Pediatric Nutrition for Dietitians

Edited by
Praveen S. Goday
Cassandra L. S. Walia

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To Thangam, Arvind, and Tara
For always being at the dinner table and nourishing my soul

Praveen S. Goday

To my parents, who always encouraged me to chase my dreams and provided unwavering support along the way. And to my husband, who helped me study and continues to support me through my career every day.

Cassandra L. S. Walia

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Preface

Many physicians, especially pediatricians, learn both the fundamentals and the nuances of practical nutrition from dietitians. Clinical dietitians, in turn, learn and sharpen their skills with the help of physicians. This book exemplifies this symbiosis not just because its editors are an MD-RD combo who have practiced together for more than a decade, but because practically all the chapters in this book have dietitian and physician authors who have contributed to this "multidisciplinary" approach. We hope that this approach will serve both the student dietitian and the dietitian who may not have the support of a physician at her side.

The book begins with the fundamentals of pediatric nutrition assessment, including growth assessment, nutrition-focused physical exam, and ADIME. Key aspects of nutrition from infancy through adolescence are discussed before moving on to the specifics of nutrition care in subspecialty areas of pediatric nutrition. Each disease-specific chapter ends with an ADIME table that summarizes nutrition care for the specific population and serves as a quick guide for providing patient care. All chapters were written by experts in the field, and then reviewed by expert dietitians actively practicing in these areas. While no book can cover the spectrum of patients seen by pediatric dietitians, the Growth Assessment, Nutrition-Focused Physical Exam, Nutrition Screening and ADIME, Care of Children and Youth with Special Health Care Needs, and Restricted Diets chapters provide the dietitian with the nutrition assessment and intervention tools needed to adapt to the ever-changing landscape of pediatric nutrition and provide expert nutrition care regardless of the situation.

We have made a few choices in this book. To make it more readable, we refer to dietitians as such instead of using Registered Dietitian or Registered Dietitian Nutritionist. Again, to enhance readability, we have elected to use female pronouns for dietitians and patients in this book, with the exception of the rare case where we have to specifically refer to a male patient.

While we, the editors, are experts in pediatric nutrition, we are not experts in every aspect of this field. To ensure that the chapters in the book are accurate and evidenced based, authors and reviewers who are experts in the field have contributed to this work. This book has benefited greatly from their suggestions and corrections. To them we are immensely grateful.

Praveen S. Goday
Cassandra L. S. Walia

Editors

Praveen Goday is a pediatric gastroenterologist at the Children's Hospital of Wisconsin and a professor of Pediatrics at the Medical College of Wisconsin in Milwaukee, Wisconsin. He is a recognized expert in nutrition and has authored > 50 research publications and ~40 book chapters. He has already served as editor of a book on Pediatric Critical Nutrition. He has served on the Board of the American Society for Parenteral Nutrition (ASPEN) and as the chair of the Nutrition Committee of the North American Society for Pediatric Gastroenterology, Hepatology, and Nutrition (NASPGHAN). He is currently on the Committee of Nutrition of the American Academy of Pediatrics. He is also the recipient of several national honors and awards including: ASPEN Excellence in Nutrition Support Education Award and the ASPEN Distinguished Nutrition Support Physician Service Award. He has been on the Best Doctors in America list continuously since 2007 and led the Children's Hospital of Wisconsin Team to an ASPEN Clinical Nutrition Team of Distinction Award.

Cassandra L. S. Walia completed the coordinated program in dietetics at Mount Mary University in 2009, and earned her Master's of Science in dietetics in 2012. Prior to working at Children's Hospital of Wisconsin, she was a dietitian at the City of Milwaukee Health Department WIC clinics. She has worked in the outpatient GI and Allergy clinics at Children's Wisconsin (CW) since 2009. She is recognized as an expert within her field, has several publications and is a Certified Nutrition Support Clinician. Cassandra has participated in a variety of quality improvement projects including creation of a nutrition lab protocol for patients with inflammatory bowel disease and improving the safety of our electronic medical record build for home parenteral nutrition. During her time at CW, Cassandra has represented Clinical Nutrition in a variety of multidisciplinary committees including the Patient Family Education Committee, Joint Clinical Practice Council, and the Food Allergy Huddle. She worked to create innovative electronic education for food allergy patients and is currently working to create additional video education on nutrition topics for patient care. In addition to her role at CW, Cassandra has been an adjunct instructor at Mount Mary University since 2015, where she teaches graduate students and dietetic interns about pediatric nutrition.

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1 Growth Assessment

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CONTENTS

Nutrition plays a major role in both the physical and intellectual development of children. Monitoring growth and development is a cornerstone of pediatric care. Healthy infants and children typically follow a predictable pattern of development, which allows growth to serve as a sensitive marker for health and nutritional status. Growth can be affected by a variety of conditions, and alterations in growth can be the first sign of a pathologic condition. Marked deviations from a normal growth pattern, particularly during early life, have also been associated with an increased risk of comorbidities later in life. Delayed growth in childhood has been associated with decreased adult height and altered body composition, including increased abdominal fat mass, in adulthood. Further, a substantial body of research has demonstrated that malnutrition can lead to abnormal brain development, including tissue damage, disordered differentiation of neural cells, reduction in synapses and synaptic neurotransmitters, and delayed myelination. These can lead to lasting cognitive impairment, affecting attention, visual, auditory, memory, and executive function, and interfering with a child's school performance and potential for achievement.

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Clinical evaluation of a child's growth should focus on key historical features, as well as accurate measurement of all growth parameters. The history should include a thorough dietary history, weight, length, and head circumference at birth, prenatal history, past medical and family history, and a complete review of systems for evidence of systemic disease. Body weight, length or height, head circumference, and weight-for-length or body mass index (BMI)-for-age are easily measured or calculated and can be compared with population standards using growth charts (Appendix A). Pediatric growth can be divided into three periods: infancy, childhood, and adolescence.

INFANT GROWTH

The intrauterine environment and maternal nutrition are primarily reflected in the growth parameters at birth and during the first few months of life, after which genetic and environmental factors exhibit a stronger influence. Many infants will significantly change growth percentiles (and hence, their corresponding z-scores) for weight and length during the first 2 years of life, but then usually follow their established growth trajectory after age 2.

Term neonates can lose up to 10% of their birth weight during the first few days of life and should get back to their birth weight by days 10–14. After return to birth weight, infants typically follow an established pattern of weight gain during the first year of life. Expected weight gain during infancy is approximately 30 g/day from age 0 to 3 months, 20 g/day for ages 3 to 6 months, and 10 g/day for ages 6 to 12 months. Infants should roughly double their birth weight by 4 months of age and triple their birth weight by 12 months of age. Weight gain slows after the infant's first birthday. Normal linear growth in infants is approximately 10 inches (~25 cm) during the first year of life.

Feeding methods can impact the weight gain patterns seen in infants. Breastfed infants typically gain weight more rapidly during the first 3–4 months of life when compared to formula-fed infants, and relatively slowly thereafter. By age 1–2 years, the weights of breastfed and formula-fed infants are similar. It is important to correct growth parameters for gestational age in preterm infants; however, there is limited consensus on the duration of "catch-up" growth in premature infants and how long to correct for gestational age when interpreting growth. The World Health Organization (WHO) suggests correction of weight, height, and head circumference until age 2–3 years for children born prematurely (Chapter 12).

CHILDHOOD GROWTH

Children gain approximately 2 kg/year between age 2 years and puberty. They typically gain 4 inches (~10 cm) in length/height during the second year of life, 3 inches (~7.5 cm) during the third year of life, and 2 inches (~5 cm)/year between age 4 years and puberty. With increasing height and slowed weight gain, toddlers and preschoolers grow taller and leaner. Of note, growth during this period is pulsatile, consisting of periods of rapid growth separated by periods of minimal growth. There is also normal deceleration of height velocity before the pubertal growth spurt during adolescence.

ADOLESCENT GROWTH

Puberty refers to the physical changes that occur during adolescence, including growth in stature and development of secondary sexual characteristics. The latter occurs in a series of events that also follows a predictable pattern, with some individual variation in sequence and timing of onset (between 8 and 13 years in girls and 9.5 and 14 years in boys). Sexual maturation can happen gradually or with several changes at once. Tanner staging is a sexual maturity rating system used to define physical measures of sexual development, including breast changes in females, genital changes in males, and pubic hair changes in both females and males. Tanner staging is commonly used to define the pre- or peri-pubertal stage of a child at a single point in time (Appendix B). In boys, the first change is

testicular development followed by penile growth and pubic hair development. In girls, the first change is breast development followed by the appearance of pubic hair which is then followed by menarche.

Approximately 20% of adult height accrual occurs during puberty, though the pattern of height accrual can be highly variable. It can be steady growth or periods of rapid growth interspersed with periods of slow growth. The typical pubertal growth pattern involves a phase of acceleration, followed by a phase of deceleration, and ending with the eventual cessation of growth with the epiphyseal (growth plate) closure. The timing of the growth spurt varies by sex, occurring 2 years earlier on average in females than in males, and is impacted by sexual development. Therefore, a child's Tanner staging can provide clues regarding the timing of an expected acceleration in growth.

Peak height velocity is reached in boys between Tanner stages 4 and 5 while in girls it is highest between stages 3 and 4 and is followed by menarche. Menarche can occur between 10 and 16.5 years. After menarche, the average height gain is about 2.75 inches (~7 cm) and can be even greater for girls who menstruate on the early side of normal. Growth typically ceases about 2 years after menarche. Early onset of puberty, and subsequent earlier peak height velocity, can lead to transient periods of tall stature when compared to same-age peers but is typically associated with reduced overall adult height accrual. The major sex differences in height are established during puberty, with a final average height difference of 4.9 inches (~12.5) cm between males and females in the general population. See Appendix B for more information about Tanner staging.

MEASUREMENT OF GROWTH

Surveillance through regular measurements of growth is an important tool to monitor the health of children. While a normal growth pattern does not guarantee overall health, atypical growth can reflect nutritional insults and can be the presenting sign of systemic illness. Accurate measurements of growth are essential for growth assessment. Growth can be measured in two ways: (1) current, attained growth relative to same-age peers, and (2) growth velocity, which reflects the change in a growth parameter over time.

Weight

Weight should be obtained naked for infants less than 2 years of age, and with only light clothing without shoes for older children. Measurements should be repeated two to three times and used to calculate an average value (Tables 1.1–1.3). Whenever possible, subsequent weights should be measured using the same scale to improve accuracy. This measurement can be plotted on a standardized growth chart (Appendix A), as described below, to assess a child's weight relative to same-age peers. Wheelchair scales can also be used for patients that are unable to stand unsupported. This can be done by recording the weight of the empty wheelchair followed by weighing the patient in the wheelchair. The difference between the weight of the patient in the wheelchair and the wheelchair alone is the patient's weight.

For hospitalized patients, weight should be measured daily for preterm and term infants and at least weekly for older children. Patients with nutrition and growth concerns may require daily weights, including older children. For patients seen in the outpatient setting, weight should be measured minimally every 3 months for infants and yearly for children. More frequent weights may be needed in the outpatient setting as well for patients with nutrition and growth concerns.

Length and Height

Length, as opposed to a standing height, is used for children < 2 years of age, < 85 cm, and/or unable to stand. Length can be obtained using an infant measuring board or measuring mat (Table 1.4) but should not be measured using a tape measure or by marking the infant's length on an exam table.

TABLE 1.1
Weight Measurement (0–2 Years)

Material required	Calibrated Electronic Infant Scale (0–20 kg maximum)
Measuring Position	Recumbent
Step 1	Undress infant down to a dry disposable diaper or nude
Step 2	Zero scale
Step 3	Place infant on scale face up, laying on back
Step 4	Read measurement to the nearest 0.01 kg

TABLE 1.2
Weight Measurement (Age > 2 Years)

Material required	Calibrated Beam Balance or Digital Scale
Measuring Position	Standing
Step 1	Remove shoes and any outerwear or heavy garments
Step 2	Zero scale
Step 3	Child stands on scale
Step 4	Read measurement to the nearest 0.1 kg

TABLE 1.3
Weight Measurement for Children (Age > 2 Years) Who Cannot Stand Unsupported or Are Reluctant to Be Weighed

Material Required	Calibrated Beam Balance or Digital Scale
Measuring Position	Child held by caregiver
Step 1	Remove shoes and any outerwear or heavy garments from both caregiver and child
Step 2	Zero scale
Step 3	Caregiver stands on scale alone
Step 4	Read measurement nearest 0.1 kg. Note this weight
Step 5	Caregiver then holds child. Weigh both caregiver and child
Step 6	Read measurement to the nearest 0.1 kg. Subtract weight of caregiver alone from weight of caregiver and child to determine child's weight

TABLE 1.4
Length Measurement (Age 0–2 Years and Patients Unable to Stand But Able to Lie Flat)

Material Required	Calibrated Infantometer or Length Board
Measuring Position	Recumbent
Additional Requirements	2-person measuring technique
Step 1	*Person 1* – Position head against the headboard. Align the inner ear canal to bottom of eye orbit (Frankfort plane) parallel to the headboard
Step 2	*Person 2* – Straighten and stretch the legs so that knees lay flat against the board. Flex feet and place flat against the foot board at a 90° angle
Step 3	*Person 2* – Read measurement to the nearest 0.1 cm

Height, used for children > 2 years of age, should be obtained with the child standing upright without shoes and looking straight ahead (Table 1.5). Similar to weight, these measurements should be repeated two to three times and used to calculate an average and can be plotted on standardized growth charts to compare a child's height to same-age peers (Appendix A). Height velocity demonstrates the rate of height accrual over time and requires a change in height over a period of at least 6 months to be calculated accurately. In certain patients, alternate measurements may be taken to estimate height as indicated (Tables 1.6–1.8). Serial measurements can be helpful in determining if a patient is demonstrating linear growth. These alternate height measurements should not be used to calculate BMI or ideal body weight (IBW) as they are only an estimate of actual height.

In the hospital setting, length/height should be measured weekly for preterm infants, monthly for term infants and younger children, and at least every 3 months for children 10 years and older. In the outpatient setting, length/height should be measured every 3 months for children under 2 years of age and at least annually for older children. More frequent length/height measurements may be necessary for patients with nutrition and growth concerns.

TABLE 1.5
Height Measurement Using Stadiometer (Age > 2 Years)

Material Required	Stadiometer
Measuring Position	Standing
Step 1	Remove shoes and all hair pieces including hats
Step 2	Align heels, buttocks, shoulder, and head against the stadiometer with arms resting at side
Step 3	Position head with the inner ear canal and bottom of eye orbit (Frankfort plane) parallel to the floor ensuring a straight spine
Step 4	Lower stadiometer paddle until it rests on the top of the head
Step 5	Read measurement to the nearest 0.1 cm

TABLE 1.6
Knee Height Measurement (Age > 6 Years)

Material Required	Knee Height Calipers
Measuring Position	Sitting upright in chair or laying supine on table. May use right or left leg
Indications	Patient unable to stand or lie flat on length board. Used for patients without Cerebral Palsy (CP) or Neurological Indication (NI) OR patients with CP or NI from ages 12 to 18 years
Step 1	Person to remove socks and shoes. Roll pants up past knee or remove
Step 2	Position knee at 90° angle
Step 3	Place the lower blade of the knee height caliper under heel and the upper blade on the thigh directly above the head of the fibula bone which is about 1–1.5 inches back from the tip of the knee
Step 4	Align shaft of knee height caliper with leg and apply slight pressure
Step 5	Read measurement to the nearest 0.1 cm
Step 6	Use knee height measurement in appropriate equation to estimate height **Knee Height Equations for 0–12 years**: Stature (cm) = [Knee Height (cm) × 2.68] + 24.2 **Knee Height Equations for Males**: **White Male 6–18 years**: Stature (cm) = [Knee Height (cm) × 2.22] + 40.54 **Black Male 6–18 years**: Stature (cm) = [Knee Height (cm) × 2.18] + 39.60 **Knee Height Equations for Females**: **White Female 6–18 years**: Stature (cm) = [Knee Height (cm) × 2.15] + 43.21 **Black Female 6–18 years**: Stature (cm) = [Knee Height (cm) × 2.02] + 46.59

TABLE 1.7
Tibial Length Measurement (Age 0–12 Years)

Material Required	Knee Height Calipers or Measuring Tape
Additional Requirements	Marking Tool (Pen or Marker)
Measuring Position	Sitting upright in chair or laying supine on table. Measure right leg
Indications	Patient unable to stand or lie flat on length board. Used for patients without CP or NI OR patients with CP or NI from ages 0 to 12 years
Step 1	Person to remove socks and shoes. Roll pants up past knee or remove
Step 2	Locate the superior surface of the medial condyle (indent where the tibia meets the femur) and mark skin
Step 3	Locate the distal tip of the malleolus (bony prominence on side of ankle) and mark skin
Step 4	Place the fixed blade of the Knee Height caliper on the malleolus landmark and measure the distance to your second mark with the shaft running parallel to the axis of the leg. A measuring tape may also be used
Step 5	Read measurement to the nearest 0.1 cm Repeat Steps 4 through 5 twice and use average measurement
Step 6	Use tibial length measurement equation to estimate height **Tibial Length Equation:** Tibia Length (TL): Stature (cm) = [3.26 × TL (cm)] + 30.8

TABLE 1.8
Arm Span Measurement (Age > 6 Years)

Material Required	Measuring Tape
Measuring Position	Sitting upright or standing
Indications	Patient unable to stand or lie flat on length board. Used for patients without CP or NI OR patients with CP or NI from ages 6 to 18 years
Step 1	Extend both arms outward
Step 2	Position at 90° angle from torso
Step 3	Measure distance from middle fingertip on left hand to middle fingertip on right hand. Two persons may be required to measure distance
Step 4	Read measurement to the nearest 0.1 cm
Step 5	Arm span measurement is the estimated height measurement

Head Circumference

Head circumference serves as a reflection of brain growth. It should be measured around the head parallel to the floor with the tape just above the eyebrows in front and around the most prominent portion of occiput (Table 1.9). Standardized head circumference charts can be used to assess a child's head circumference compared to the median for age and gender (Appendix A). Head circumference typically increases approximately 1 cm/month during the first year of life, with the most rapid growth during the first 6 months of life. Most head growth is complete by 4 years of age.

Head circumference should be measured for infants and children until 2 years of age, and in older children as needed. In the hospital setting, it should be measured monthly and at least every 3 months in the outpatient setting. More frequent measurements may be indicated in patients with nutrition and growth concerns.

TABLE 1.9
Head Circumference Measurement (Age 0–36 Months)

Material Required	Measuring Tape
Measuring Position	Recumbent
Step 1	Lay infant flat on table face up. Remove braids and hair ornaments that will interfere with measurement
Step 2	Place measuring tape securely around the widest circumference of the infant's head. Typically, this is one to two finger widths above the eyebrow on the forehead and across the most prominent part of the back of the head
Step 3	Read measurement to the nearest 0.1 cm

Body Mass Index (BMI)

BMI is a measure of proportionality and demonstrates how well a child's weight and height correlate with each other. It is calculated using weight (in kg) and height (in meters) using the following formula:

$$\textbf{BMI} = \text{body weight} \div \text{height}^2$$

BMI can vary based on age, gender, and pubertal stage and is used as the clinical standard for diagnosing obesity in children 2 years of age and older. BMI is typically normal in children who have constitutional growth delay or familial short stature. A BMI less than the 5th percentile or greater than the 85th percentile may demonstrate that a child is underweight or overweight, respectively. Alternate height measurements should not be used to calculate BMI. Indices of body proportionality are valuable in the assessment of overall nutrition status, and the indices typically used are the ratio of weight to length (typically expressed as a percentile or a z-score) and BMI. Traditionally, weight-for-length z-score is used in children under the age of 2 years and BMI-for-age z-score beyond that age. However, BMI-for-age z-scores are available in children under 2 and can be used with the caveat that inaccuracy in length measurements (that are unfortunately common in infants) can change the BMI-for-age z-score more than it changes the weight-for-length z-score.

Mid-Upper Arm Circumference (MUAC)

MUAC is an anthropometric measurement that measures both fat mass and fat-free mass. Measurements are compared to age- and gender-based standards and reflected as a percentile or z-score based on population norms. MUAC is a tool that predicts pediatric malnutrition due to undernutrition. MUAC measurement is an inexpensive procedure and requires minimal equipment (Table 1.10). In specific patient populations, where weight may be skewed by fluid retention, peritoneal dialysate, casts, or other medical devices, the use of MUAC is preferred over weight-for-length or BMI.

MUAC should be frequently measured for infants and children that are at risk of malnutrition. Clinically significant changes in MUAC can often be noted on a monthly basis. Z-scores can be calculated for patients 6–60 months old using WHO reference data or reference tools such as peditools.org. For patients 6 years and older, MUAC can be compared to normative data to determine percentiles or z-scores (Appendix C).

TABLE 1.10
Mid-Upper Arm Circumference Measurement (MUAC) (Age > 3 Months)

Material Required	Measuring Tape
Measuring Position	Standing or sitting upright. Arm measured depends on data set used for comparison (left arm for WHO data set, right arm for Addo data set). If using the reference in Appendix C, use the right arm.
Additional Requirements	Marking Tool (Pen or Marker)
Step 1	Position person standing with weight equally distributed on both feet or sitting in position where arm hangs free. If measuring an infant, position upright and held by caregiver
Step 2	Flex the arm at the elbow to a 90° angle with palm face up
Step 3	Measure upper arm length from the tip of the acromion (tip of the shoulder blade) to the tip of the olecranon (tip of the elbow)
Step 4	Divide the measurement in half to find the mid-point and mark. Release 90° angle
Step 5	Extend arm down, gently shaking to ensure it is relaxed
Step 6	Place measuring tape around the arm at the mid-point mark. Support tape near the back of the arm and hold without pinching or gaping
Step 7	To read measurement, place one end of the tape above the mark and the other end below the mark
Step 8	Read measurement to the nearest 0.1 cm Repeat Steps 5 through 8 twice and use average measurement

ADDITIONAL GROWTH MEASUREMENTS

Additional growth measurement techniques may be used in specific patient populations. They can be particularly helpful in determining the nutrition status of patients with fluid retention, patients with enlarged organs (i.e., liver failure), and patients with large tumors.

