-angle head.⁴ Early units were water driven, but subsequent units were air driven (Online Figs. 23-12 and 23-13, A). Although most current air-turbine handpieces (Online Fig. 23-14) have free-running speeds of approximately 300,000 rpm, the small size of the turbine in the head limits their power output. The speed can decrease to 200,000 rpm or less, with small lateral workloads during cutting, and the handpiece may stall at moderate loads.⁵ This tendency to stall under high loads is an excellent safety feature for tooth preparation because excessive pressure cannot be applied. Air-driven handpieces continue to be the most popular type of handpiece equipment because of the overall simplicity of design, ease of control, versatility, and patient acceptance. The external appearance of current handpieces is similar to the earliest models.



Online Fig. 23-12 Turbo-Jet portable unit (circa 1955). A small turbine in the head of the angle handpiece is driven by water circulated by a pump housed in the mobile base.



Online Fig. 23-13 Air-turbine handpiece. **A**, The Borden Airotor handpiece (circa 1957) was the first clinically successful air-turbine handpiece. Current air-driven handpieces are similar in the basic design. **B**, Air-turbine straight handpiece (circa 1980).

The low torque and power output of the contra-angle turbines made them unsuitable for some finishing and polishing techniques, for which large heavy instruments are needed. The application of the turbine principle to the straight handpiece eliminated the necessity of having an electric engine as part of a standard dental unit. The design of the straight handpiece turbine provided the desirable high torque for low-speed operation (see Fig. 23-13, B).

Increasing concern about patient-to-patient transfer of infectious agents has put emphasis on other aspects of handpiece performance. Advancements in straight and angle handpieces allow repeated sterilization by several methods



Online Fig. 23-14 Contemporary contra-angle air-turbine handpiece connected to the air-water supply line. (Courtesy of KaVo Dental Corp., Charlotte, NC.)



Online Fig. 23-16 Electric handpieces and unit. (Courtesy of DENTSPLY International, York, PA.)



4-port
spray

Fiberoptic
lighting

Online Fig. 23-15 View of the handpiece showing four spray ports for cooling and fiberoptic illumination. (Courtesy of KaVo Dental Corp., Charlotte, NC.)

(see Online Chapter 19). Sterilization produces some damage to parts of the handpiece, however, necessitating more frequent service and repair. Other improvements of the angle handpiece include smaller head sizes, more torque, lower noise levels, and better chucking mechanisms. Since 1955, angle handpieces have had an air-water spray feature to provide cooling, cleansing, and improved visibility.⁶ Most modern-angled handpieces also include fiberoptic lighting of the cutting site (Online Fig. 23-15). Electric handpieces that compete effectively with air-turbine designs have also been developed (Online Fig. 23-16).

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