Skinfold Thickness

Skinfold thickness measures subcutaneous body fat and is an indicator of total body fat composition. Triceps skinfold (TSFT) measures subcutaneous fat on the limbs and subscapular skinfold (SSFT) measures subcutaneous fat on the body trunk (Tables 1.11 and 1.12). Skinfold thickness varies based on age and gender with assessment of measurement based on median and standard deviations of the population. TSFT measurement is the most common and correlates with estimates of total body fat in women and children whereas SSFT is shown to be the best predictor of total body fat in men. TSFT and SSFT are not indicated as short-term measurements of fat stores. Skinfold thickness may not reflect total body fat stores and may not correlate with visceral fat deposits surrounding internal organs.

Measurement of MUAC and skinfold thicknesses can be dependent on the person doing the measurements. It is important that dietitians acquire and maintain these measurement skills through consistent practice. Z-scores can be calculated using WHO reference data or reference tools such as peditools.org. For patients 6 years and older, TSFT can be compared to normative data to determine percentiles or z-scores.

Handgrip Strength

Handgrip strength is measured by the amount of static force that a hand can squeeze around a dynamometer device (Table 1.13). It is a predictor of nutrition status and a marker of muscle quality. Normative data for handgrip strength is available and stratified by gender and age (see Bohannon et al in references). Static force measurements indicate if an individual has weak, normal, or strong hand strength based upon stratified norms. Analysis demonstrates that males at all ages show higher grip strength than females with grip strength peaking in all genders in the fourth decade of life.

TABLE 1.11
Triceps Skinfold Measurement (Age > 6 Years)

Material Required	Measuring Tape and Triceps Skinfold Caliper
Measuring Position	Standing or sitting upright. Measure right arm (using WHO comparative data)
Additional Requirements	Marking Tool (Pen or Marker)
Step 1	Position person standing with weight equally distributed on both feet or sitting in position where arm hangs free. If measuring an infant, position upright and held by caregiver
Step 2	Flex the arm at the elbow to a 90° angle with palm face up
Step 3	Measure upper arm length from the tip of the acromion (tip of the shoulder blade) to the tip of the olecranon (tip of the elbow)
Step 4	Divide the measurement in half to find the mid-point and mark. Release 90° angle
Step 5	Extend arm down, gently shaking to ensure it is relaxed
Step 6	Above the mid-point mark, use your thumb and middle finger to lift the fold of fat and skin away from the underlying muscle tissue
Step 7	While holding skinfold, open calipers and place the tips just below the fingertips and release the calipers to begin measuring
Step 8	Open calipers and remove from arm then release skinfold
	Repeat Steps 5 through 8 twice and use average measurement

TABLE 1.12
Subscapular Skinfold Measurement (Age > 6 Years)

Material Required	Skinfold Caliper
Measuring Position	Standing or sitting upright
Step 1	Position person standing or sitting upright and facing away from you with arms at their side
Step 2	Position person's arm behind their back by bending the arm at the elbow and placing arm on back with palm of hand facing out. This position aids in locating the scapula
Step 3	Locate the scapula and find the most inferior point of the scapula called the inferior angle. Mark this point as your skinfold site
Step 4	Pinch at the skinfold site which runs diagonally. Place your skinfold caliper about 1 cm below and to the right of the pinch to measure
Step 5	After 3 seconds take the reading to the nearest 0.2 mm (Holtain®) or 0.5 mm (Lange®)
Step 6	Open calipers and remove from back then release skinfold
	Repeat Steps 4 through 6 twice and use average measurement

TABLE 1.13
Handgrip Strength Measurement (Age > 6 Years)

Material Required	Handgrip Dynamometer
Measuring Position	Sitting upright in chair, measure both right and left hands
Step 1	Adjust grip size of the dynamometer by turning silver knob of the device until the second joint of the index finger is at a 90° angle of the handle
Step 2	Position person sitting upright in chair with back supported and feet flat on the floor
Step 3	With dynamometer in hand, place elbow at side and bend arm at a 90° angle
Step 4	Instruct patient to squeeze dynamometer as hard as possible and hold for three seconds then release. There is a tendency to straighten or curl arm when squeezing, ensure person keeps arm at a 90° angle
Step 5	The dynamometer will output a force measurement in kilograms or pounds
Step 6	Repeat with opposite hand

Handgrip strength and BMI have been loosely correlated with underweight and overweight individuals having lower grip strength than normal weight individuals.

INTERPRETING GROWTH MEASUREMENTS

Growth charts are an essential tool in pediatric growth assessment. They allow the dietitian to plot measurements over time, view trends, and compare patients to normative data.

Standard Growth Charts

Growth charts are used to compare anthropometric measurements against age, gender, and population standards (Appendix A). Percentile ranges and standard deviation z-scores are used to assess both short-term nutrition status and long-term growth trends. In children, weight-for-length, BMI-for-age, and length/height-for-age z-scores are utilized to diagnose malnutrition based on undernutrition (Chapter 10). Overnutrition is based on BMI percentiles (Chapter 25).

Serial anthropometric measurements are an essential component of nutrition assessment. Although some information can be gathered from measurements at a single point in time, historical measurements help the dietitian understand the child's growth pattern and determine if there is concern for growth faltering (Figure 1.1). Whenever possible, the dietitian should obtain historical data to accurately assess a child's growth pattern.

Age-appropriate weight gain standards are based on WHO growth chart data from 0 to 24 months and Centers for Disease Control and Prevention (CDC) growth chart data from 2 to 18 years (Table 1.14). When assessing a child's growth, the dietitian can compare current weight gain velocity and linear growth velocity to the standards to determine if a patient is growing appropriately. This is especially useful in assessing acute changes (<3 months) in the hospital or outpatient setting, as these changes may be more difficult to discern from the growth chart alone. Length velocity norms are available on the WHO website free of charge (https://www.who.int/tools/child-growth-standards).

WHO vs. CDC Growth Charts

In the USA, the WHO growth chart is recommended from birth to age 24 months. In 2006, the WHO released updated international growth standards which defined normal growth for children living in environments that supported optimal development. The USA was one of the six countries to be included in the data set. WHO growth charts establish growth of a breastfed infant as the norm and provide a better description of physiological growth in infancy than the alternative CDC growth charts for infants.

The CDC recommends transition to the CDC growth chart for children aged 2 years and older. Of note, this recommended approach of transitioning between growth chart standards can lead to shifts in growth percentiles for children at age 2 years. The WHO growth chart for older children is, however, available to provide information up to age five. For children from 2 to 5 years of age, similar methods were used to collect data in both the WHO and CDC populations.

Specialty Growth Charts

For specific populations where standard growth is not the norm, specialty growth charts are used to assess nutrition status. Conditions that alter growth that may require specific growth charts include chromosomal disorders, genetic disorders, and neurological disorders that impair ambulation. Infants born preterm also require population-specific growth charts (Chapter 12). See Chapter 21 for more information on assessing growth in special populations.

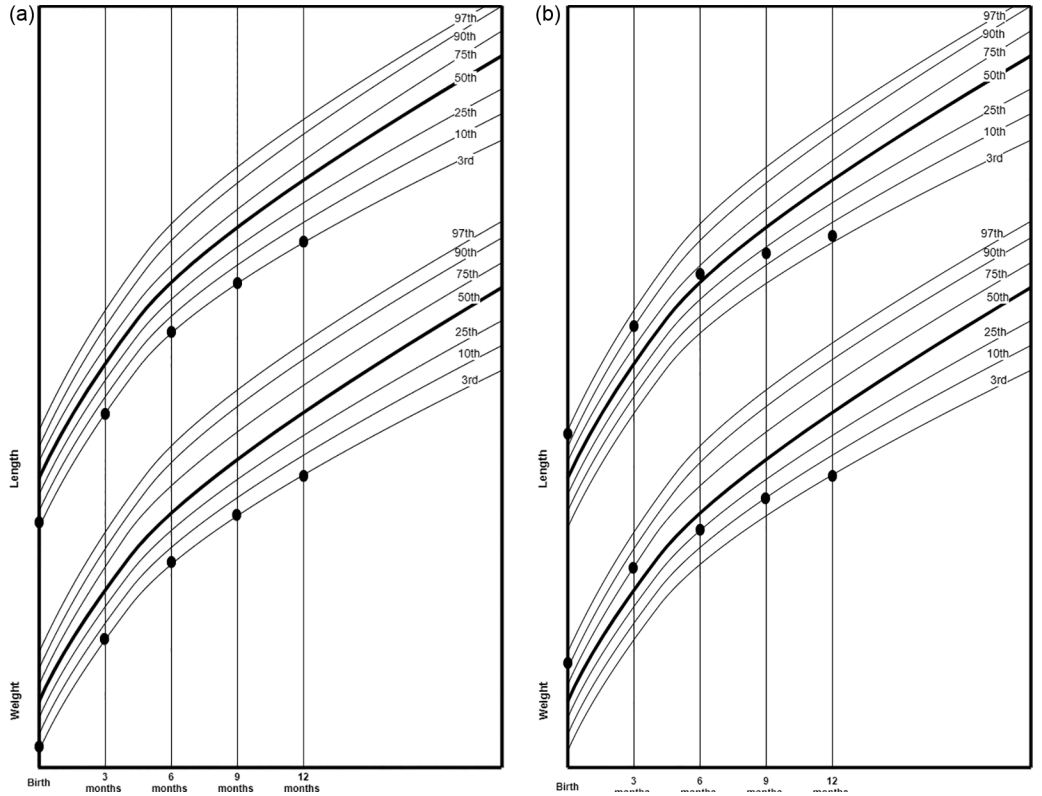

FIGURE 1.1 (a and b) Serial measurements of growth. These figures demonstrate the importance of serial anthropometric measurements using fictional infant boys. Patients A and B have the same weight and length measurements at 12 months of age. However, the historical data shows that Patient A has been following his growth curve since birth, tracking along the 3rd percentile for weight-for-age and length-for age. In contrast, Patient B has deviated from his growth curve. His weight-for-age percentile has slowly decreased from the 90th percentile at birth to the 3rd percentile at 12 months. His length-for-age percentiles followed a similar trajectory, decreasing from the 95th percentile at birth to the 3rd percentile at 12 months. Serial anthropometric measurements help the dietitian visualize growth patterns and identify patients with alterations in the growth patterns. When assessing infant growth, it is also important to track weight-for-length and head circumference-for-age, which are not included in these figures.

Z-Scores

On a growth chart, a z-score (otherwise called a standard deviation score) is defined as a score that indicates how far a measurement is away from the mean score, which is a z-score of zero. This score is utilized to assess nutrition status, monitor anthropometric trends, and diagnose malnutrition due to undernutrition. Z-scores are more precise than percentile ranges and are recognized as the gold standard for analysis of anthropometric data. Healthy children typically grow parallel to the mean line, but minor variations in z-scores are incredibly common and growth chart assessment is a skill that is learned over time. However, children who are at risk of malnutrition will demonstrate a decline of z-score lines. Z-scores outside +2 and −2, which reflect scores that are two standard deviations above and below the median respectively, are likely to be abnormal. Malnutrition due to undernutrition in the pediatric population is diagnosed by z-scores for weight-for-length, BMI, length-for-age, or height-for-age (Chapter 10).

TABLE 1.14
Weight Velocity in Children (50th Percentile)

0–24 months (g/day)		
Age (months)	**Male**	**Female**
0–3	27–40	24–34
3–6	14–21	13–20
6–9	8–12	9–11
9–12	8–9	8
12–15	7	6–7
15–18	7	6–7
18–21	6–7	6–7
21–24	6	6
2–18 years (g/month)		
Age (years)	**Male**	**Female**
2–3	138	151
3–4	158	161
4–5	180	178
5–6	191	192
6–7	199	210
7–8	215	239
8–9	243	280
9–10	282	325
10–11	330	360
11–12	381	370
12–13	427	348
13–14	451	295
14–15	440	224
15–16	387	153
16–17	304	104
17–18	219	87

Source: Table created using data from WHO weight velocity charts (https://www.who.int/tools/child-growth-standards/standards/weight-velocity) using the medians for weight gain at 1-, 2-, and 3-month intervals and Danner E, Joeckel R, Michalak S, Phillips S, Goday P. Weight Velocity in Infants and Children. *Nutr Clin Pract*. 2009; 24: 7679.

ADDITIONAL GROWTH ASSESSMENT TOOLS

Mid-Parental Height

Adult heights of both parents, along with parental patterns of growth in childhood, strongly influence their child's growth velocity and ultimate height. An estimate of a child's adult height potential can be obtained by calculation of the mid-parental height (MPH). MPH can be calculated using the following formulas:

$$\text{MPH for females (cm)} = \text{Average of parents' heights in cm} - 6.5$$

$$\text{MPH for males (cm)} = \text{Average of parents' heights in cm} + 6.5$$

A child's final height typically falls within 2 standard deviations above or below the calculated MPH. Children growing outside of this range may have impaired linear growth due to malnutrition or other causes.

Ideal Body Weight

The percent of IBW is another method of assessing proportionality. IBW is used in some patient populations to determine nutrition risk or calculate nutrient needs. For infants 0–24 months old, the IBW is the 50th percentile for the infant's age on the weight-for-length chart. For children 2–18 years old, the ideal BMI is the 50th percentile for the child's age on the BMI-for-age chart. This must then be converted into IBW by multiplying by the square of the height (m^2).

Weight Age and Height Age

Weight age is a tool that dietitians can use for patients that are underweight (Figure 1.2). To determine weight age, on the growth chart follow the patient's current weight horizontally to the 50th percentile. At the 50th percentile, looking vertically, find the corresponding age, which is the patient's weight age. Weight age can help the dietitian visualize the size of the patient. It can also be used to set weight gain goals that will result in catch-up growth. Height age can be calculated using the same method on the length-for-age or height-for-age chart (Figure 1.2); follow the patient's current length or height horizontally to the 50th percentile and then follow this vertically to determine their length or height age. Height age is useful in determining nutrient needs in patient-specific medical conditions, including renal disease (see Chapter 20).

DIAGNOSIS OF UNDERWEIGHT AND OVERWEIGHT

Children who are malnourished due to undernutrition are diagnosed using multiple criteria including current anthropometric data, anthropometric changes, and reported oral intake. Anthropometric data expressed in z-scores aid in classifying degree of undernutrition. Malnutrition criteria assess weight trends when evaluating degree of severity; thus, not all patients who are undernourished are underweight for age or height.

When a child is malnourished, her weight is affected first. She will demonstrate weight loss or slow weight gain that results in a decrease in weight-for-age z-score. If malnutrition is not corrected, linear growth will begin to falter. This will result in decreased length-for-age or height-for-age z-scores. The weight-for-length or BMI-for-age z-score may improve, but this is due to the decreasing length- or height-for-age percentile, not correction of malnutrition. If malnutrition is not corrected, this may also result in slowing of brain growth leading to decreased head circumference z-scores. See Chapter 10 for more details about the effects of pediatric malnutrition on growth and development.

Diagnosis of overweight and obese patients in the pediatric population is determined by BMI percentiles as greater than the 85th percentile or greater than the 95th percentile, respectively. At this time, no definition exists for overweight or obesity in children 0–24 months of age. For this population, the patient would be diagnosed with rapid weight gain or above-expected weight gain velocity for age. For more details on diagnosis overweight and obesity, see Chapters 10 and 25.

Growth assessment is an essential component of a thorough nutrition assessment for all pediatric patients. Monitoring weight, length or height, and other anthropometric measurements provides important insight into nutrition status and nutrient needs. Serial measurements are beneficial in identifying trends over time and allow the dietitian to intervene when patients are not following their growth curves. Information gathered and calculated in the growth assessment can be used in the nutrition diagnosis, nutrition prescription, and nutrition intervention. Patients requiring nutrition reassessment will also require reassessment of growth status.

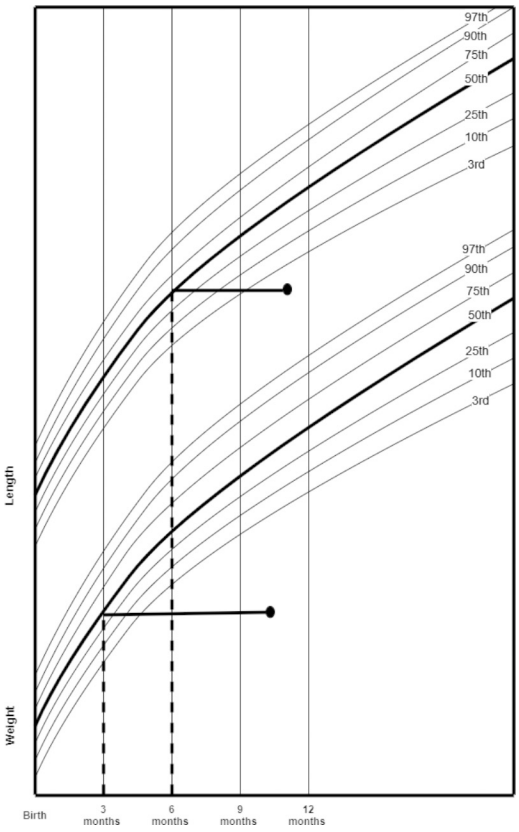

FIGURE 1.2 Weight age and height age.

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2 Nutrition-Focused Physical Exam

Hanna Leikin, MS, RD, CSP, LD; Merideth Miller, RD, CSP, LD; and Sara Bewley, MS, RD, CSP, LD

CONTENTS

The nutrition-focused physical exam (NFPE) is a valuable part of a thorough nutrition assessment. The primary techniques used to assess fat stores and muscle mass in pediatrics are inspection and palpation. Inspection includes a general observation of the patient's physical appearance. The dietitian should observe color, texture, size, and symmetry of body parts. Palpation requires hands-on examination of the body to evaluate texture, temperature, muscle rigidity, and skin hydration.

From birth to 6 months of age, the percentage of fat in the body significantly increases from 14% to 26% of body weight. It can be difficult to distinguish between fat and muscle stores in young children. When assessing general wasting in infants, fat stores and muscle mass are typically assessed together. There is subjectivity when evaluating the degree of depletion. Dietitians should become comfortable completing the NFPE and use clinical judgment when completing the exam. It is important to rule out any non-nutritive wasting that may be related to a disease or deconditioning as this differs from depletion related to malnutrition.

The NFPE should be interpreted within the context of the full clinical picture (including medical history, growth trends, nutrient intake, functional status, and biochemical data) and is part of a complete nutrition assessment. The NFPE should be re-evaluated at each nutrition reassessment.

PERFORMING A HEAD-TO-TOE NUTRITION-FOCUSED PHYSICAL EXAM

The NFPE is part of a thorough nutrition assessment and can be completed in clinical and community settings. The dietitian interviews the patient to collect nutrition-related information and to help identify baseline body composition as a comparison. Prior to the NFPE, the dietitian should explain what will be evaluated and assess the patient's level of comfort with the examination. The NFPE can be completed while interviewing the patient. For example, as you examine the oral cavity, ask if the patient has experienced any issues such as difficulty chewing or taste changes.

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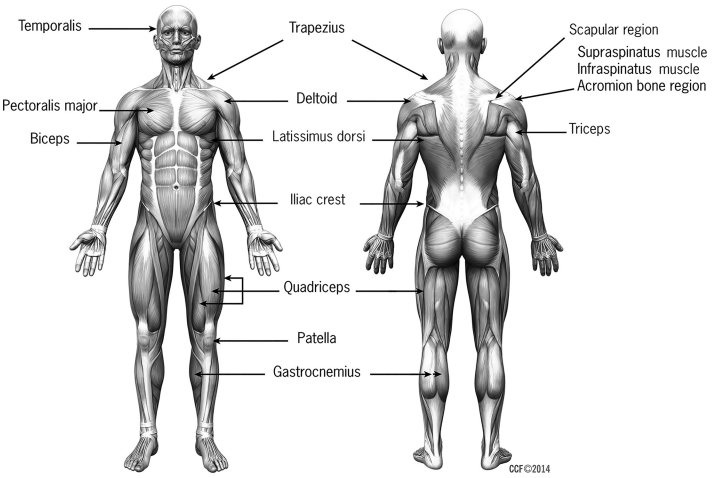


FIGURE 2.1 Review of major muscles in the human body. (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography ©2021. All Rights Reserved.)

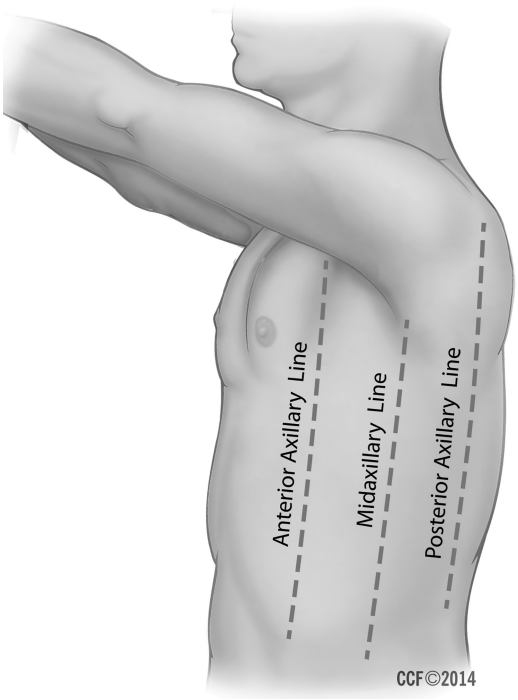


FIGURE 2.2 Midaxillary line and rib region. (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography ©2021. All Rights Reserved.)

To complete an accurate NFPE, the dietitian must be able to discern between different muscle and fat regions in the body (Figures 2.1–2.3).

To begin the exam, complete a general inspection of the child to identify any obvious underweight/overweight status or asymmetric features. Distinguishing between patients who have the genetic predisposition to be thin versus those who are malnourished is imperative. Ask questions about family history and use anthropometric assessments such as mid-parental height to aid

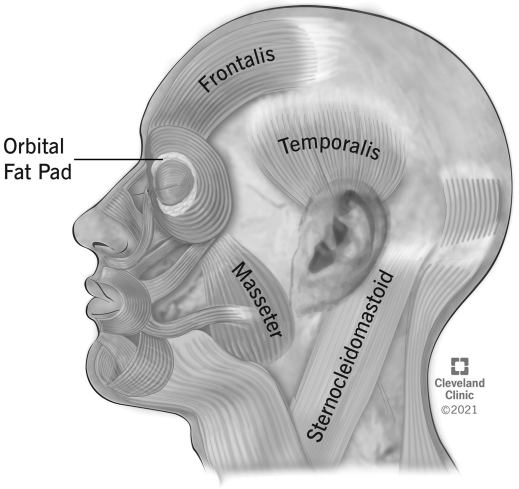


FIGURE 2.3 Orbital fat pad and temporalis muscle region. (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography ©2021. All Rights Reserved.)

in your assessment (Chapter 1). If able, properly position the patient to perform the exam (see the examination section of this chapter). Remove any objects such as blankets or clothing that may be obstructing your view. Wound dressings or restraints may limit the dietitian's ability to complete a full exam and should be noted in the documentation. To ensure a comprehensive physical exam, examine the patient from head to toe while using appropriate techniques to identify subcutaneous fat and muscle mass depletion and signs of micronutrient deficiency. Hollow cheeks, prominent ribs, and flat or baggy buttocks are signs of subcutaneous fat loss. Bone protrusion and hollowing of muscles are suggestive of muscle depletion (Tables 2.1–2.8). In general, physical examination findings of micronutrient toxicities are rare.

Examination of the Head and Face

TABLE 2.1
Common NFPE Findings of the Head and Face

	Orbital Region (Orbital Fat Pads)	Buccal Region (Buccal Fat Pads)	Temple Region (Temporalis Muscle)
Normal	Slightly bulging fat pads	Full, round cheeks	Well-defined muscle, flat
Mild-to-moderate malnutrition	Slightly dark circles, somewhat hollow	Flat cheeks, minimal bounce	Slight depression
Severe malnutrition	Dark circles, hollow appearance, loose saggy skin	Hollow, sunken cheeks	Deep hollowing/scooping

TABLE 2.2
Photos of the Head and Face

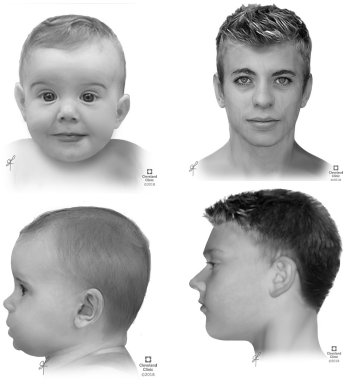
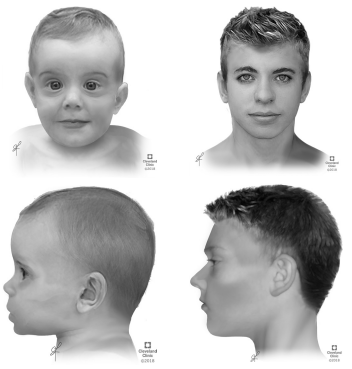
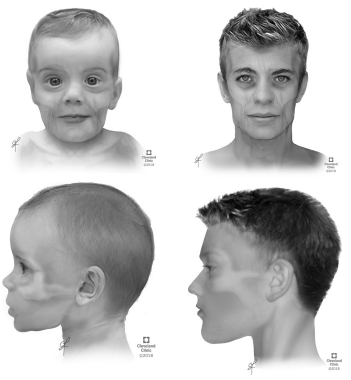
	Infant	Older Child
Normal		
Mild-to-moderate malnutrition		
Severe malnutrition		

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TABLE 2.3
Exam Tips for Head and Face

	Orbital Region (Orbital Fat Pads)	Buccal Region (Buccal Fat Pads)	Temple (Temporalis Muscle)
Positioning	Frontal view	Frontal view	Frontal and lateral views
Technique	Lightly palpate above cheekbones	Lightly palpate around buccal area	Palpate temple area

Examination of the Upper Body

TABLE 2.4
Common NFPE Findings of the Upper Body

	Upper Arm Region (Area under the Triceps Muscle)	Clavicle Bone Region (Pectoralis Major, Trapezius)	Acromion Bone Region (Deltoid Muscle)
Normal	Arms full and round, ample fat tissue	Clavicle may be visible but not prominent	Rounded curves at arms, shoulders, and neck
Mild-to-moderate malnutrition	Some depth to pinch, not ample	Clavicle shows some protrusion	Acromion process slightly protruded, shoulders not square
Severe malnutrition	Very little space between fingers	Clavicle protrudes and shows prominence	Shoulder-to-arm joints squared, bones prominent

TABLE 2.5
Photos of the Upper Body

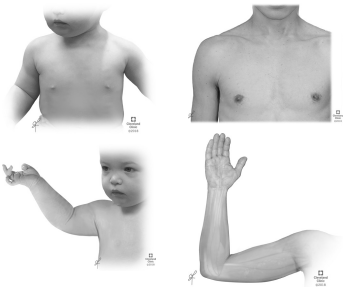
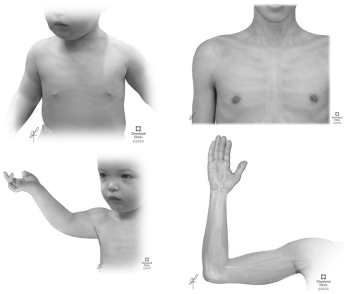
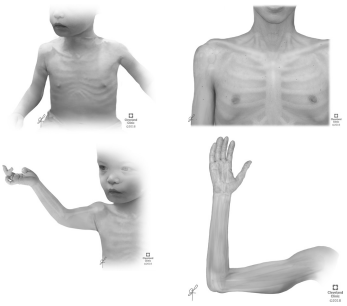
	Infant	Older Child
Normal		
Mild-to-moderate malnutrition		
Severe malnutrition		

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TABLE 2.6
Exam Tips for Upper Body

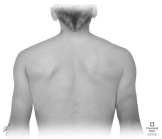
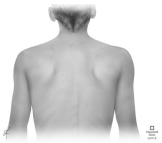
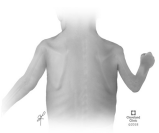
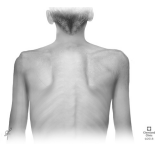
	Upper Arm Region	Clavicle Bone Region	Acromion Bone Region
Positioning	Arm bent at 90°	Upright position	Upright position with arms at side
Technique	Pinch tissue and roll between thumb and fingers to differentiate between muscle and fat	Observe and palpate line around the clavicle bone	Observe shape from front and back

Examination of the Upper Back (Muscle)

TABLE 2.7
Common NFPE Findings of the Upper Back

	Scapular Bone and Spine Regions (Trapezius, Infraspinatus, Supraspinatus, Latissimus Dorsi, and Spine)
Normal	Bones not prominent; no depressions
Mild-to-moderate malnutrition	Mild depression around scapula; spine or bones may show slightly
Severe malnutrition	Prominent visible scapula; spine depression is significant

TABLE 2.8
Photos of the Upper Back (Muscle)

	Infant	Older Child
Normal		
Mild-to-moderate malnutrition		
Severe malnutrition		

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Exam Tips for the Upper Back

Have the patient push forward on object or use your hand as support for the patient to push against (Figure 2.4). If the patient is unable to sit or stand, ask the patient to roll to the side extending arms as able and push against a solid object (Figure 2.5). For infants, the caregiver or dietitian should hold infant in an upright position for this assessment (Figure 2.6).

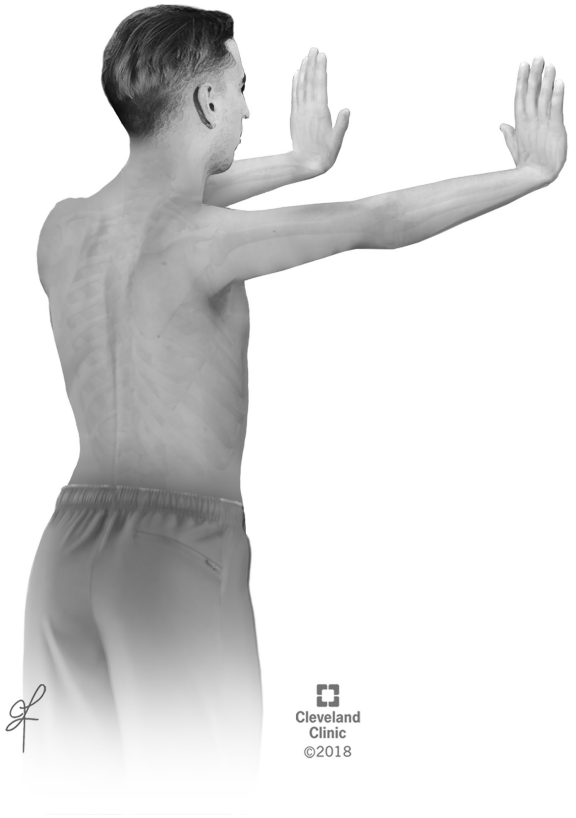


FIGURE 2.4 Positioning child for upper back exam (standing). (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography ©2021. All Rights Reserved.)

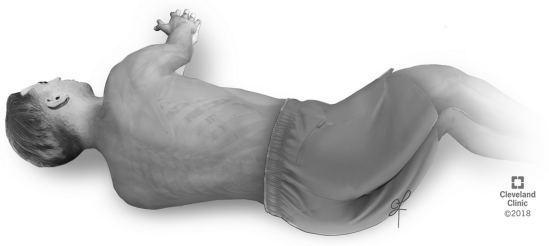


FIGURE 2.5 Positioning child for upper back exam (side lying). (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography ©2021. All Rights Reserved.)

FIGURE 2.6 Positioning infant for nutrition-focused physical exam. (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography ©2021. All Rights Reserved.)

Examination of the Ribs/Midaxillary Line (Fat)

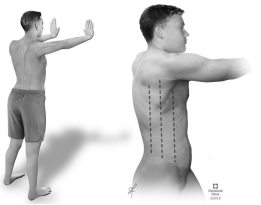
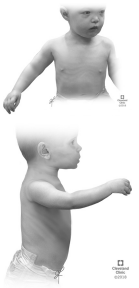
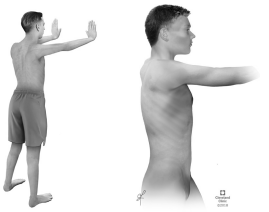
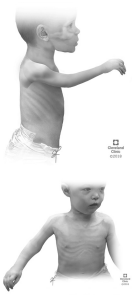
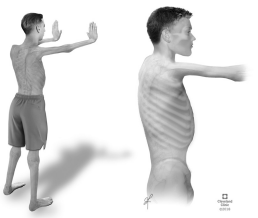
Examination Tips for Ribs/Midaxillary Line

For infants, the caregiver or dietitian should hold the patient in an upright position for this assessment. For older children, have the patient press their hands against a solid object (Tables 2.9 and 2.10).

TABLE 2.9
Common NFPE Findings of the Ribs/Midaxillary Line

	Thoracic and Lumbar Region (Ribs, Lower Back, Midaxillary Line at Iliac Crest)
Normal	• Chest is full and round with ribs not evident • Minimal ability to visualize the iliac crest
Mild-to-moderate malnutrition	• Ribs are apparent with slightly visible depressions between them • Iliac crest is slightly visible
Severe malnutrition	• Progressive prominence of ribs with loss of intercostal tissue • Iliac crest is very visible

TABLE 2.10
Photos of the Ribs/Midaxillary Line

	Infant	Older Child
Normal		
Mild-to-moderate malnutrition		
Severe malnutrition		

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Examination of Lower Extremities (Muscle)

TABLE 2.11
Common NFPE Findings of the Lower Extremities

	Anterior Thigh Region (Quadriceps)	Patellar Region (Quadriceps)	Posterior Calf Region (Gastrocnemius)
Normal	Well rounded, no depressions	Muscle protrudes; kneecap is not prominent	Well-developed bulb of muscle
Mild-to-moderate malnutrition	Slight depressions	Kneecap is more prominent	Less-developed bulb of muscle
Severe malnutrition	Significant depressions	Kneecap is prominent; little sign of muscle around knee	Thin, little to no muscle definition

TABLE 2.12
Photos of the Lower Extremities

	Infant	Older Child
Normal		
Mild-to-moderate malnutrition		
Severe malnutrition		

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TABLE 2.13
Exam Tips for Lower Extremities

Positioning	• For infants, have the caregiver hold infant in position for assessment. An exam table can be used for evaluation as needed (see Figure 2.6) • For older children, ask patient to sit up with leg bent and propped up • If patient is unable to sit up, have them bend knee (while lying down) so that the calf and quadriceps are off the bed
Technique	Grasp quadriceps and calf to distinguish between muscle and fat

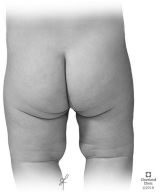
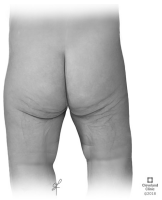
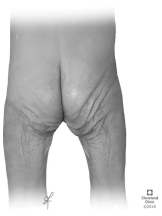
Examination of Lower Extremities (Fat)

This section is only applicable to infants and toddlers.

Examination Tips for Lower Extremities

For infants, the caregiver or dietitian should hold the patient in position for assessment. For older children, the patient should stand, if able, or sit upright with leg bent and propped (Table 2.14).

TABLE 2.14
Examination of Lower Extremities

	Buttocks (Gluteal Fat Pads)	
Normal		Full and round
Mild-to-moderate malnutrition		Slightly curved, but not round
Severe malnutrition		Skin wrinkled in appearance; no fat evident

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Examination for Nutrient Deficiencies

A physical exam of hair, eyes, mouth, nails, and skin can help identify macro- and micronutrient deficiencies and non-nutrient-related problems that can mimic nutrient concerns. The dietitian should inspect the body for any nutrient abnormalities that may require nutrition interventions to correct. Examination of eyes can be done in a well-lit room or with the use of a penlight. Inspect the skin and nails for color and texture. Palpate the skin to assess temperature, texture, moisture, and skin turgor. Refer to Freeman et al. in the reference list for photo examples of nutrient deficiencies (Tables 2.15–2.19).

TABLE 2.15
Nutrition-Focused Physical Exam of Hair

Physical Sign	Possible Nutrient Findings	Possible Non-Nutrient Causes
Alopecia, hair thinning, or loss	Protein, zinc, biotin, essential fatty acid, or selenium deficiency	Hypopituitarism, hypothyroidism, cancer treatment, chemical alterations, infection, psoriasis, Cushing disease, medication
Lightened hair color	Copper, selenium, essential fatty acid, or protein deficiency	Chemical alterations (i.e. hair dye)
Corkscrew hair (arms, legs)	Vitamin C deficiency	Chemical alterations
Lanugo (fine, soft hair like that of a newborn)	Energy deficiency	Therapeutic steroid use, endocrine disorders

TABLE 2.16
Nutrition-Focused Physical Exam of Eyes

Physical Sign	Possible Nutrient Findings	Possible Non-Nutrient Causes
Pale conjunctiva	Anemia (iron, folate, and/or vitamin B_{12} or copper deficiency)	Low cardiac output
Burning, itching eyes with photophobia	Riboflavin deficiency	Allergies and eye infections
Dull, dry membrane with foamy spots	Vitamin A deficiency (Bitot's spots)	Gaucher disease

TABLE 2.17
Nutrition-Focused Physical Exam of Nails

Physical Sign	Possible Nutrient Findings	Possible Non-Nutrient Causes
Spoon-shaped nails (koilonychia)	Iron deficiency	Trauma; hereditary or environmental factors; hematologic conditions; diabetes
Lackluster, dull nails	Protein deficiency	Trauma, environmental factors
Mottled, pale nails; poor blanching	Vitamin A or C deficiency	Poor circulation

TABLE 2.18
Nutrition-Focused Physical Exam of Oral Cavity

Physical Sign	Possible Nutrient Findings	Possible Non-Nutrient Causes
Dry, cracked, red lips	Riboflavin, niacin, or pyridoxine deficiency	Environmental factors, trauma
Bleeding gums	Vitamin C deficiency	Poor oral hygiene, environmental factors, trauma, hematologic conditions
Dry mouth	Dehydration, zinc deficiency	Certain medications, cancer treatments, and systemic diseases
Inflamed mucosa	Deficiency of multiple B vitamins, iron, or vitamin C	Cancer treatments, poor oral hygiene
Glossitis (inflammation of tongue, red/magenta in color)	Niacin, folate, riboflavin, iron, vitamin B_{12}, or pyridoxine deficiency	Crohn's disease, uremia, malignancy, cancer treatment, trauma, oral residue from recent intake of red-colored solids or fluids
Beefy red tongue	Niacin, folate, riboflavin, iron, or vitamin B_{12} deficiency	None
Poor dentition	Excessive simple carbohydrate intake, bulimia	Poor oral hygiene

TABLE 2.19
Nutrition-Focused Physical Exam of Skin

Physical Sign	Possible Nutrient Findings	Possible Non-Nutrient Causes
Pallor	Iron, folate, or vitamin B_{12} deficiency	Trauma, hereditary factors, diabetes, hypothyroidism
Dry, scaly skin	Vitamin A or essential fatty acid deficiency	Environmental factors, hygiene-related factors
Non-healing wounds	Zinc, vitamin C, or protein deficiency	Cellulitis, environmental factors
Acanthosis nigricans	Possible indicator of insulin resistance or type 2 diabetes	Hormonal disorders, medications, cancer (rare)
Hirsutism	Obesity, polycystic ovary syndrome	Hereditary factors
Dermatitis	Essential fatty acid, zinc, niacin, riboflavin, or tryptophan deficiency	Allergic reaction, medication, psoriasis, diaper rash

When a micronutrient deficiency is suspected based on NFPE findings, it is important to work with the medical team to determine next steps. For most micronutrients, laboratory tests can be ordered (Table 2.20). If a micronutrient deficiency is confirmed with laboratory testing, appropriate intervention should be provided and reassessment is indicated to ensure micronutrient stores improve. Labs are most commonly drawn to assess fat soluble vitamin status, and intervention is based on the results. Apart from vitamin B_{12}, tests for water-soluble vitamin deficiencies are less commonly utilized. These vitamins are typically supplemented when deficiency is suspected since there is minimal risk of toxicity. With regard to minerals, labs to assess iron status are used in day-to-day practice. Other mineral labs are uncommonly utilized, except in patients with significant malabsorption, chronic medical conditions, and/or long-term medication use.

Testing a wide range of vitamins and minerals for deficiency is not recommended due to the lack of clinical utility with this approach as well as the considerable costs incurred. Targeted vitamin and mineral studies should be recommended based on findings of the NFPE. It is important to understand the patient's clinical course when reviewing nutrition labs. For a variety of reasons, the levels of serum micronutrients decline with metabolic stress or inflammation. This is true in the case of iron, zinc, selenium, vitamins A, B_6, C, D, E, and folate. One notable exception to this rule is that serum copper rises with inflammation due to the fact that serum copper is bound to ceruloplasmin, which is an acute phase reactant (see Table 2.20).

A thorough NFPE provides valuable information to the nutrition assessment of pediatric patients. NFPE findings are used to support pediatric malnutrition diagnoses, identify suspected micronutrient deficiencies, and identify muscle wasting and depletion of fat stores. The NFPE is one part of a complete nutrition assessment and is used in conjunction with growth assessment and assessment of nutrient intake to determine the overall nutrition status of a patient. NFPE should be repeated as part of the nutrition reassessment.

TABLE 2.20
Nutrient Deficiencies, Diagnostic Tests, and Supplementation Recommendations

Nutrient	Diagnostic Tests	Supplementation for Confirmed Deficiency	Things to Consider
Vitamin A	Serum retinol	Consider high-dose oral supplementation as follows: Infants < 6 months: 3 doses of 15,000 mcg RAE Infants 6–12 months: 3 doses of 30,000 mcg RAE Children > 12 months: 3 doses of 60,000 mcg RAE The first dose is given immediately on diagnosis, the second on the following day, and the third dose at least 2 weeks later	Vitamin A dosing is now measured in mcg RAE (retinol activity equivalents), but was previously measured in International Units (IU) – may find both units in supplements *At risk populations:* Patients with fat malabsorption
Vitamin D	Serum 25-OH vitamin D	Infants: 25–50 mcg daily for 6 weeks to achieve a level >20 ng/mL, followed by a maintenance dose of 10–25 mcg daily Children and adolescents: 50 mcg daily for 6–8 weeks to achieve serum level >20 ng/mL, followed by a maintenance dose of 15–25 micrograms daily Assess need for standard supplementation vs water-soluble form which may be needed in patients with liver disease and other forms of malabsorption	Monitoring of calcium and phosphorus also recommended *At risk populations:* Patients with fat malabsorption, patients with limited sun exposure, patients with darker complexions, and obesity
Vitamin E	Vitamin E/Serum Alpha-Tocopherol Consider serum vitamin E: total lipid ratio (or vitamin E: cholesterol ratio) for patients with cholestatic liver disease who may have falsely normal values of vitamin E due to hyperlipidemia	Infants: 25–50 IU/day for 1 week, followed by adequate dietary intake Children: 1 IU/kg per day; adjust dose based on serum concentrations Assess need for standard supplementation vs water-soluble form which may be needed in patients with liver disease or other forms of malabsorption. These children will also require much higher doses for treatment of deficiency	Deficiency is uncommon in the USA 1 IU natural form of vitamin E = 0.67 mg 1 IU synthetic form of vitamin E = 0.45 mg *At risk populations:* Premature infants and patients with fat malabsorption
Vitamin K	Prothombin time	1 mg/day	Deficiency common in infants; hence, routine administration at birth prevents hemorrhagic disease of the newborn *At risk populations:* Patients with fat malabsorption

TABLE 2.20 (*Continued*)
Nutrient Deficiencies, Diagnostic Tests, and Supplementation Recommendations

Nutrient	Diagnostic Tests	Supplementation for Confirmed Deficiency	Things to Consider
Thiamine (vitamin B_1)	Therapeutic trial of supplement if deficiency suspected; Erythrocyte transketolase activity	WHO recommendation: Mild deficiency: oral doses of 10 mg for 1 week, then 3–5 mg/day × at least 6 weeks Severe deficiency: 25–30 mg intravenously in infants and 50–100 mg intravenously in adults, then 10 mg/day intramuscularly for 1 week followed by 3–5 mg/day orally for at least 6 weeks	Usually occurs with other B vitamin deficiencies Other water-soluble vitamins should be supplemented at the same time *At risk populations:* Patients with prolonged diarrhea, hyperthyroidism, diet of highly refined carbohydrates, breastfed infants of deficient mothers
Riboflavin (vitamin B_2)	Therapeutic trial of supplement if suspected deficiency. 24-hour urine riboflavin level; If no clinical change to oral trial may consider the following: Erythrocyte glutathione reductase activity coefficient (EGRAC) <1.2 or less usually indicates adequate riboflavin 1.2–1.4 indicate marginal deficiency, >1.4 to indicate riboflavin deficiency	Infants: 0.5 mg orally twice a week Children: 1–3 mg orally 3×/day until resolution Adolescents-Adults: 5–10 mg/day orally until resolution	Deficiency is uncommon in the USA Deficiency usually occurs with other B vitamin deficiencies Other water-soluble vitamins should be supplemented at the same time *At risk populations:* Dialysis patients, vegan, vegetarian athletes
Niacin (vitamin B_3)	Urinary niacin and N-methylnicotinamide, RBC nicotine adenine dinucleotide (NAD) and nicotine adenine dinucleotide phosphate (NADP) to determine "niacin number" = NAD/ NADP × 100. (Deficient < 130)	Children and adolescents: 10–50 mg/dose orally 4×/day for 3–4 weeks	Nicotinamide as a treatment is preferred as it does not cause flushing like nicotinic acid *At risk populations:* Those with chronic diarrhea, carcinoid syndrome, and Hartnup disease
Pyridoxine (vitamin B_6)	Plasma pyridoxal 5-phosphate	Children and adolescents: 5–25 mg/day orally for 3 weeks. Children with pyridoxine-dependent seizures will need higher doses	Isolated deficiency is uncommon *At risk populations:* Those with other B vitamin deficiencies microcytic anemia, chronic renal disease, and malabsorption syndromes

(*Continued*)

TABLE 2.20 (*Continued*)
Nutrient Deficiencies, Diagnostic Tests, and Supplementation Recommendations

Nutrient	Diagnostic Tests	Supplementation for Confirmed Deficiency	Things to Consider
Biotin (vitamin B_7)	24-hour urinary biotin	150 mcg/day. Children with biotinidase deficiency will need higher doses	Serum concentrations of biotin and its catabolites may not reveal mild deficiencies *At risk populations:* Biotin requirements may increase during anticonvulsant therapy
Folate (vitamin B_9)	Red blood cell folate, plasma homocysteine	Infants, children, and adolescents: 0.5–1 mg/day for 3–4 weeks	Selective serotonin reuptake inhibitor (SSRIs) drugs, anti-convulsants, methotrexate, and metformin can decrease levels Plasma homocysteine is elevated in both folate and vitamin B_{12} deficiencies *At risk populations:* Those with malabsorption disorders and those who are undernourished
Cobalamin (vitamin B_{12})	Serum cobalamin, plasma homocysteine, serum methylmalonic acid (MMA)	Infants: 1,000 mcg/day for 2–7 days, followed by 100 mcg once weekly for 4 weeks and then maintenance dose of 100 mcg/month Children: 100 mcg/day subcutaneously/intramuscularly for 6–7 days, followed by 100 mcg subcutaneously/intramuscularly every month or 1 mg/day orally Children with vitamin B_{12} malabsorption due to ileal disease or resection should be given parenteral vitamin B_{12} as they will not absorb the oral vitamin	Stores last 3–5 years before deficiency begins because a large amount of vitamin B_{12} is stored in the liver Plasma homocysteine is elevated in folate and vitamin B_{12} deficiencies; elevated MMA is considered more specific for vitamin B_{12} deficiency, but it may be falsely elevated with bacterial overgrowth in short bowel syndrome *At risk populations:* Vegan diet, breastfed babies of vegan mothers, those with gastrointestinal disorders, pernicious anemia, those with malabsorption disorders, patients with ileal resection
Vitamin C	Vitamin C Plasma White blood cell vitamin C is a better indicator of body stores but is not widely available	Children: 25–100 mg 3×/day for 1 week orally, intramuscularly or intravenously intravenous, followed by 100 mg/day orally for 1–3 months	*At risk populations:* Those with limited fruit and vegetable intake, those with graft-versus- host disease, excessive stool losses
Calcium	History of bone fractures or low bone mineral density	Dietary reference intake for age and gender	Avoid using laboratory values to diagnose as many other conditions change laboratory values

TABLE 2.20 (*Continued*)
Nutrient Deficiencies, Diagnostic Tests, and Supplementation Recommendations

Nutrient	Diagnostic Tests	Supplementation for Confirmed Deficiency	Things to Consider
Iron	Total iron binding capacity (TIBC), ferritin, CBC with differential Non-responders to oral iron may consider an oral iron challenge under the direction of hematology to determine if they have iron-refractory iron deficiency anemia	Infants: 3–6 mg/kg per day in 3 divided doses ferrous sulfate Children and adolescents: 3–6 mg/kg per day ferrous sulfate or polysaccharide-iron complex, maximum recommended dose of 200 mg/day	Consider gastrointestinal losses, non-compliance, genetic abnormality and excessive concomitant calcium intake *At risk populations:* Vegan/vegetarian diet, exclusively breastfed infants after 4 months of age, individuals with excessive milk intake, eating disorder patients, adolescent females
Selenium	Serum or whole blood selenium	Start with recommended dietary allowance (RDA) for age/gender	Deficiency is uncommon in the USA Deficiency can exacerbate iodine deficiency *At risk populations:* Patients on dialysis, HIV, those living in selenium-deficient regions, prolonged parenteral nutrition
Copper	Serum free copper, ceruloplasmin	Start with RDA for age/gender	Can be related to elevated zinc levels *At risk populations:* Celiac and other malabsorptive diseases, Menckes disease, patients on dialysis, preterm infants
Zinc	Serum zinc Low serum alkaline phosphatase levels for age provide supportive evidence for zinc deficiency	Children and adolescents: 0.5–2 mg/kg per day elemental zinc for 4–6 weeks	With low albumin, optimize albumin and then re-check zinc Deficiency can be related to elevated copper levels *At risk populations:* Digestive disorders, vegan/vegetarian diet, sickle cell, and exclusively breasted infants
Iodine	24-hour urinary iodine and creatinine Serum iodine	Add iodized salt to daily intake to meet RDA for age/gender	If iodine intake falls below ~10–20 mcg/day, hypothyroidism occurs *At risk populations:* Patients who do not consume iodized salt; vegans/vegetarian diets
Protein/energy deficiency	Malnutrition, subcutaneous fat loss, or muscle mass depletion	Catch-up growth calorie and protein requirements (see Chapter 10)	Avoid using laboratory values to diagnose as many other conditions change laboratory values

(*Continued*)

TABLE 2.20 (*Continued*)
Nutrient Deficiencies, Diagnostic Tests, and Supplementation Recommendations

Nutrient	Diagnostic Tests	Supplementation for Confirmed Deficiency	Things to Consider
Essential fatty acid deficiency (EFAD)	Triene:tetraene ratio – this may be found in the fatty acid profile; although a ratio >0.2 is considered a biochemical EFAD, clinical signs and symptoms of EFAD may be more clinically detected at ratios ≥0.4	Provide patient with adequate calories with 30% coming from fat	Deficiency is uncommon in the USA in oral or enteral fed patients EFAD generally seen in patients with insufficient PN lipid infusion. A minimum of 0.5–1 g/kg per day of Intralipid® is needed to meet EFA requirements *At risk populations:* Prolonged low-fat diet, eating disorder patients, fat malabsorption

Source: Created using information from: Kleinman RE, Greer FR. *Pediatric Nutrition*. Itasca, IL: American Academy of Pediatrics; 2013; Merck Manuals Professional Edition. Published 2018. Accessed May 25, 2021. https://www.merckmanuals.com/professional; Phillips SM, Jensen C. Micronutrient deficiencies associated with malnutrition in children. In: Motil, K and Hoppin, A, ed. *UpToDate*; 2021. Accessed May 25, 2021. www.uptodate.com; Vitamin and Mineral Supplement Fact Sheets. Nih.gov. Published 2017. Accessed May 25, 2021. https://ods.od.nih.gov/factsheets/list-VitaminsMinerals/; Lo C. Micronutrient deficiencies. In Buchman AL, ed. *Clinical Nutrition in Gastrointestinal Disease*. Thorofare, NJ. SLACK Incorporated; 2006: pp. 24–25; Pediatric & Neonatal Lexi-Drugs. Lexicomp. https://online.lexi.com/lco/action/home. 2021. Accessed July 11, 2021.

Deficiencies for patients at high risk due to an underlying chronic disease should be assessed based on disease-specific recommendations.

For best interpretation of results it is recommended that no vitamins or minerals be consumed prior to lab draw on the day of the test.

IU, International units; mcg, micrograms.

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3 Nutrition Screening and ADIME

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CONTENTS

Nutrition screening and assessment are essential steps in the nutrition care of pediatric patients. Nutrition screening can determine if nutrition risks may be present and can help the dietitian prioritize patient care. Patients with a positive nutrition screen should receive a full nutrition assessment following the Academy of Nutrition and Dietetics (The Academy) Nutrition Care Process (NCP) Model. The NCP includes nutrition Assessment, Diagnosis, Intervention, Monitoring, and Evaluation (ADIME). Each of these steps will be covered in detail in this chapter and will be discussed in subsequent chapters as it relates to each specific disease state or condition.

NUTRITION SCREENING

The purpose of the nutrition screen is to identify those patients who may be at risk for potential nutrition issues and who warrant further nutrition assessment. This may be due to a preexisting

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nutrition-related issue or an issue that may alter the level of nutrition intervention needed as a disease state changes. A nutrition risk screen includes parameters which are compared to standards to determine nutrition risk. The parameters may include, but are not limited to, anthropometric data, dietary intake, and biochemical data.

A nutrition screening tool (NST) may be broad or general in nature; it should be cost effective and of minimal risk to the patient. Some may be used upon admission to an acute care setting or be specific to a disease state, such as cancer, cerebral palsy, or cystic fibrosis. The NST is designed to assign a level of nutrition risk: from the lowest risk which may not require any nutrition evaluation to the highest risk needing immediate nutrition evaluation. The NST may be administered by a qualified member of the healthcare team such as a dietitian, Registered Nurse (RN), or Dietetic Technician Registered (DTR). It is recommended that the NST tool used by an institution be valid and reliable. The ultimate goal of the nutrition screen is to promote interventions that lead to improved health outcomes.

Pediatric Nutrition Screening Tools

There are a number of pediatric screening tools available. These tools can be used for inpatient use, others for outpatient use, and can be disease specific. Common tools used to screen for nutrition risk are listed in Tables 3.1 and 3.2.

TABLE 3.1
Pediatric Nutrition Screening Tools for Inpatient Use

Pediatric Screening Tools for Inpatient Use	Intended Use
IMCI: Integrated Management of Childhood Illness	Developed by WHO/used in developing countries by health care workers
STAMP: Screening Tool for the Assessment of Malnutrition	For children from 2 to 17 years – can also be used for repeat screening
PMST: Pediatric Malnutrition Screening Tool	Modified version of STAMP for <2–17 years – screens for both under- and overnutrition
PNRS: Pediatric Nutrition Risk Score	For children >1 month old, at risk for acute malnutrition
PNST: Pediatric Nutrition Screening Tool	Designed to improve simplicity of screening
PYMS: Pediatric Yorkhill Malnutrition Score	For children >1 year old
STRONGkids: Screening Tool for Risk on Nutrition Status and Growth	For children, to lessen the complexity of previous screening tools

TABLE 3.2
Pediatric Nutrition Screening Tools for Outpatient Use

Pediatric Screening Tools for Outpatient Use	Intended Use
NRST-CF: Nutrition Risk Screening Tool for Children and Adolescents with Cystic Fibrosis	For inpatient and outpatient use for children with cystic fibrosis
SCAN: Nutrition Screening Tool for Childhood Cancer	For children with a cancer diagnosis
STAMP-Modified: Screening Tool for the Assessment of Malnutrition in Pediatrics	A modified version of STAMP for children
E-KINDEX: Electronic Kids Dietary Index	An electronic tool for community use which involves self-reported nutrition behaviors that parallel the risk for obesity
NutriSTEP: Nutrition Screening Tool for Every Preschooler	A caregiver administered, community-based screening tool for preschoolers
NutriSTEP-Toddler: Nutrition Screening Tool for Every Preschooler – Toddler	A modified version of NutriSTEP, for community use, caregiver administered for children at 18–35 months

Studies have determined that not all NSTs are created equal. For this reason, some hospitals develop their own nutrition screening tools.

NUTRITION ASSESSMENT

The NCP is a standardized model used to direct dietitians to provide superior quality nutrition care. The NCP is comprised of four steps (the ADIME model) which include (Figure 3.1):

1. Nutrition Assessment
2. Nutrition Diagnosis
3. Nutrition Intervention
4. Nutrition Monitoring and Evaluation

The purpose of nutrition assessment, as defined by the Academy, is "to obtain, verify, and interpret data needed to identity nutrition-related problems, their causes and significance". It is the initial step of the NCP. Nutrition Assessment includes re-assessment as data and information becomes available and is an ever-changing process. The five domains of Nutrition Assessment include:

1. Patient history
2. Food/Nutrition-related history

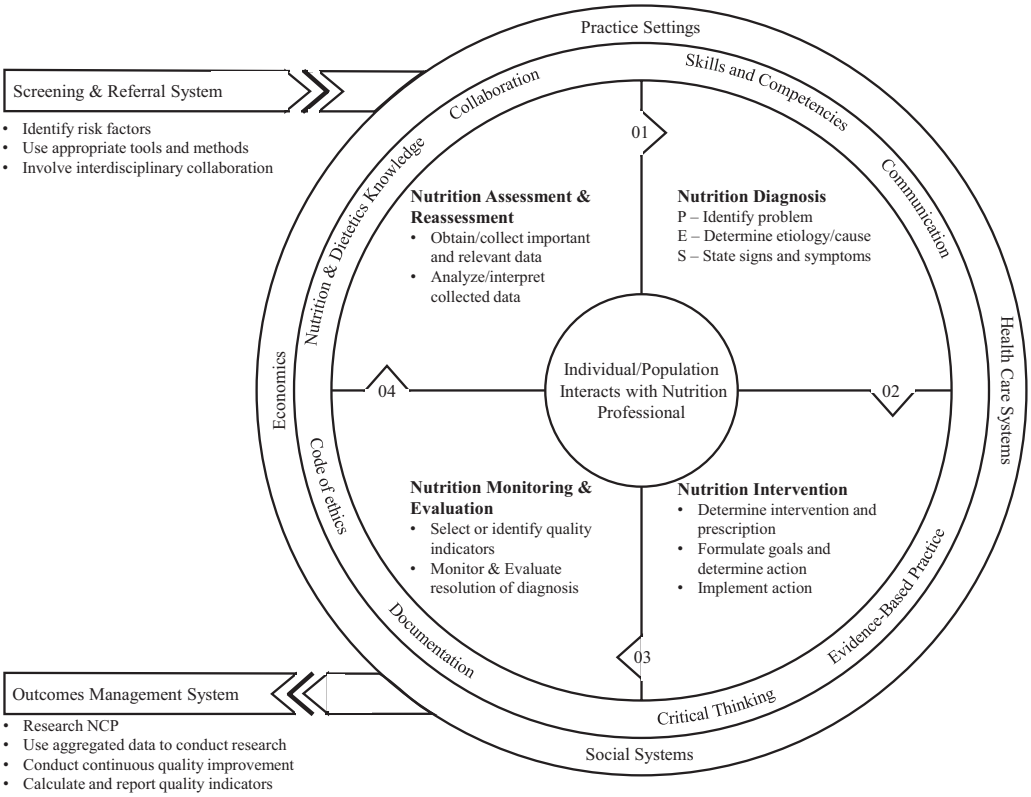

FIGURE 3.1 The Nutrition Care Process Model. (Reprinted from the Swan WI, Vivanti A, Hakel-Smith NA, Hotson B, Orrevall Y, Trotstler N, Howarter KB, Papoutsakis C. Nutrition care process and model update: toward relaxing people-centered care and outcomes management. *J. Acad. Nutr. Diet.* 2017;112:2003–2014, copyright 2017, with permission from Elsevier.)

3. Anthropometric data
4. Nutrition-focused physical examination
5. Biochemical data/tests/procedures

Nutrition assessment in the pediatric population is more critical than in adults as children can become malnourished more quickly due to their limited reserves and needs for growth. Malnutrition can adversely affect growth and development which may in turn cause undesirable long-term outcomes.

Medical Diagnosis

Due to growth and development from infancy through adolescence, nutrient requirements are elevated to support this dynamic process. Various medical diagnoses may affect growth and development during these life stages, therefore, affecting the overall nutrition plan. There are alternate methods for estimating energy requirements for those with underlying medical conditions and these methods will be covered in upcoming chapters.

Acute/Critical Illness

The American Society for Parenteral and Enteral Nutrition (ASPEN) and the Society of Critical Care Medicine (SCCM) guidelines are intended to be used in critically ill children, ages >1 month to <18 years with an expected length of stay >2–3 days in the pediatric intensive care unit (PICU) which admits surgical, cardiac, and medical patients. The guidelines are not to be used for adults or neonates and stress the importance of nutrition assessment, especially the identification of malnutrition in patients that are most susceptible. Indirect calorimetry (IC), when appropriate, is encouraged over predictive equations when determining energy needs so as not to over- or underfeed these patients. Optimal protein intake is encouraged due to its correlation with clinical outcomes. Based on expert opinion, enteral nutrition (EN) is the preferred route of nutrient delivery over parenteral nutrition (PN), unless there are specific contraindications. When EN is indicated, it is recommended that all critically ill patients have EN initiated within 24–48 hours after admission (Chapter 13).

Typical Developmental Abilities

The developmental abilities of the infant, child, and adolescent vary greatly with each stage of life. These abilities determine the child's feeding skills and have an impact on nutrient intake. As children grow and become adolescents, feeding behaviors may prompt the development of nutrition irregularities. In order to provide guidance, the dietitian must be aware of the typical behaviors of each life stage to assist in establishing appropriate healthy eating habits (Table 3.3).

Food/Nutrition History

Typical Eating/Feeding Behaviors for Age

Understanding typical feeding behaviors of infants and children helps the dietitian determine if a patient's feeding behaviors are a cause for concern. While general feeding behaviors for each age group are described here, the feeding behaviors of infants and children are described in detail in Chapters 5 and 6, respectively. Infants are totally dependent on the caregiver; therefore, the caregiver must be observant of hunger cues. Infants need only human milk or iron-fortified formula for the first 6 months of life to meet nutrition requirements. Around 6 months of age, most infants are developmentally ready for complementary foods such as infant cereal and infant foods.

Toddlers exhibit self-feeding skills and are able to communicate food preferences and desires. They use eating/food to prompt a reaction from the caregiver and may exhibit food "jags" limiting themselves to eating certain foods while excluding others. Toddlers that, as infants, were considered

TABLE 3.3
Developmental Milestones

Age	Gross & Fine Motor	Feeding Skills	Problem Solving	Social & Emotional	Language
1 month	Turns head in supine position	Sucks well	Gazes at black/white objects, follows face	Discriminates mothers voice	Startles to sound
2 months	Head bobs when held in sitting position, holds rattle if placed in hand	Opens mouth at sight of bottle/human	Recognizes mother	Reciprocal smiling	Alerts to sound, coos
3 months	Props on forearms in prone position, rolls to side	Brings hands to mouth	Reaches for face	Visually follows person moving across a room	Vocalizes when talked to
4 months	Sits with support, rolls front to back	Briefly holds on to breast or bottle	Mouths objects	Smiles spontaneously	Stops crying to soothing voice, laughs
5 months	Rolls back to front, sits with arms supporting trunk, palmar grasps cube	Transfers objects from hand to mouth	Turns head to look for dropped object	Forms attachment relationship to caregiver	Begins to respond to name
6 months	Transfers hand-to-hand	Places hands on bottle	Bangs and shakes toys	Stranger anxiety	Smiles/vocalizes to mirror
7 months	Sits without support	Refuses excess food	Finds partially hidden object	Looks from object to caregiver and back when wanting help	Looks toward familiar object when named
8 months	Gets into sitting position	Holds own bottle, finger feeds	Seeks object after it falls silently to floor	Lets caregiver know when happy or upset	Shakes head for “no”
9 months	Pulls to stand	Bites, chews food	Rings bell	Uses sound to get attention, separation anxiety	Orients to name, imitates sounds
10 months	Cruises around furniture, walks with two hands held	Drinks from cup held for child	Uncovers toy under cloth	Experiences fear	Waves “bye-bye”
11 months	Stands for a few seconds, throws objects	Stirs with spoon	Looks at pictures in book	Stops when told “no”	Says first word
12 months	Stands well, takes independent steps	Finger feeds parts of meal	Lifts box lid to find toy	Points to get desired object	Follows one-step commands
15 months	Walks carrying toy, creeps up stairs	Drinks from cup with some spilling, uses spoon with some spilling	Turns pages in book	Solitary play, shows empathy	Uses three to five words
18 months	Runs well, walks backwards	Drinks from cup independently	Matches pairs of objects	Begins to show possessiveness	Uses 10–15 words

(*Continued*)

TABLE 3.3 (*Continued*)
Developmental Milestones

Age	Gross & Fine Motor	Feeding Skills	Problem Solving	Social & Emotional	Language
24 months	Walks down stairs holding rail	Uses a straw	Sorts objects	Parallel play	Two-word sentences, uses 50+ words
3 years	Pedals tricycle, catches ball with stiff arms	Independent eating, pours liquid from one container to another	Knows own age, matches letters/number	Starts to share, imaginative play	Uses 200+ words
4 years	Balances on one food, gallops	Uses tongs to transfer, washes hands/face	Counts to 4, points to colors	Group play	Uses 300–1,000 words, tells stories
5 years	Jumps backward, writes first name	Spreads with knife	Names letters/number out of order, reads 25 words	Has group of friends, apologizes for mistakes	Uses 2,000 words

Source: Adapted from Scharf R, Scharf G, Stroustrup A. Developmental milestones. *Pediatr Rev*. 2016;37:25–38.

to be good eaters may be fair-to-poor eaters and they may not want to try new foods. The risk of choking is increased as some foods may be difficult to swallow.

Preschoolers can show unpredictability with regards to eating. They have a limited attention span at mealtime and environmental cues influence food selections and intake patterns (time of day, size of portions, and the influence of other family members that are of importance to them). They are able to mimic adult eating patterns but are incapable of choosing a well-balanced diet.

School-age children show increased independence of food choices which may include less nutritious foods when not at home. However, they may be more inclined to learn concepts of good nutrition. They may begin comparisons of body image with peers and be influenced by the media.

Adolescents are more independent, have busier schedules, and may be more likely to skip meals and snack on foods of low nutritional value. They likely will eat more meals outside of the home and may experience body image dissatisfaction. As with school-aged children, adolescents may be influenced by the media. They may also include or discontinue use of various foods due to ethical or religious reasons or following fads.

Nutrient Intake

Traditional diet intake methods include food records, 24-hour diet recalls, and food frequency questionnaires (FFQs). Each has its strengths and weaknesses.

Food records are usually from 3 to 7 days in duration. They require literacy, motivation on the part of the child's caregiver, and place a burden on the caregiver. It has been found that typically the longer duration of the record, the lesser the quality of reporting.

A 24-hour recall is used to assess current energy intake over a 24-hour period of time. It involves short-term recall and takes around 20–30 minutes to complete. This can be used with low-literacy and low-income subjects as reading or writing are not a requirement to complete them. This recall can be used to determine eating occasions, sources of foods/beverages, as well as the location and timing of snacks and meals. It may also include details for activities which take place when eating, such as TV, electronic device, and computer use during meals/snacks and where meals occur (i.e., highchair, table, or away from table). It can be used to determine meal/snack patterns and foods being consumed away from the home as well as in the home. That specific day may not be representative of the usual diet, which may be a disadvantage. For younger children, the caregiver will be completing the 24-hour recall. If the patient attends school or daycare, the caregiver may not have accurate information to share.

FFQs are used primarily in larger groups of people to provide approximations of diet intake over time – usually 6 months to 1 year. It is comprised of a list of specific foods, requires the subject to document if they eat a specific food, and if so, how much and how often. They are at times used in cohort studies to lump subjects into broad categories based on nutrient intake distribution. FFQs should be specific to the culture being studied and capture usual food/diet intake. They can measure macro- and micronutrient details as well as intake of food groups and/or foods. FFQs are typically not used to assess current energy intake but may be useful for long-term treatments using diet therapy.

Anthropometrics

As discussed in Chapter 1, anthropometric assessment is a key component of the nutrition assessment of children. Anthropometric assessment is defined as the measurement of body composition and dimensions. These values are compared to already determined, standard growth data or norms of a particular reference population. The measurements include weight, length or height, head circumference, skinfold thicknesses, and mid-upper arm circumference.

Nutrition-Focused Physical Exam

A nutrition-focused physical examination (NFPE) may reveal signs and symptoms of nutrient deficiencies which then may be proven with further testing. NFPE is important because it distinguishes or confirms subcutaneous fat loss, edema, and muscle wasting. Micronutrient deficiencies may be identified by examining the appearance of the skin, hair, nails, and the mucous membranes. See Chapter 2 for more information about the NFPE.

Biochemical Data/Tests/Procedures

Malnutrition, in the hospital setting, is a risk factor for morbidity, mortality, and increased cost of hospitalization. Inflammation has been identified as a risk factor for malnutrition. Traditionally, albumin and prealbumin have been used to determine the nutritional status of a patient. However, this is no longer recommended. Albumin and prealbumin are not good markers of total body muscle mass or total body protein and they decline in the presence of inflammation regardless of nutrition status. Instead, when available, nitrogen balance can be used as a marker of protein intake.

Nitrogen balance is calculated as nitrogen intake minus nitrogen loss from the body. Nitrogen balance is useful when evaluating protein metabolism, as nitrogen is a crucial part of protein building blocks or amino acids. Negative nitrogen balance is defined as more loss than intake, which is then used as a marker for nutrition risk. Nitrogen balance is evaluated by calculating the concentration of urea in the urine. This requires a 24-hour urine collection which can be burdensome.

Obtaining vitamin and mineral levels can be useful in some circumstances in pediatric assessment (see Chapter 2). In addition, when these levels are obtained they should be targeted toward the specific vitamins and/or minerals that are in question (Table 3.4).

Other Considerations in Nutrition Assessment

Medications and Side Effects

All medications, vitamin, mineral, and herbal supplements used in the hospital (for inpatients) and at home should be reviewed by the dietitian for potential drug-nutrient interactions.

Certain antibiotics may interact with minerals, fat, or protein causing a decrease in absorption which may lead to nausea, diarrhea, and possibly vomiting.

TABLE 3.4
Common Laboratory Markers Used in Pediatric Nutrition Assessment

Nutrient	Common Lab/Reason
Alkaline phosphatase	For evaluating bone health in neonates or with concern for zinc deficiency
Serum blood urea nitrogen (BUN)/creatinine	In cases with concern for dehydration and kidney function
Hemoglobin and Hematocrit	For anemia or if concern for inflammation
Hemoglobin A1c%	For patients with diabetes
Lipid profile (triglycerides, HDL, LDL, cholesterol)	For evaluation of hyperlipidemia
Liver enzymes (ALT/AST)	To assess for liver injury
Comprehensive metabolic panel (including sodium, potassium, chloride, bicarbonate, and calcium), magnesium, phosphorus	To assess for electrolyte and mineral imbalance in patients receiving parenteral nutrition and in patients with renal disease

See Chapter 2 for laboratory markers of vitamin and mineral deficiencies.

Anticonvulsants may affect vitamins D, K, B_6, and B_{12}, calcium, and folate by decreasing the absorption or stores. Vitamin and mineral supplements should be reviewed with the physician as they may impact the effectiveness of concomitantly administered medications.

Diuretics may deplete potassium, calcium, magnesium, and folate stores and also result in nausea, vomiting, and diarrhea which may lead to poor appetite.

Corticosteroids may affect levels and stores of phosphorus, calcium, vitamin D, glucose, protein, sodium, zinc, water, vitamin C, and potassium. They may cause weight gain due to increased appetite as well as fluid retention. In addition, when used long term, they may stunt growth, cause bone loss, and cause glucose intolerance.

Laxatives or bulking agents may affect fat-soluble vitamin absorption, and when used long term they may deplete fat-soluble vitamin stores. If other medications that will not deplete the fat-soluble vitamins are available, they should be discussed with the physician as an alternative.

Anti-gastroesophageal reflux medications may affect iron, calcium, and vitamin B_{12}. They may cause nausea and diarrhea as well as long term declines in absorption of iron and vitamin B_{12}.

Stimulants used for attention-deficit/hyperactivity disorder (ADHD) can cause a decrease in appetite and poor nutrient intake which in the long term may affect overall growth. Monitoring growth while on these medications is key.

Dietitians work closely with medical providers who prescribe and assess the efficacy of medications that can affect nutrition status. Dietitians may discuss the need for medications with the provider, including appetite stimulants, pancreatic enzymes, reflux medications, and others, which may improve intake and absorption of nutrients.

Gastrointestinal Considerations/Findings

Evaluating feeding and formula tolerance includes assessing gastrointestinal symptoms such as vomiting, diarrhea, constipation, nausea, abdominal discomfort/pain, or distention. Isolating other causes of these symptoms such as bacterial overgrowth, infections, or medications should be evaluated prior to altering the nutrition care plan. Stool frequency, color, consistency, and presence of fat or blood should be monitored and noted. For patients with ostomies, it is imperative to monitor and document the volume of ostomy output each day. Increase in volume of stool in children with an ostomy may warrant changes to the nutrition care plan.

NUTRITION DIAGNOSIS

The second step in the NCP is Nutrition Diagnosis. Data obtained during the nutrition assessment is used to identify a nutrition diagnosis. The Academy publishes frequent updates to the International Dietetics and Nutrition Terminology (IDNT) Reference Manual which lists the standard language or diagnoses to be used. It is important to use the reference manual to confirm that the nutrition diagnosis is most appropriate for the patient and to verify at least one indicator described in the reference sheet is present within the nutrition assessment. The purpose of a nutrition diagnosis is to identify and describe a specific nutrition problem which can be improved or resolved through nutrition treatments and interventions by a dietitian. A nutrition diagnosis is not a medical diagnosis – it is unique to the nutrition professional.

Nutrition diagnoses are arranged into three categories: intake, clinical, and behavioral-environmental. Intake nutrition diagnoses relate to inadequate or excessive intake of a nutrient compared to what is expected. Clinical nutrition diagnoses relate to issues from medical or physical conditions. Behavioral-Environmental nutrition diagnoses relate to knowledge, beliefs, location, food access, or food safety. See Appendix D for commonly used nutrition diagnoses in pediatrics.

In order to describe a nutrition diagnosis, a PES statement is written. The statement includes a problem (P) or the nutrition diagnosis, an etiology (E) or the cause of the nutrition diagnosis, and sign/symptom (S) which is the evidence to the nutrition diagnosis. As a reminder, a nutrition diagnosis is a problem which can be improved or resolved by a dietitian. Etiology is the primary cause of

the problem that the dietitian can impact with a nutrition intervention. The etiology should be proceeded by "related to" in the statement. Signs and symptoms are measurable and show improvement or resolution of the nutrition diagnosis. They describe how the dietitian knows the problem exists, and how the dietitian can measure progress or improvements. The signs and symptoms should be proceeded by "as evidenced by" in the statement.

PES Statement
_____(P)_____ related to _____(E)_____ as evidenced by _____(S)_____.

A well-written Nutrition Diagnosis should be:

1. Clear and concise
2. Specific – patient centered
3. Related to one patient problem
4. Accurate – related to one etiology
5. Based on reliable and accurate assessment data

Pediatric patients may have no identified nutrition diagnosis. In this case, "no nutrition diagnosis at this time" may be documented. This can occur when patients with chronic conditions are followed throughout a disease process. If these patients have a nutrition assessment performed at regular intervals, there may be times when patients have active nutrition problems and other times when they do not.

Example PES statements:

- Inadequate mineral intake (calcium) related to current diet choices as evidenced by intake at <50% Dietary Reference Intakes (DRI) for age based on 24-hour food recall.
- Inadequate oral intake related to initiation of ADHD medication as evidenced by weight loss and intake at <75% expected energy needs based on 3-day food diary analysis.
- Food and nutrition knowledge deficit related to lack of prior exposure to nutrition information as evidenced by new diagnosis inflammatory bowel disease.

NUTRITION INTERVENTION

Nutrition intervention is the third step in the NCP. The nutrition intervention includes the nutrition prescription and specific interventions recommended to meet the nutrition prescription.

Nutrition Prescription

The nutrition prescription includes the recommendations the dietitian is providing for the patient for energy, foods, or nutrients based on current reference standards and guidelines. These recommendations are also in relation to the patient's health condition, growth needs, and nutrition diagnosis. In addition to estimating needs for energy, protein, and fluids, the dietitian should consider the Acceptable Macronutrient Distribution Range (AMDR), which varies by the age of the patient:

- **Fat**: 30%–40% of energy for children 1–3 years of age, 25%–35% of energy for children 4–18 years of age
- **Carbohydrate**: 45%–65% of energy
- **Protein**: 5%–20% of energy for children 1–3 years of age, 10%–30% of energy for children 4–18 years of age

Energy

Energy requirements for healthy infants and children are typically calculated using predictive equations. The estimated energy requirement (EER) is defined as the dietary energy intake that is predicted to maintain energy balance in a healthy individual of a defined age, gender, weight, height, and physical activity level (PAL). In pediatrics, the EER includes the needs associated with the deposition of tissues at rates consistent with good health (Table 3.5).

Hospitalized pediatric patients may have altered energy needs. Total Energy Expenditure (TEE) includes basal metabolic rate, thermic effect of food, energy required for physical activity, energy required for somatic growth, and energy lost due to inefficiencies of absorption and metabolism. Four of the five TEE components are often impacted in the critically ill child (thermic effect of food, physical activity, somatic growth, and gastrointestinal losses).

Indirect calorimetry is considered the gold standard for establishing energy goals for the critically ill patient. Indirect calorimetry is the determination of heat production of a biochemical reaction by measuring uptake of oxygen and release of carbon dioxide. Oxygen consumption (VO_2) and carbon dioxide production (VCO_2) measured by the calorimeter are entered into the Weir equation to calculate resting energy expenditure (REE):

$$\text{REE (kcal/day)} = 5.50\ VO_2\ \text{(mL/min)} + 1.76\ VCO_2\ \text{(mL/min)} - 1.99\ \text{total urinary nitrogen (g/day)}$$

Measuring indirect calorimetry requires trained personnel and expensive equipment which is why the majority of PICUs utilize predictive equations. Commonly used equations to determine energy requirements in hospitalized pediatric patients include, but are not limited to, Schofield and

TABLE 3.5
Estimated Energy Requirements

Age	Estimated Energy Requirements (kcal/day)
0–3 months	(89×W − 100) + 175
4–6 months	(89×W − 100) + 56
7–12 months	(89×W − 100) + 22
13–35 months	(89×W − 100) + 20
	Males
3–8 years	88.5 − (61.9×age) + PA×[(26.7×W) + (903×H)] + 20
9–18 years	88.5 − (61.9×age) + PA×[(26.7×W) + (903×H)] + 25
	Females
3–8 years	135.3 − (30.8×age) + PA×[(10×W) + (934×H)] + 20
9–18 years	135.3 − (30.8×age) + PA×[(10×W) + (934×H)] + 20
	Physical Activity Factor
Sedentary	1.0
Low active	1.12
Active	1.24
Very Active	1.45

Source: Table created from data in Institute of Medicine, 2005. *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids*. Washington, DC: The National Academies Press. https://doi.org/10.17226/10490.

Legend: age, Age in years; PA, physical activity factor; W, weight in kg; H, height in m.

TABLE 3.6
Schofield Equations for Estimating Basal Metabolic Rate

Age	Gender	Equation
	Schofield (Weight Only)	
0–3 years	Male	(59.48×W)−30.33
0–3 years	Female	(58.29×W)−31.05
3–10 years	Male	(22.7×W)+505
3–10 years	Female	(20.3×W)+486
10–18 years	Male	(13.4×W)+693
10–18 years	Female	(17.7×W)+659
	Schofield (Weight and Length/Height)	
0–3 years	Male	(0.167×W)+(1517.4×H)−617.6
0–3 years	Female	(16.25×W)+(1023.2×H)−413.5
3–10 years	Male	(19.6×W)+(130.3×H)+414.9
3–10 years	Female	(16.97×W)+(161.8×H)+371.2
10–18 years	Male	(16.25 x W)+(137.2 x H)+515.5
10–18 years	Female	(8.365×W)+(465×H)+200

Source: Table created with data from Koletzko B, Goulet, O, Hunt J, Krohn K, Shamir R. Guidelines on Paediatric Parenteral Nutrition of the European Society of Paediatric Gastroenterology, Hepatology and Nutrition (ESPGHAN) and the European Society for Clinical Nutrition and Metabolism (ESPEN), Supported by the European Society of Paediatric Research (ESPR): Energy. *J Pediatr Gastroenterol Nutr.* 2005;41:S5–S11.

W, weight in kilograms; H, length/height in meters.

FAO/WHO/UNU (Tables 3.6 and 3.7). Studies suggest the use of such predictive energy equations are often inaccurate and may place a patient at risk for over- or underfeeding. Nutrition reassessment is essential in ensuring that the energy provided to a patient is appropriate.

Individual disease states may have modified predictive equations specific to how a condition may change energy requirements. The disease-specific chapter outlines modifications to energy calculations for specific populations.

Protein

Ensuring adequate protein intake is especially important in pediatrics due to the rapid growth rate. The DRI for estimated protein requirements for infants were based on intake of protein from human milk for infants and analyses of nitrogen balance studies for the non-infant. The DRI for protein can be used as a minimum recommended intake. The disease-specific chapters will outline modifications for these recommendations for specific medical conditions (Table 3.8).

Fluids

Fluid requirements are generally calculated using the Holliday-Segar method. Patients may be on fluid restrictions for specific disease states, including cardiac diagnoses and renal disease. Some patients may have fluid requirements higher than calculated, such as patients requiring fluid replacements for excessive gastrointestinal losses. It is important to work with the medical team to ensure that the Holliday-Segar method is appropriate given the patient's medical management (Table 3.9).

TABLE 3.7
FAO/WHO/UNU Equation for Estimating Resting Energy Expenditure

Age	Gender	Equation
0–3 years	Male	(60.9×W)−54
0–3 years	Female	(61×W)−51
3–10 years	Male	(22.7×W)+495
3–10 years	Female	(22.4×W)+499
10–18 years	Male	(12.2×W)+746
10–18 years	Female	(17.5×W)+651

Source: Table created with data from Koletzko B, Goulet, O, Hunt J, Krohn K, Shamir R. Guidelines on Paediatric Parenteral Nutrition of the European Society of Paediatric Gastroenterology, Hepatology and Nutrition (ESPGHAN) and the European Society for Clinical Nutrition and Metabolism (ESPEN), Supported by the European Society of Paediatric Research (ESPR): Energy. *J Pediatr Gastroenterol Nutr.* 2005;41:S5–S11.

W, Weight in kilograms.

TABLE 3.8
Dietary Reference Intakes for Protein

Age	Protein (g/kg/day)
0–6 months	1.52[a]
7–12 months	1.2[b]
1–3 years	1.05[b]
4–13 years	0.95[b]
14–18 years	0.85[b]

Source: Table created from data in Institute of Medicine, 2005. *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids*. Washington, DC: The National Academies Press.

[a] adequate intake (AI)

[b] recommended dietary allowance (RDA).

TABLE 3.9
Holliday-Segar Method for Maintenance Fluid Needs

First 10 kg	100 mL/kg/day
Second 10 kg	50 mL/kg/day
Every kg thereafter	20 mL/kg/day

Vitamins and Minerals

DRIs are established by the Institute of Medicine's Food and Nutrition Board. The DRIs consist of four nutrient-based reference values including the Estimated Average Requirement (EAR), Recommended Dietary Allowance (RDA), Adequate Intake (AI), and Tolerable Upper Intake Level (UL). They are divided by age and gender. The RDA and AI are used to determine nutrient requirements for children while the UL is used to determine nutrient intake limits (Appendix E).

Nutrition Intervention in Pediatrics

The intent of nutrition intervention is to improve or resolve a nutrition diagnosis. Nutrition interventions provide the basis for monitoring progress and measuring outcomes. Nutrition interventions are organized into four categories:

- Food and/or nutrition delivery
- Nutrition education
- Nutrition counseling
- Coordination of nutrition care

Food and/or nutrition delivery describes the dietitian's method for nutrition provision. Nutrition education is imparting knowledge to the patient or the patient's caregivers to understand how to modify food, nutrition choices, and behavior based on individual needs. Nutrition counseling is the process used to establish nutrition priorities, goals, and action plans to promote success in improving or resolving nutrition issues. Coordination of nutrition care includes consulting with or referring to other healthcare professionals, institutions, or agencies which can assist with improving or resolving nutrition issues (Table 3.10).

NUTRITION MONITORING AND EVALUATION

The fourth and final step in the NCP is Nutrition Monitoring and Evaluation. The purpose is to measure progress toward meeting nutrition goals or outcomes. The outcomes are related to the nutrition diagnosis and intervention. They are measureable and are an important component of reassessment throughout the child's clinical course. These indicators will assist the dietitian in determining whether nutrition interventions are resulting in improvements in nutrition status.

Nutrition Monitoring and Evaluation terms are combined with the nutrition assessment terms and organized in four domains:

- Food and nutrition-related history
- Anthropometric measurements
- Biochemical data, medical tests, and procedures
- Nutrition-focused physical examination findings

TABLE 3.10
Common Nutrition Interventions in Pediatrics

Domain	Subcategory	Intervention
Food and/or nutrient delivery	Meals and snacks	General healthful diet
		[a]Composition of meals/snacks
	Enteral and parenteral nutrition	Composition
		Concentration
		Rate
		Volume
		Schedule
	Supplements	Commercial beverages
	Vitamin and mineral supplements	Multivitamin/mineral
		Vitamins: A, D, E, K, B_{12}, folate
		Minerals: calcium, iron, phosphorus, zinc
Nutrition education	Content	Recommended modifications
	Application	Skill development
Nutrition counseling	Strategies	Motivational interviewing
		Goal setting
		Self-monitoring
		Problem solving
Coordination of nutrition care	Collaboration and referral of nutrition care	Team meeting
		Referral to dietitian with different experience
		Collaboration with other nutrition professionals
		Collaboration with other providers
		Referral to other providers
		Referral to community agencies/programs

[a] Composition of meals/snacks is not a nutrition intervention of itself, it is further categorized and those categories can be used as a nutrition intervention.

During the initial assessment, appropriate outcomes or indicators are selected to be monitored and evaluated for in subsequent interactions. The dietitian monitors and evaluates the progress or resolution of the nutrition diagnosis and determines whether reassessment is necessary. In pediatrics, nutrition goals will change overtime as children are growing. In infancy, growth happens rapidly and continues throughout childhood and adolescence, albeit at a slower rate. Total energy intake is an essential component to growth. Energy needs will change over time and may differ with disease states. Infants and children develop specific skills for feeding as they grow older which will also affect monitoring and evaluation criteria. Examples include human milk and/or formula intake, meal/snack patterns, and physical ability to self-feed. For children with chronic conditions who may be followed by a dietitian for years, some indicators will progress and resolve, and new criteria will be documented to monitor new nutrition diagnoses as they are identified.

If no progress is identified during monitoring and evaluation, this will inform the dietitian to make changes in nutrition interventions. It is important to determine appropriate frequency of follow-up and reassessment based on age and condition. Infants during the first year of life should be reassessed frequently, particularly premature infants and newborns. Toddlers and children will

also require consistent follow-up, however, not as frequently as infants. Adolescents and teenagers may not be growing as rapidly as infants and children, however, should be establishing independence and interventions should focus on self-monitoring and self-management as they transition to adulthood.

In summary, pediatric nutrition screening is important for identifying nutrition risk. Pediatric nutrition assessments performed by a dietitian identify nutrition problems and offer potential solutions. Utilizing NCP as a framework for nutrition assessment utilizes steps to thoroughly gather, organize, plan, and implement nutrition treatments and to evaluate and modify such treatments to improve patient nutrition outcomes using the ADIME format. Appendix F contains two example ADIME notes for pediatric patients.

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4 Fetal Development and Maternal Diet

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CONTENTS

Achieving and maintaining a healthy diet before, during, and after pregnancy play a vital role in fetal development and health outcomes for both mother and infant. Maternal nutrition is perhaps the most influential non-genetic factor in fetal development. Both maternal undernutrition and overnutrition can affect placental development and utero-placental blood flow leading to decreased nutrient supply to the fetus. However, dietary interventions implemented only during pregnancy may miss a critical window of fetal development. For instance, congenital anomalies like neural tube defects develop very early in pregnancy (likely before the woman realizes she is pregnant). Hence, this peri-conceptional period is as important as the events during pregnancy. Use of substances like tobacco, alcohol, and illegal drugs during pregnancy can have short- and long-term effects on the developing fetus. It is widely accepted that deficiencies or excesses of certain nutrients may have a negative impact on fetal growth and diet modification might reverse those effects.

OVERVIEW OF FETAL GROWTH AND DEVELOPMENT

Human fetal growth is characterized by sequential patterns of tissue and organ growth, differentiation, and maturation. Fetal growth has been divided into three phases, which are different from the pregnancy trimesters. The initial phase is characterized by a rapid increase in cell number and occurs in the first 16 weeks. The second phase, which extends up to 32 weeks of gestation, includes an increase in cell number and size. After 32 weeks, fetal growth is by cellular hypertrophy, and it is during this phase that most fetal fat and glycogen are accumulated. The corresponding fetal growth

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rates during these three phases are 5 g/day at 15 weeks' gestation, 15–20 g/day at 24 weeks, and 30–35 g/day at 34 weeks. Fetal growth is dependent on maternal provision of substrate, placental transfer of these substrates, and fetal growth potential governed by the genome.

Fetal Development

Figure 4.1 outlines key milestones during fetal development. The milestones that affect nutrient intake will be discussed in detail here. Pregnancy typically lasts 40 weeks, starting from the first day of the last menstrual period (LMP). Ovulation occurs 2 weeks after the LMP. After fertilization, the zygote develops to the blastocyst stage. The blastocyst implants 6- or 7-days following fertilization.

Organogenesis (development of the organs) occurs from 3 to 8 weeks of conceptual age and is termed an embryonic period. Avoiding teratogens during these weeks is especially crucial.

During the third week, fetal blood vessels in the chorionic villi appear. In the fourth week, the cardiovascular system and the neural plate form, and it subsequently folds to form the neural tube. By the end of the fifth week, the embryo is 3 mm long and can be measured sonographically. The cranial end of the neural tube closes by 38 days from the LMP, and the caudal end closes by 40 days. Thus, the neural tube has closed by the end of the sixth week. And by the end of the eighth week, the crown-rump length approximates 22 mm. Fingers and toes are present, and the arms bend at the elbows. The upper lip is complete, and the external ears form definitive elevations on either side of the head.

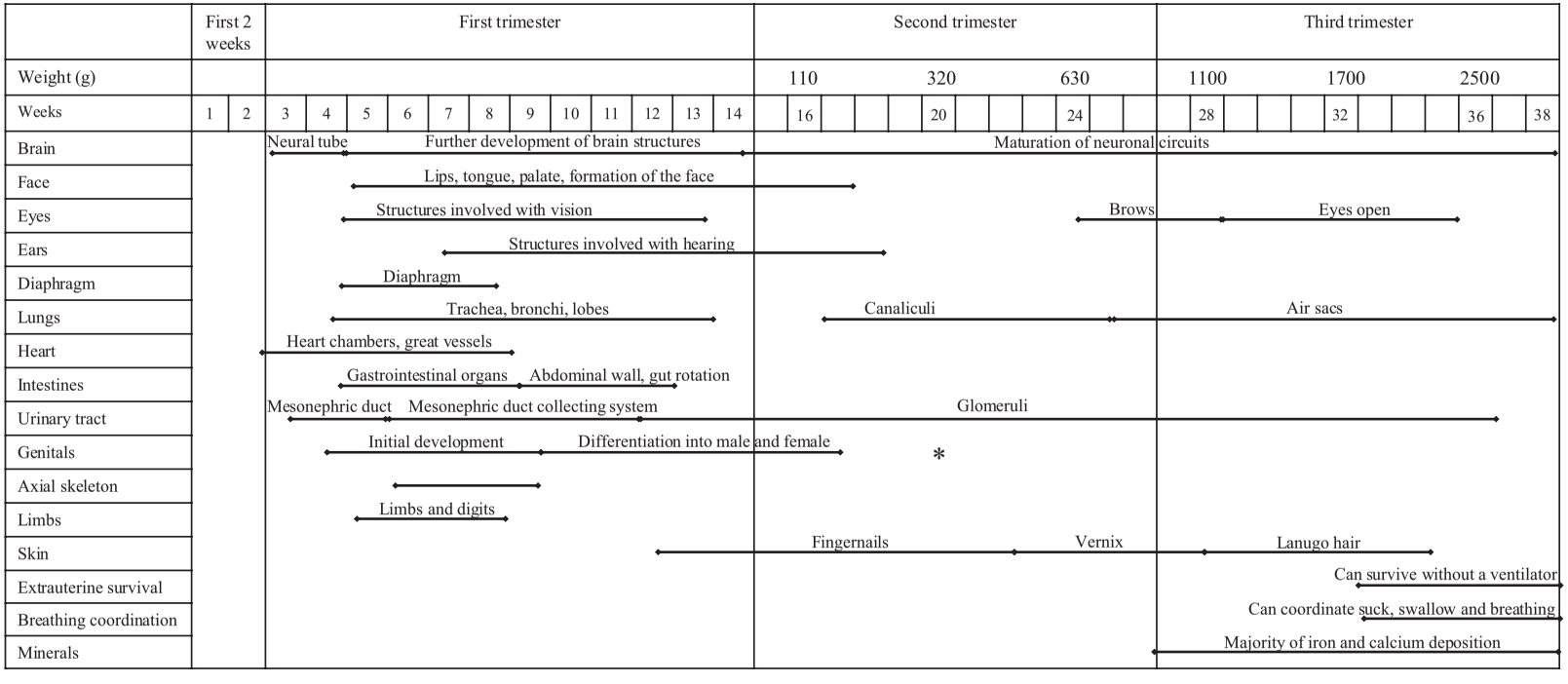
Neural tube defects, including anencephaly, myelomeningocele (spina bifida), and other rare spinal fusion abnormalities, can occur during this time. They result from incomplete closure of the neural tube by the embryonic age of 26–28 days. Hence, folic acid supplementation to prevent neural tube defects must be in place before this point to be efficacious. Many neural tube defects can be prevented with folic acid supplementation. When isolated, neural tube defect inheritance is multifactorial, and the recurrence risk without peri-conceptional folic acid supplementation is 3%–5%.

The gastrointestinal (GI) tract initially begins as a simple tubular structure that forms in the fourth week of gestation and quickly polarizes along the anterior-posterior axis. Continued cellular division results in the formation of the endoderm, mesoderm, and ectoderm layers, from which the primary components of the GI tract arise. Endoderm gives rise to the epithelial cells, which further differentiate to encompass all the cell types necessary for digestion and absorption. The mesoderm gives rise to the cells of the muscular layers and the lamina propria, and includes smooth muscle, vascular, and lymphatic contributions. The ectoderm gives rise to migrating neural crest cells, from which the enteric nervous system develops.

Gastroschisis is a full-thickness abdominal wall defect located to the right of the umbilical cord insertion. Bowel herniates through the defect into the amniotic cavity. Gastroschisis is an isolated defect that is more common in infants of younger mothers and does not involve other organ systems. Coexisting bowel abnormalities such as jejunal atresia are found in approximately 15% of cases. Fetal growth restriction complicates gastroschisis in 15%–40% of cases. See Chapter 17 for the nutrition management of patients with gastroschisis.

Omphalocele forms when the lateral ecto-mesodermal folds fail to meet in the midline. This leaves the abdominal contents covered only by a two-layered sac of amnion and peritoneum into which the umbilical cord inserts. More than half of cases are associated with other major anomalies. Omphalocele also is a component of syndromes such as Beckwith–Wiedemann syndrome, cloacal exstrophy, and pentalogy of Cantrell.

Esophageal atresia may be suspected when the stomach cannot be visualized on a fetal ultrasound and polyhydramnios (an increased quantity of amniotic fluid) is present. However, in up to 90% of cases, a concomitant tracheoesophageal fistula allows fluid to enter the stomach, such that prenatal detection is problematic. More than half have associated anomalies or genetic syndromes. Approximately 10% of cases of esophageal atresia occur as part of the VACTERL association



Legend: * Traditional time for ultrasound where sex of the baby can be determined although sex can be determined much earlier

FIGURE 4.1 Stages of fetal development.

Embryofetal development according to gestational age determined by the first day of the last menses. Times are approximate.

(Vertebral defects, Anal atresia, Cardiac defects, TracheoEsophageal fistula, Renal anomalies, and Limb abnormalities).

The gestational age from 22 to 24 weeks is considered a peri-viable period. The lower the gestational age (GA) at birth, the higher the risk of death and disability; survival at 22, 23, and 24 weeks GA is 23%, 33% and 57%, respectively. Among these survivors, the risk of moderate to severe disability at these gestational ages respectively is, 43%, 40%, and 28%. The fetus at 24 weeks weighs approximately 500 g. All of the essential organs have formed. The skin is characteristically wrinkled, and fat deposition begins. The head is still comparatively large, and eyebrows and eyelashes are usually recognizable. By 24 weeks, which is the end of the canalicular period of lung development, bronchi and bronchioles enlarge and alveolar ducts develop into terminal sacs. A fetus born at this time will attempt to breathe, but many will die despite active intervention because of poor gas exchange, infection, intraventricular hemorrhage, and other complications of prematurity.

From 28 weeks onwards, there is a 90% chance of survival to 18–24 months of age. During this period, most of the nutrients are used to promote organ growth and maturity and building of tissue stores. Premature infants born between 28 and 38 weeks usually do not have enough subcutaneous fat, muscle tissue, or tissue stores of iron and calcium. These infants are at high risk of nutritional deficiency and extrauterine growth retardation and will require external supplementation of nutrients during the neonatal period (Chapter 12). Infants born after 37 weeks of completed gestation are considered full term. Infants born at 37 weeks or later are at decreased risk of complications associated with prematurity.

Oral Feeding Skills

Swallowing begins at 10–12 weeks, coincident with the ability of the small intestine to exhibit peristalsis and actively transport glucose. Preterm infants have cardiorespiratory immaturity and cannot inhibit respiration during the act of swallowing; this leads to feed-related apnea, bradycardia, oxygen desaturations, and aspiration. Preterm infants also have inadequately developed orofacial musculature resulting in difficulties latching with an inefficient suck. Infants, particularly those born at less than 32–34 weeks, typically have nutrition provided via enteral tubes (nasogastric [NG] or orogastric [OG]), generally through a corrected age of 33–34 weeks, at which age most infants have developed oral coordination comparable with full-term infants (Chapter 12). However, the use of NG/OG tubes has an increased risk of gastroesophageal reflux and aspiration pneumonia. Early feeding therapy and oral skill development is very important in preterm infants.

MATERNAL NUTRITION STATUS AND IMPACT ON FETAL DEVELOPMENT

Nutritional optimization prior to conception is ideal to minimize risks or complications peri-conceptually. In addition to the state of health during pregnancy, pregravid nutrition status can have significant impacts on the outcome of pregnancy. Women with comorbid conditions, pre-pregnancy nutritional concerns (such as overly restrictive diets, food insecurity, obesity, low intake of fresh fruits or vegetables, high intakes of added sugar/fats), or women at increased risk for malnutrition should be identified early so necessary nutrition interventions can be implemented and appropriate weight gain goals can be set early on.

Nutrition Assessment

Nutrition assessment for a pregnant woman does not need to be unlike other nutrition assessments; it should include gathering information from the medical record, patient, or friends/family that include nutrition-related history, biochemical data, medical tests/procedures that may impact nutrition status, anthropometric measurements, and a nutrition-focused physical exam. In addition to a

typical intake history, clinicians should determine other factors that may impact growth of the fetus, including vitamin/mineral supplements, herbal supplements, smoking, alcohol, or illegal drug use.

Obese patients and patients who are or are at risk for malnutrition (such as acutely ill patients with weight loss or poor nutrition intake, patients with hyperemesis, or patients with active chronic illnesses with poor nutrition tolerance) should be monitored closely. Women with a high body mass index (BMI) pre-pregnancy are at a higher risk for unfavorable perinatal outcomes such as gestational diabetes, preeclampsia, delivery by cesarean section, and adverse fetal effects such as stillbirth, birth defects, or abnormal fetal growth. Women should be counseled pre-pregnancy to lose weight to a more desirable weight range to minimize the negative effects of obesity on maternal and fetal health. Identification of malnutrition in the pregnant patient can be difficult, as there is currently no validated tool for specifically evaluating malnutrition in this population.

Maternal Weight Gain

Maternal weight gain is an important indicator of overall fetal development and outcomes. Weight gain can be attributed to maternal gain (breast tissue, uterus, blood volume, and fat stores) and gestational gain (fetus, amniotic fluid, and placenta). Weight gain recommendations are determined using pre-pregnancy BMI and the number of gestations (Table 4.1). The overall incidence of pregnancy complications associated with inappropriate weight gain is more prevalent at the upper and lower ends of weight gain.

Less than recommended gestational weight gain during the second and third trimesters is associated with small for gestational age (SGA) neonates in women of all weight categories except class II or III obesity. Obese or severely obese women may be able to appropriately slow maternal gain or lose weight, as long as the fetus is meeting growth milestones. However, marked weight gain restriction after mid-pregnancy should not be encouraged even in obese women. Even so, it appears that food restriction to <1,500 kcal/day adversely affects fetal growth minimally. The best documented effect of famine on fetal growth was in the *Hunger Winter* of 1944 in Holland. For 6 months, the German occupation army restricted dietary intake to 500 kcal/day for civilians, including pregnant women. This resulted in an average birth weight decline of only 250 g.

Although metabolic changes associated with poor weight gain or weight loss during pregnancy are not well studied, increased insulin resistance may accelerate the time to starvation which leads to an increased risk for developing ketonemia, increased urinary urea nitrogen excretion, and

TABLE 4.1
Weight Gain Recommendations for Pregnant Women 19–50 Years Old

Pre-Pregnancy Weight Category and BMI (kg/m²)	Range of Recommended Weight Gain for Singleton		Range of Recommended Weight Gain for Twins through Full Pregnancy
	Full Pregnancy	Weekly Rate in Second and Third Trimesters	
Underweight (BMI < 18.5)	12.5–18 kg (28–40 lbs)	0.44–0.58 kg (1–1.3 lbs)	No recommendation
Healthy Weight (BMI 18.5–24.9)	11.5–16 kg (25–35 lbs)	0.35–0.5 kg (0.8–1 lbs)	17–25 kg (37–54 lbs)
Overweight (BMI 25–29.9)	7–11.5 kg (15–25 lbs)	0.23–0.33 kg (0.5–0.7 lbs)	14–23 kg (31–50 lbs)
Obese (BMI ≥ 30)	5–9 kg (11–20 lbs)	0.17–0.27 kg (0.4–0.6 lbs)	11–19 kg (25–42 lbs)

Source: Created using data from Institute of Medicine and National Research Council. *2020–2025 Dietary Guidelines for Americans*. Washington, DC: The National Academies Press. https://www.dietaryguidelines.gov/resources/2020-2025-dietary-guidelines-online-materials and Academy of Nutrition and Dietetics, 2021. *Nutrition Care Manual*. Chicago, IL. https://www.nutritioncaremanual.org.

For triplets, recommended weight gain is about 23 kg (50 lbs), although data are insufficient.

decreased gluconeogenic amino acid production. Maternal ketonemia has been related to abnormal fetal growth or later neurocognitive development.

Conversely, excessive gestational weight gain is associated with an overgrown newborn in all maternal weight categories and may lead to maternal complications such as preeclampsia, gestational diabetes, prolonged maternal weight retention after delivery, and increased risk for childhood obesity in the infant.

Nutrition Diagnosis

Common nutrition diagnoses for pregnant women include:

- Inadequate energy intake
- Excessive energy intake
- Increased nutrient needs (specify)
- Inadequate vitamin intake (specify)
- Inadequate mineral intake (specify)

Nutrition Intervention

Nutrition Prescription

Energy

Energy depletion during pregnancy has been reported to be approximately 80,000 kcals due to increased metabolic demand and body composition changes, with increasing energy expenditure noted throughout each trimester to account for fetal and placental growth. See Table 4.2 for equations for determining energy requirements during pregnancy. For women with increased metabolic demand in addition to pregnancy (i.e., instances of trauma or illness while pregnant), predictive equations are likely to underestimate overall requirements. Use of standard predictive equations is recommended with the addition of 340 or 452 calories per day for the second or third trimesters, respectively. It should be noted that women who are severely underweight are likely to require additional energy to promote proper maternal and fetal growth. Women with a BMI ≥ 30 kg/m^2 are likely to require less than the standard estimated requirements to minimize excessive fat mass deposition. Overall, maternal weight gain can be a reliable indicator of appropriate energy intake.

TABLE 4.2
Estimated Energy Needs for Pregnant Women

EER[a] = 354 − ([6.91 × (age in years)] + PA[b] × (9.36 × [weight in kg]) + (726 × [height in meters])

First Trimester	Second Trimester	Third Trimester
No change in energy requirement	Non-pregnant EER + 340 calories/d	Non-pregnant EER + 452 calories/d
	Non-pregnant EER + 500 calories/d for multiples	Non-pregnant EER + 500 calories/d for multiples

Source: Created using data from Institute of Medicine, 2005. *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids*. Washington, DC: The National Academies Press. https://doi.org/10.17226/10490.

[a] EER = estimated energy requirements based on pregravid weight; may need to make adjustments in instances of additional stress such as trauma or illness.

[b] PA = physical activity, 1.0 (sedentary), 1.12 (moderate), 1.27 (active), 1.45 (very active).

Macronutrients

Dietary macronutrient composition recommendations during pregnancy are similar to the non-pregnant state, with a few exceptions. Protein requirements are increased during pregnancy to support fetal tissue development; however, excessive protein supplementation during pregnancy does not improve maternal or perinatal outcomes. It is estimated that the mother's overall increase in protein requirement during pregnancy is roughly 1,000 g, with the majority of the increased requirement occurring over the last 6 months of pregnancy due to increased protein turnover (Table 4.3).

Omega-3 Fatty Acid Supplementation and Fish Intake

Fat can be an important energy source and it plays an important role in the structural integrity of cells. While a well-balanced diet is encouraged during pregnancy, optimal omega-3 fatty acid intake, chiefly of docosahexanoic acid (DHA), may benefit fetal and maternal outcomes. Supplementation with omega-3 fatty acids has been associated with improved neurodevelopment, visual acuity, increased birth weight, and increased length of gestation with decreased risk of preterm delivery. Deficiency or low levels of omega-3 fatty acids have been linked to higher postpartum depression risk. The best source of omega-3 fatty acids are oily fish (salmon, mackerel, herring, anchovies, sardines) or eggs, flaxseeds, and walnuts. However, caution should be taken with excessive high-fat fish intakes due to possible contaminants (see "Fish Intake" section below). Recommended intake is up to 1.4 g/day of omega-3 fatty acids and 13 g/day of omega-6 fatty acids. Excessive intakes should be avoided as there has been an association with prolonged gestation and high neonatal birth weight.

Micronutrients

Micronutrient needs during pregnancy are increased for many vitamins and minerals when compared to non-pregnancy requirements (Appendix E). Table 4.4 includes a list of key micronutrients with increased needs during pregnancy and food sources of each nutrient. It is recommended that women who are pregnant or who may become pregnant take a prenatal multivitamin with minerals daily to promote key nutrient consumption, particularly of folate, iron, vitamin A, vitamin D, calcium, and iodine (Table 4.4).

Folate requirements during pregnancy are higher than at any other life stage and it is an important nutrient in preventing neural tube defects. The USA began fortifying grains with folic acid in the 1990s, which led to a decrease of neural tube defects by roughly 50%. As mentioned before, folate is considered important peri-conceptually for neural tube closure, and it is highly recommended that women start taking folic acid supplementation prior to conception. Women with increased risk of folic acid deficiency, including patients with a history of neural tube defects, history of bariatric surgery, malabsorptive disorders, or active smokers, may require supplementation above the standard recommendation.

TABLE 4.3
Daily Macronutrient Requirements for Pregnant Women

	Pre-Pregnancy, First Trimester	Second Trimester	Third Trimester
Protein (pre-pregnancy weight)	0.8 g/kg	1.1–1.2 g/kg Multiples: maintenance protein + 50 g	1.52 g/kg Multiples: maintenance protein + 50 g
Carbohydrate	RDA 130 g	RDA 175 g (likely to be insufficient in multiples)	RDA 175 g (likely to be insufficient in multiples)
Fat		20%–35% of daily energy	

RDA = recommended dietary allowance.

TABLE 4.4
Key Micronutrients with Increased Dietary Reference Intakes for Pregnant Women

Micronutrient	Food Sources
Choline	Dairy, egg yolks, meat, seafood, beans, peas, lentils
Folate[a]	Dark green vegetables, beans, peas, lentils, enriched grains
Iodine[a]	Dairy products, eggs, seafood, iodized table salt
Iron[a]	Heme iron: lean meat, poultry, seafood
	Non-heme: beans, peas, lentils, dark green vegetables, enriched grains
Magnesium	Green leafy vegetables, legumes, nuts, seeds, whole grains
Niacin	Liver, chicken breast, tuna, turkey, salmon, anchovies
Potassium	Bananas, oranges, cantaloupe, honeydew, apricots, grapefruit, spinach, broccoli, potatoes
Riboflavin	Milk, eggs, fortified cereals, mushrooms, plain yogurt
Thiamine	Whole grains, meat, fish, poultry, eggs, milk, green leafy vegetables, legumes
Vitamin A[a]	Liver, eggs, fortified cereals, orange and yellow fruits or vegetables
Vitamin B_6	Pork, poultry, fish, peanuts, soy beans, oats, bananas
Vitamin B_{12}	Fish, meat, poultry, eggs, milk, fortified cereals
Vitamin C	Citrus fruits, peppers, strawberries, broccoli, potatoes, Brussels sprouts
Zinc	Oysters, red meat, poultry

[a] Nutrient of importance.

Iron is an important nutrient that supports proper fetal growth and development, and maternal requirements nearly double during pregnancy. Iron deficiency is not uncommon during pregnancy (up to 38% of pregnant women), and has been linked to fetal growth restriction, premature birth, and fetal death. Patients should undergo routine screening of iron status, especially women with increased risk of deficiency (history of iron deficiency anemia, gastrointestinal disease, malabsorptive disorders, bariatric surgery, or diets lacking in iron such as vegetarian or vegan diets), and should be supplemented as appropriate (Table 4.5).

Fat-soluble vitamins are necessary for proper fetal development and long-term outcomes of the infant. Negative pregnancy outcomes due to vitamin D deficiency may include preeclampsia, gestational diabetes, low birth weight, recurrent unexplained pregnancy loss, and post postpartum depression. Women at risk for vitamin A or D deficiency include those with fat malabsorptive disorders, women of darker skin tone or living in high latitudes (vitamin D), or women who may follow restrictive diets or experience hyperemesis.

TABLE 4.5
Laboratory Values for Diagnosing Iron Deficiency Anemia Determination in Pregnant Women

Trimester	Hemoglobin Concentration (g/dL)	Hematocrit (<%)
First	< 11.0	< 33.0
Second	< 10.5	< 32.0
Third	< 11.0	< 33.0

Source: Created using data from Academy of Nutrition and Dietetics, 2021. *Nutrition Care Manual*. Chicago, IL. https://www.nutritioncaremanual.org.

Vitamin D deficiency is quite prevalent among women and is a major risk factor for newborn hypocalcemia and development of rickets. Hypocalcemia is of particular concern for preterm infants, as the majority of fetal calcium is accrued during the third trimester. Vitamin D adequacy has also been linked with lower risk of preterm birth.

Adequate, but not excessive, intake or supplementation of vitamin A is a vital factor for proper fetal growth and development. Vitamin A plays a critical role in embryogenesis, and deficiency has been associated with growth restriction, eye abnormalities, and impaired vision in children. Conversely, vitamin A toxicity (intakes > 10,000 IU/day) has been linked to high rates of spontaneous abortion and birth defects.

Adequate iodine intake during pregnancy is essential for appropriate neurocognitive development and thyroid hormone synthesis. Subclinical hypothyroidism can double the risk of miscarriage, and sufficient fetal synthesis of iodine does not occur until 17–19 weeks of gestation. Iodine deficiency has been additionally associated with developmental impairments (including impaired neurodevelopment, cognitive development, and learning skills as well as behavioral issues). Iodine intake is generally adequate among women; however, women who do not regularly consume high-iodine containing foods (or women experiencing hyperemesis) may be at risk.

Common Nutrition Interventions

Avoidance of Harmful Substances

Avoiding tobacco and alcohol are key components of a healthy pregnancy. Cigarettes (including e-cigarettes) contain thousands of chemicals including nicotine that can pass from the mother to the fetus. Nicotine causes vasoconstriction which in turn compromises oxygen and nutrient delivery to the fetus. In addition to nicotine, alcohol consumption can impact normal fetal growth and development. Lifelong complications may occur, with the most severe being fetal alcohol syndrome leading to growth problems, mental disability, behavioral problems, and abnormal facial features.

Mercury is a naturally occurring element that can be harmful to the developing fetus. Mercury is turned into methylmercury in water sediment. Accumulation of methylmercury in the body can be damaging to the brain and nervous system if someone is exposed for prolonged periods. Most fish contain some amount of methylmercury; however, some fish contain higher amounts. See Table 4.6 for guidelines for fish intakes during pregnancy.

Fish can be a high-quality source of protein, vitamins B_{12} and D, minerals such as iron and iodine, and healthy fats that can be beneficial to the mother and developing fetus. All seafood should be cooked thoroughly (63°C [145°F]), as raw seafood may contain bacteria such as *Listeria* (see the Foodborne Illness section below). In general, recommendations for pregnant women suggest consumption of 240–360 g (8–12 oz) of a variety of seafood per week, focusing on choices that are lower in mercury.

Early studies have demonstrated a risk of both maternal and fetal outcomes such as miscarriage, poor fetal growth, SGA, preterm birth, and stillbirth with excessive caffeine intake. Current

TABLE 4.6
Fish Intake Recommendations for Pregnant Women

Recommended (up to 2–3 servings per week)	Anchovy, Atlantic croaker, Atlantic mackerel, black sea bass, butterfish, catfish, clam, cod, crab, crawfish, flounder, haddock, hake, herring, lobster, mullet, oyster, pacific chub mackerel, perch, pickerel, plaice, pollock, salmon, sardine, scallop, shad, shrimp, skate, smelt, sole, squid, tilapia, trout, tuna canned light, whitefish, whiting
Limit (up to 1 serving per week)	Bluefish, buffalo fish, carp, Chilean sea bass, grouper, halibut, mahi mahi, monkfish, rockfish, sablefish, sheepshead, snapper, Spanish mackerel, striped sea bass, tilefish, tuna albacore/white, tuna yellowfin, weakfish, white croaker
Avoid (highest mercury levels)	King mackerel, marlin, orange roughy, shark, swordfish, tilefish, tuna bigeye

research does not suggest a safe level of caffeine intake for pregnant women. Women who are pregnant or contemplating pregnancy should be advised to limit caffeine.

Supplements

Supplement use is not uncommon in the pregnant population; however, neither safety nor effectiveness of supplements is well known. Herbal and dietary supplements are poorly regulated in the USA, and there is little control over content of individual products. High-quality trials to determine safety and efficacy of supplements during pregnancy are scarce; while some studies show a lack of any effect on pregnancy, others have shown a negative impact on pregnancy and fetal outcomes. In general, avoidance of herbal supplementation due to lack of quality evidence and potential harm is recommended.

Prenatal vitamins are recommended starting pre-pregnancy. It is recommended that women who are pregnant or who may become pregnant take a prenatal multivitamin with minerals daily to promote key nutrient consumption, particularly of folate, iron, vitamin A, vitamin D, calcium, and iodine.

Food Safety

Pregnancy's effect on a mother's immune system decreases its ability to fight foodborne illness. *Listeria monocytogenes* (foodborne illness) and *Toxoplasma gondii* (found in cat feces) are two organisms that can pass to an unborn child if the mother is affected. Pregnant women are ten times more likely than the general population to be affected by listeriosis. If infected with *Listeria*, a pregnant woman may remain asymptomatic or experience only mild flu-like symptoms. However, *Listeria* has been linked with miscarriage, infants born SGA, and neonatal sepsis. Cooking meats, fish, and poultry until well done to prevent *Listeria* is recommended. Other sources of *Listeria* include unpasteurized milk, unheated hot dogs or luncheon meats, imported or unpasteurized soft cheeses, and smoked seafood.

Special Considerations

Multiple Gestations

Weight gain recommendations increase in instances of multiple gestations, and the maternal metabolic rate is markedly higher than in singletons. Micronutrient requirements are also increased, and deficiencies in iron, folate, vitamin D, and calcium are significantly more common. Recommended dietary allowance (RDA) recommendations remain the same for micronutrient intakes. Refer to Table 4.1 for weight gain recommendations.

Gestational Diabetes

Gestational diabetes (GDM) is defined as glucose intolerance beginning or first diagnosed during pregnancy and is associated with higher incidence of fetal macrosomia (disproportionate enlargement of shoulders and trunk), birth trauma, and fetal hypoglycemia at birth. Insulin resistance is increased during the second and third trimesters, and if women are unable to overcome the resistance or produce adequate insulin to maintain desired glucose concentrations, GDM may develop. Pre-gestational diabetes refers to women with diabetes prior to pregnancy and can be associated with a variety of malformations and vascular complications, placental insufficiency, and growth restriction. Additional complications associated with GDM include maternal hypertension, preeclampsia, polyhydramnios (associated with preterm delivery, premature rupture of membranes, and placental abruption), and operative deliveries. Women who develop GDM are at increased risk of developing type 2 diabetes and GDM in subsequent pregnancies. Fetuses exposed to GDM may have additional risks for developing obesity or adult-onset diabetes.

The time frame for risk of congenital malformations is during organogenesis (weeks 3–8). The most common site of malformations is the heart followed by the central nervous

system, GI tract, and kidneys. Improvement of the glycemic profile during the preconceptual period is required to prevent malformations; ideally preconception fasting glucose should be <100 mg/dL, and 2-hour postprandial level <140 mg/dL. Glucose concentration goals for women who develop GDM are ≤95 mg/dL fasting, ≤140 mg/dL 1-hour postprandial, or <120 mg/dL 2-hour postprandial.

For women who are obese, early screening for glucose intolerance is recommended and treatment should be implemented, if needed. Typical GDM screening occurs between weeks 24–28, and there are multiple oral glucose tolerance test (OGTT) strategies for diagnosis. See Table 4.7 for guidelines.

Hypertensive Disorders of Pregnancy

Hypertension during pregnancy consists of gestational hypertension, preeclampsia, eclampsia, and pre-gestational hypertension. Pregnancy-induced hypertension is a new-onset hypertension typically identified after the 20th week of gestation. Women with chronic hypertension present prior to pregnancy are at an increased risk for development of preeclampsia. Preeclampsia is defined as elevated blood pressure (20–30 mmHg systolic increase and/or 10–15 mmHg diastolic pressure increase) observed on two separate occasions at least 6 hours apart accompanied by proteinuria and/or edema. Other associated maternal morbidities include elevated liver function tests, blurred vision, severe headache, altered consciousness, and pulmonary edema. Eclampsia is the worsening of preeclampsia leading to seizures. The only cure for eclampsia is delivery of the fetus and placenta.

Hypertensive disorders of pregnancy are a leading cause of intrauterine growth restriction, stillbirth, preterm delivery, neonatal morbidity, and death. Risk factors for hypertensive disorders include nutritional deficiencies, malnutrition, multiple gestation, older age, diabetes, familial predisposition, and obesity. When preeclampsia develops, oxidative stress is heightened due to reduced placental perfusion leading to an increased production of free radicals.

Numerous strategies have been tested for prevention of preeclampsia, including protein or salt restriction and supplementation with zinc, magnesium, fish oil, calcium, and vitamins. Most of them failed to show benefit in preventing preeclampsia or adverse outcomes. Current nutrition interventions include increased emphasis on intake of vegetables, fruits, and whole grains; including low-fat dairy products, poultry, fish, legumes, non-tropical vegetable oils, and nuts; limiting sweets and red meats. Evidence suggests a beneficial effect of calcium supplementation of 1.5–2 g/day for preeclampsia prevention in populations with low calcium intake. Sodium recommendations for non-pregnant patients with hypertension are <1.5 g/day. These recommendations may be extrapolated to hypertension during pregnancy. Supplementing with Vitamin C and E to reduce oxidative stress has not shown benefit and is not recommended.

TABLE 4.7
Strategies for Diagnosing Gestational Diabetes Mellitus

"One-Step" Approach: perform a 75 g, 2-hour oral glucose tolerance test (OGTT) with glucose measurements first after 8 hours of fasting and at 1 and 2 hours post glucose challenge. Diagnosis can be made if:

Fasting > 92 mg/dL	1 hour >180 mg/dL	2 hour >153 mg/dL

OR

"Two-Step" Approach, Step 1: perform a 50-g glucose, non-fasting load with measurements at 1 hour. If glucose level is above the desired cutoff (>130, 135, or 140 mg/dL (practitioner dependent), proceed to Step 2

"Two-Step" Approach, Step 2: perform a fasting 100-g, 3 hour OGTT with measurements at fasting, 1 hour, 2 hour, and 3 hours. Diagnosis is made when two of the below values are exceeded:

Fasting >95 mg/dL	1 hour >180 mg/dL	2 hour >155 mg/dL	3 hour >140 mg/dL

Maternal Diet and Atopic Disease

There have been theories that avoiding or consuming common food allergens (peanuts, milk, eggs, fish, etc.) during pregnancy may impact the frequency of food allergies in the child; however, the evidence is inconclusive. More recent data suggests avoidance diets may actually increase risk of atopic disease in a child. In regards to allergenic food ingestion during pregnancy, it is recommended that women do not avoid certain foods and should follow a general, healthy diet with an emphasis on fresh fruits and vegetables, low-fat dairy (if tolerated), and lean proteins such as fish, as this may be associated with lower rates of food allergy development.

Maternal Diet and Impact on Lactation

Breastfeeding after birth has many benefits for both mother, in whom it may promote post-partum weight loss and decrease development of breast and ovarian cancers, and the infant, providing nutrition that is easy to digest and antibodies to support the immune system while also decreasing the risk of sudden infant death syndrome (SIDS). Lactation poses a significant nutrition demand on the mother, and women typically require an additional 450–500 calories and up to 3.0 L of fluid per day to produce sufficient milk. There are no foods to avoid specifically while nursing, although caffeine consumption should be limited to <200 mg/day, and high-mercury fish should be limited. Alcohol consumption is safe in moderation, if waiting to feed the infant until alcohol has left the mother's system.

A small portion of infants fed human milk have adverse reactions to certain foods. The severity of the food reaction is typically associated with the amount of food mom consumed, with the most common culprits being cow milk protein, soy, wheat, corn, eggs, or peanuts. Signs of an intolerance may include rash, hives, eczema, or intestinal upset including diarrhea or mucousy stools with blood. If there is concern for a food sensitivity, women should avoid that food for 2–3 weeks to see if symptoms improve. Many infants grow out of sensitivities after several months, although some allergies persist long term. Women should take caution, though, to not unnecessarily over restrict their diet, as adequate nutrition is most important for proper lactation and supporting the infant's growth. See Chapter 15 for more information about food allergies and elimination diets.

Nutrition Monitoring and Evaluation

Pregnant women requiring nutrition intervention also require close follow-up. Monitor maternal weight gain and adjust nutrient intake if weight gain is outside of recommendations (Table 4.1). Monitor laboratory values for nutrients of concern and supplement appropriately. Achieving and maintaining a healthy diet before, during, and after pregnancy plays a vital role in fetal development and health outcomes for both mother and baby. Nutrition interventions should focus on ensuring the health of both mother and baby (Table 4.8).

Maternal nutrition has an effect on fetal growth and development. The period of fetal growth and development is important to the health of the fetus after birth, during early childhood, and beyond. Conditions that develop during the fetal growth period can have an impact on the nutrition status of the infant and the dietitian should understand these concepts to provide the best evidenced based pediatric care.

TABLE 4.8
ADIME Summary for Pregnant Women

- Assessment
  - Growth assessment
    - Ensure weight gain is within recommendations. See Table 4.1
  - Nutrition-focused physical exam
  - Nutrient intake
  - Labs
  - GI findings
  - Medications/side effects
- Diagnosis
- Intervention
  - Nutrition prescription
    - Increased energy needs. See Table 4.2
    - Increased protein needs. See Table 4.3
      - Increased needs of key micronutrients, including folate, iron, vitamin A, vitamin D, calcium, and iodine. See Table 4.4 and Appendix E
  - Common nutrition interventions
    - Education
      - Avoidance of harmful substances
      - Food safety
    - Laboratory monitoring
    - Supplements
      - Recommend prenatal vitamin
      - Avoid herbal supplements
- Monitoring and evaluation
  - Maternal weight gain
  - Laboratory values as indicated

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5 Infant Nutrition

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CONTENTS

The neonatal period and the first year of life are times during which appropriate growth and neurodevelopment is dependent on adequate nutrition. Emphasis on nutrition during the first 1,000 days of a human's life (270 days of pregnancy + 730 days of life from birth to 2 years of age) is a critical window to promote growth, neurodevelopment, and gross motor development and has significant impact on long-term outcomes. It has been documented that total brain volume increases 101% in the first year of life. During this time, specific nutrients such as iodine, essential fatty acids, folic acid, copper, zinc, iron, choline, vitamin A, and B vitamins play an important role in various processes such as proliferation of neurons, growth of axons and dendrites, formation of connections called synapses, and myelination.

A newborn is expected to lose about 10% of birth weight in the first week of life as extracellular fluid that was needed in utero is excreted through urine, stool, and insensible losses. The infant is expected to regain birth weight by day of life 10–14. An initial weight loss of greater than 15% and

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the inability to regain birth weight by 14 days of life is concerning and should be investigated by the pediatrician. Initially, a newborn may sleep between 12 and 20 hours a day, but it is important to feed her 8–12 times in a 24-hour period. A typical feeding pattern could evolve into feeding every 2–4 hours, and it is important to wake sleepy infants for feeding if they are having trouble gaining weight. A healthy newborn should be gaining weight at an average of 30 g/day either via consumption of human milk, infant formula, or a combination of both (Chapter 1).

STAGES OF INFANT DEVELOPMENT AND EXPECTED FEEDING MILESTONES

In order to meet nutrition needs, the infant has to learn oral feeding skills starting with breastfeeding or bottle feeding and then advancing to solid foods. These skills develop rapidly as both the gastrointestinal tract and nervous system mature and coordination is established. By understanding the developmental stages during infancy, we can better understand expected feeding milestones and nutrition requirements at each stage (Chapter 3).

The newborn will demonstrate hunger cues by making sucking motions with her lips and mouth, bringing hands to the mouth or face, and "rooting" where the newborn turns her head to the side in search of the breast or bottle when mouth or cheek is touched. Late signs of hunger include crying, exhaustion, and falling asleep. It may take several days before the infant learns to properly latch on to the breast and develop a rhythmic feeding pattern of suck-swallow-breathe.

As the 1-month mark approaches, the infant will be able to hold her chin up and turn her head; however, her head will still lag when pulled to a sitting position. The infant's visual acuity will improve during this stage and she will be able to follow a moving object. At 2 months of age, she may feed at the breast for longer periods of time or bottle feed larger volumes to meet her needs. There is some improvement in the ability to raise the head farther; however, it will continue to lag when she is pulled to a sitting position. The ability to follow a moving object extends to 180° at 2 months. At 3 months of age, an infant can lift her head and chest with arms extended and starts reaching for objects though mostly missing the target. Some infants may start sleeping longer periods overnight as they develop a circadian rhythm. Feeding volume continues to increase and the infant may start to go longer than 3–4 hours between feeds. Between the 3- and 4-month stage, growth slows down to an average of 20 g/day, and the birth weight is doubled at 4 months. The infant begins to evaluate objects that are midline and can manipulate them with both hands. There is interest in reaching and grasping objects and exploration with the mouth. She may start to show a clear indication of excitement at the sight of food. At 4 months, the infant has advanced to having no head lag when pulled to sitting position. Sleep takes the form of longer stretches of time with minimal waking or interruptions. Pediatricians recommend introducing solids around 6 months of age, when the infant is able to hold her head up and has adequate truncal support. Premature infants should be introduced to solid foods based upon a corrected age of around 6 months.

The period of 6 months to a year of age in an infant is full of developmental milestones that help perfect the skills of nutrient acquisition and consumption. Around 6–7 months, the infant starts sitting unsupported and may even be crawling. At 7 months, an infant starts reaching for larger objects and can transfer from hand to hand. By 9–10 months, the infant is pivoting while sitting and can pull to a standing position. Around this time, human milk or formula feeding may decrease to about four to five times per day. More fine motor skills get acquired such as thumb-finger grasp at 8–9 months and pincer grasp at 1 year of age. Additionally, the primary teeth erupt between 6 and 12 months to assist with cutting and biting. Infants are expected to have tripled their birth weight by their first birthday. Their length at that time will have increased by 50%. Human milk or formula feeding may further decrease to around three times per day at the 1-year mark.

The above description of stages of development is meant to serve as a guide. Normal development occurs along a spectrum and may not follow this exact timing. It is important to remember that every infant is different and will mature at her own pace. If there is concern for safety or delayed development, a referral to the pediatrician or primary care provider should be made (Table 5.1).

TABLE 5.1
Infant Feeding Recommendations

Age	Developmental Milestones	Expected Food Textures	Examples/Ideas
Birth	Sucking, moves tongue in and out and up and down	Human milk and/or formula	Breast or bottle feeding 8–10 times per day. 2–3 oz per feeding, every 2–3 hours
0–6 months	Head control improving Visual acuity improves Starts to hold objects	Human milk and/or formula	Breast or bottle feeding 8–10 times per day. 4 oz per feeding every 3–4 hours
6–7 months	Head control improved, needing minimal support in seated position Starts to point at, grab for, and hold food Brings food to mouth Begins to sit with support	Human milk and/or formula Around 6 months, pureed and mashed food (vegetables, meat, fruit, etc.), infant cereals, open to a wide range of tastes in this period If baby is showing signs of reaching for food, and demonstrates safe swallowing – can try small, soft foods that easily "squish" when pinched	Breast or bottle feeding 5–8 times per day. 4 oz per feeding every 3–4 hours Avocado, chickpeas, sweet potato, black beans, pear, spinach, pumpkin, squash, kale, mango, apple, meat or tofu, soft toast, scrambled egg yolk, peanut butter "puffs"
7–8 months	Begins to feed from spoon with less spilling Chewing – though may not be fully coordinated Eruption of teeth Open cup drinking – sippy cups commonly used to minimize spills	Human milk and/or formula Mashed with soft, progressively larger lumps, soft chew, finger foods	Breast or bottle feeding 4–7 times per day. 6–8 oz per feeding Eggs, meats, fish, quinoa, lentils, green beans, mushrooms, berries, citrus fruit, potatoes, zucchini, yogurt, whole milk yogurt, soft cheeses like fresh mozzarella[a]
8–9 months and beyond	Can close the lips to clear the spoon, can bite into harder foods when teeth have erupted, pincer grasps with finger and thumb, sits without support	Human milk and/or formula mostly still from breast or bottles Harder, lumpy solids, soft meats. Cow's milk should not be introduced prior to 12 months of age	May only be breastfeeding or bottle feeding 2–5 times per day. 7–8 oz per feeding Continue to offer a variety of foods, textures and the same foods the family is eating at mealtimes, in a softer texture, much smaller pieces, and in much smaller amounts.

[a] As feeds get progressively more solid, it is imperative to avoid certain foods or cut food into very small pieces to minimize choking risk. Examples of foods that are commonly choked on: raw vegetables, apples or apple skins, grapes, raisins, hot dogs, meat, chunks of cheese, popcorn, whole nuts, seeds, clumps of peanut or other nut butters

HUMAN MILK

Human milk provides nutrition and bioactive components unique to a human infant's needs. Breastfeeding and providing human milk are recommended for the first 6 months of life by all professional medical associations as well as the World Health Organization (WHO) and United Nations Children's Fund (UNICEF), and breastfeeding should complement foods until 12 months of age or beyond. Its unique composition is specifically designed to optimize an infant's ability to digest and absorb macro- and micronutrients in amounts required to promote growth and support neurodevelopment. Human milk also contains non-nutritive factors such as growth hormones, digestive enzymes, and stem cells and has diverse immune-enhancing properties (see Table 5.2).

TABLE 5.2
Select Human Milk Bioactive Components and Function

Select Human Milk Bioactive Components	Function
Lactoferrin[a]	Trophic properties, immunomodulation, iron chelation, prevents bacterial adhesion to the intestine, promotes bone growth
Milk Fat Globule Membrane (MFGM)[a]	Surrounds the milk fat globule to allow delivery of fat in a water-based fluid, impart a signaling mechanism between mother and baby via markers for growth factors and cytokines as well as preventing attachment of pathogens to intestinal wall
Human Milk Oligosaccharides (HMOs) and Glycans (glycoproteins, glycopeptides, and glycolipids)	Act as prebiotics, prevent bacterial adhesion in the intestine
Secretory IgA	Anti-infection
Lysozymes	Breaks down bacteria, immunomodulation
Epidermal Growth Factor (EGF)	Intestinal repair and growth
Bile salt-stimulated lipase (BSSL) and lipoprotein lipase (LPL)	Fat digestion and synthesis

[a] Bovine (or cow's milk)-derived lactoferrin, MFGM, and oligosaccharides are now being added to some infant formulas.

Our understanding of the seemingly infinite components of the human milk is constantly changing as the tools to measure its composition improve and facilitate more research. Beyond meeting nutritional needs, feeding at the breast allows the infant to learn to self-regulate intake and it is a time for bonding facilitated through skin-to-skin contact, eye contact, and familiar odors. Human milk is dynamic in its make-up, constantly changing to meet the nutritionl and immunological needs of the infant and is influenced by maternal diet and environmental exposures. Human milk composition changes throughout the day and throughout the first year of life as the nutrient needs for infant change and table foods are introduced.

The early milk, or first milk produced, is the colostrum. Colostrum is very highly concentrated in protein, fat-soluble vitamins, minerals, electrolytes, as well as trophic factors and antimicrobials and has immune-enhancing properties. It is produced in the first 24–48 hours after birth and is typically a deep-yellow or orange color and is only made in small volumes to match the infant's stomach capacity – which is only about 10–15 mL during that time. For some mothers, the onset of lactation may be delayed, an additional 24–48 hours due to cesarean section delivery or other obstetric complications. As early as 72 hours after birth, the mother may enter the second phase of lactogenesis, which results in the onset of greater milk production when her milk transitions from colostrum to mature milk and evolves to an expected white color. Mature milk is higher in carbohydrates, lipids, and vitamins.

Energy

Human milk can vary greatly in the amount of energy it provides. The energy provided differs between individual mothers, depends on time of the day, and can vary over the time of the feeding or pumping session. Human milk that is available at the beginning of a feeding is called foremilk and is typically higher in water and lower in fat content. Towards the end of the session, hindmilk is produced, which provides a higher-fat, lower-carbohydrate content. Fat content can vary from feeding to feeding, but within a given feeding it rises steadily from foremilk to hindmilk. Human milk analysis is evolving and continues to be refined for improved accuracy. At this time, there is a general consensus that on average, human milk provides 18–22 kcal/oz with the most common value assigned as 20 kcal/oz.

Fat

Fat is the main source of energy in human milk and needed by infants for more than just growth. Human milk lipases also aid in the digestion and absorption of fatty acids. Dietary lipids make up brain structural components, affect gene expression, transport components such as fat-soluble vitamins, build adipose tissue to aid with temperature regulation, allow for satiety between feeds, and ensure adequate energy stores for periods of rapid growth or illness. Human milk provides varying amounts of omega-3 and omega-6 fatty acids that are influenced by maternal diet and are essential for neurodevelopment, retinal structure, and modulating inflammatory responses.

Protein

Protein needs are higher in the first months of life to support rapid brain growth. Human milk reflects those needs by containing higher levels of protein for the first 5 months, and slowly decreasing in protein content through 12 months of life. Protein content can be as low as 5% of total energy, though is highly bioavailable and predominantly whey with an estimated whey to casein ratio of 80:20 initially and closer to 60:40 as milk matures beyond the second week of life. Whey protein in human milk promotes gastric emptying and provides a higher amount of cysteine, which is one of the conditionally essential amino acids for newborns. Tyrosine is the other that is not made in sufficient amounts by the body and therefore must be obtained from the diet until about 6 months of age.

Carbohydrates

Lactose is the most prevalent sugar and source of digestible carbohydrate in human milk. While intestinal lactase concentration is low at birth, over time and with exposure to lactose, most healthy term infants with or without a familial history of lactose intolerance are able to digest it with some undigested lactose acting as a prebiotic to help colonize the microbiome. Lactose also acts like a gentle laxative to promote looser stools. Oligosaccharides are complex in structure and are the next most abundant carbohydrate found in human milk. They are "resistant" to digestion in the small bowel thereby providing energy through fermentation in the colon that creates short-chain fatty acids that are then absorbed. This prebiotic action selectively stimulates growth and activity of beneficial bacteria found in the intestine which may strengthen an infant's immunity by strengthening bowel wall barrier function, reduce the presence of pathogenic bacteria, and aid in calcium absorption. Overall, about 40%–45% of energy in human milk is from carbohydrates.

Micronutrients

While the content of micronutrients in human milk is less than what is provided by formula, the micronutrients are more bioavailable and therefore easier to absorb and utilize. As volume of milk increases, so does the infant's intake of micronutrients and usually healthy term infants are able to meet their estimated micronutrient needs through human milk, with the exception of iron, vitamin D, and in certain circumstances, vitamin B_{12}.

Iron

Full-term infants are born with iron stores that deplete over time, typically around 4–6 months of age. Iron is important for growth and particularly important for neurodevelopment in infants and toddlers. The bioavailability of iron in human milk is up to 50% compared to only 10% of the iron in fortified formulas. Introducing iron-containing foods by at least 6 months as part of complementary feeding will help to meet estimated iron needs as the stores from birth have been depleted. Infants fed human milk without iron-rich complimentary foods or supplements are at risk of iron deficiency at 6–9 months of age. If iron deficiency or iron deficiency anemia is suspected, a liquid iron supplement may be recommended.

Vitamin D

Vitamin D is another micronutrient that is found in low concentrations in human milk, and infants are at risk for becoming deficient, especially if the mother was vitamin D deficient during her pregnancy. A supplement of 10 mcg/day (400 IU) is recommended for infants receiving human milk, and they should continue the supplementation until they are weaned to cow's milk after 12 months. If an infant transitions to formula feeding, they may not need the supplement if they consume greater than 1 L of vitamin D-fortified formula.

Vitamin B_{12}

Human milk typically has sufficient Vitamin B_{12} to meet the infant's needs. However, if a mother is vitamin B_{12} deficient, there may be insufficient vitamin B_{12} in the human milk. This may occur in vegan mothers with insufficient vitamin B_{12} supplementation. In this case, supplementation may be recommended for the mother, the infant, or both.

Beyond absorption of nutrients, the neonatal gut is an organ that contains endocrine functions to regulate metabolism and tries to maintain fluid and electrolyte homeostasis. A myriad of diverse, bioactive components in human milk are remarkably beneficial in digestion, immunity building, growth promotion, and neurodevelopment.

Benefits of Feeding Human Milk

Both short- and long-term benefits are attributed to feeding human milk. Infants fed human milk have a lower risk of common infant and early childhood ailments, including acute otitis media, atopic dermatitis, gastroenteritis, sudden infant death syndrome, significant lower airway tract infections during infancy, and a lower risk of asthma in young children. Maternal exposure to bacterial or viral illnesses can transfer antibodies through human milk which in turn help protect the infant from those same organisms. Long-term benefits for the infant include but are not limited to a lower risk of obesity, metabolic syndrome, type 1 and type 2 diabetes mellitus, and childhood leukemia. While long hypothesized, no direct relationship has been definitively shown to relate cognitive outcomes and human milk feeding or duration of breastfeeding. Long-term benefits for the mother may encompass lower rates of breast cancer, hypertension, epithelial ovarian cancer, and type 2 diabetes mellitus.

While breastfeeding and expressing human milk is a choice, there are some instances where it may be not advised. In general, there are few absolute contraindications. Maternal diagnoses that are contraindications include human immunodeficiency virus (HIV) in high-income countries, cancer, or others that require certain medications that may be excreted in milk and are unsafe for the infant. Mothers using drugs of abuse such as cocaine, heroin, methamphetamines, or excessive alcohol should not breastfeed or express human milk. Marijuana use is strongly discouraged, though research as to how it may affect infant is inconclusive at this time. Prescribed medications for the mother should be reviewed by her medical team. A non-maternal related reason to not provide human milk would be an infant diagnosed with certain inborn errors of metabolism (see Chapter 23). Very rarely, human milk may be contraindicated in patients with food allergies, if the mother is unable to remove the allergens from her diet (see Chapter 15).

Common Human Milk Feeding Issues

For mother-infant dyads, many common problems are attributed to a poor latch on the breast. A poor latch can happen for a variety of reasons. While breastfeeding is typically seen as the most normal, natural, and intuitive thing to do as a mother and new infant, for many, it takes great effort, skill, and support to find and maintain a good latch. Lactation specialists can help troubleshoot issues and provide support to caregivers (Table 5.3).

TABLE 5.3
Common Breastfeeding Problems, Causes, and Potential Solutions

Common Problems or Symptoms	Causes	Potential Solutions
Nipple pain, with or without blanching (turning white)	Trauma from vigorous sucking on the nipple and not fully suckling with the whole mouth; baby not opening mouth wide enough, infant's lips are tucked under at the point of latch instead of open "fish lips"; if infant has a tongue tie; or later due to chomping and/or biting the nipple as infant starts teething; vasospasm of nipple; Raynaud phenomenon, infection.	While this is very common in the first few days to a week, eventually it should subside. If not, a feeding should be observed by a lactation professional for analysis and assistance. Proper positioning and techniques should be taught. If infant starts to chomp or bite the nipple as they start teething, it is important for mother to break the latch to teach the infant not to do that. May be a sign to start weaning if mutually desired by mother and infant.
Jaundice (Hyperbilirubinemia) Lighter skin infant color may appear more yellow; more difficult to notice in darker skin infant – sometimes the eyes may have a yellow tint	Breastfeeding jaundice: Occurs in the first week of life and is due to inadequate volume of breastfeeding, therefore the bilirubin is not being excreted and building up in the blood. Commonly human milk may not be "in", or infant is not removing sufficient volume from the breast. Other causes may be blood group incompatibility or urinary tract infection.	Urgent referral to pediatrician or primary care provider for serum checks of liver function tests and potential medical treatment. If mother with inadequate milk supply, or unsure of how much volume infant is feeding, try bottle feeding and encourage mother to express human milk to increase her supply. Also make sure infant is making adequate urine and stool.
Infant with slow weight gain/growth	Weak suck, inadequate milk intake, not emptying the breast to get the high-fat hindmilk	Investigate anatomic and feeding position for possible changes and improvements; have infant feed only one breast at a time in order to fully empty the breast; or have mother pump for about 3–5 minutes before putting infant to breast so that the infant gets more of the higher-fat hind milk. Weigh infant before and after feeding to determine feeding volume.
Itchy, white patches, shooting pain in the breast	Candida infection	Antifungal treatment for both mother and infant, referral to see her physician, and possibly infant's pediatrician.
Cracked or bleeding nipples	Persistent nipple trauma from expressing milk or mechanical problem with latch; inadequate or excessive drying of the nipple due to nipple hygiene or care.	Referral to a lactation professional or physician; applying human milk to the cracks after feeds may aid with healing; manual or electric pump expression for 1–2 days to minimize further trauma may help; tools such as nipple creams or salves, nipple shields, or breast shells may be options – depending on the situation and at the direction of the lactation professional.
Color change seen in milk	Medications; mother's diet (i.e. greenish hues seen with high intake of green foods); a bluish tint is common in fore milk (milk that first comes out in the beginning of a pumping session); and pink, red, orange, and brown are colors often caused by blood from cracked nipples.	Milk of these hues is still safe to feed; however, if blood becomes more prominent and/or does not subside after 2–3 days, mother should see her physician.

(*Continued*)

TABLE 5.3 (*Continued*)
Common Breastfeeding Problems, Causes, and Potential Solutions

Common Problems or Symptoms	Causes	Potential Solutions
Breast engorgement – breasts feel very full, sometimes painful or warm to the touch	Infrequent or insufficient milk removal from the breast	Increase the frequency of feedings; try different positioning or latching techniques; hand expression or short pumping session to relieve initial pressure and let-down – electronic pumping should be done at the direction of a lactation professional as it may then result in an "oversupply" or exacerbate the engorgement.
Clogged milk duct – palpating a lump in the breast	Inadequate milk emptied from the breast therefore milk remains in the duct and inflammation develops.	Gentle massage of the clogged duct, warm compress, increased breastfeeding or expressing to drain the breast.
Mastitis – commonly presents after 10 days post-partum; appears as a localized area of warmth, tenderness, edema, redness; sometimes with a fever, malaise, and breast pain.	Bacteria from skin or saliva is transmitted via cracks in the skin or through milk ducts. Also if milk ducts remain clogged and inflammation turns into infection.	Immediate referral to physician for antibiotics to treat the infection and help to prevent a breast milk abscess; breastfeeding does not need to stop if mother still desires, and infant continues to tolerate milk. May consider expressing milk, if direct breastfeeding is too painful.

Expressed Human Milk

Many infants receive expressed human milk. Expressed human milk can be provided to infants that are unable to breastfeed and infants with enteral feeding tubes. Mothers that work outside of the home may express human milk that the infant receives from a bottle while they are separated. Expressed human milk should be stored correctly in order to prevent illness and infection (Table 5.4).

TABLE 5.4
Human Milk Storage Guidelines

	Storage Location and Temperatures		
Type of Human Milk	Countertop 77° F (25°C) or Colder (Room Temperature)	Refrigerator 40°F (4°C)	Freezer 0°F (–18°C) or Colder
Freshly Expressed	Up to 4 hours	Up to 4 days	Within 6 months is best Up to 12 months is acceptable
Thawed, Previously Frozen	1–2 hours	Up to 1 day (24 hours)	NEVER refreeze human milk after it has been thawed
Leftover from a Feeding (infant did not finish the bottle)	Within 2 hours after the baby is finished feeding		

Source: https://www.cdc.gov/breastfeeding/recommendations/handling_breastmilk.htm. Reference to specific commercial products, manufacturers, companies, or trademarks does not constitute its endorsement or recommendation by the U.S. Government, Department of Health and Human Services, or Centers for Disease Control and Prevention. This material is available at the above website, free of charge.

INFANT FORMULA

Iron-fortified cow's milk-based infant formulas are recommended by the American Academy of Pediatrics (AAP) when human milk is not available or the mother chooses to feed infant formula. Infant formulas are derived from cow's milk, soy, or other protein sources and must contain a minimum amount of macro- and micronutrients to meet the needs of infants 0–12 months of age, per FDA guidelines. The FDA does not proactively regulate infant formulas; however, it is the agency designated to investigate reports of contamination, adverse outcomes in which the formula may have contributed to that outcome, company recalls of products, and general complaints. It identifies ranges of 30 specific macro- and micronutrients to meet the needs of an infant 0–12 months of age. These nutrient ranges must be met for a manufacturer to market the product as an "infant" formula.

Infant formula nutrient composition is modeled after human milk while taking into account the sub-optimal absorption of both macro- and micronutrients derived from various sources and ingredients. Most term formulas provide 20 kcal/oz, a range of 2–2.8 g of protein per 100 kcals, and over half of the energy from fat. Lactose is the dominant carbohydrate source, as it is in human milk, although there are multiple variations where it is reduced, or another carbohydrate is used in its place. As in human milk, most formulas provide about 40% of total calories from carbohydrates. Protein in formulas provides the two additional conditionally essential amino acids (cysteine and tyrosine) which are needed from the diet until at least 6 months of age.

Infant formulas are available in multiple forms. The most common infant formula is powder formula that is reconstituted with water. Concentrated liquid infant formula is also available and is reconstituted with water prior to feeding. It is important to follow the directions on the formula package to achieve the correct formula mixing recipe to ensure the infant is receiving the correct concentration of energy, macro-, and micronutrients. Premixed, ready-to-feed infant formulas are also available. Once a formula package is opened, it is important to follow the manufacturer recommendations for storage in order to prevent illness and infection. Once an infant has started drinking from a formula bottle, it should be used within 1 hour or discarded.

There are multiple categories of term infant formulas based on the protein component of the formula (Table 5.5). See Chapter 12 for preterm infant formulas. Standard infant formula contains intact cow's milk protein. Multiple variations of standard formula are available on the market. Formulas with added rice starch are intended for patients with gastroesophageal reflux. The rice starch expands in the stomach when it encounters stomach acid, which thickens the formula so it is more likely to stay in the stomach. Formulas are also available with lower lactose levels, partially hydrolyzed protein, and prebiotics or probiotics. These formulas are marketed for a variety of symptoms, including fussiness, gas, and constipation. It is important to note that partially hydrolyzed formulas are not hypoallergenic. Additional variations of standard infant formula are available, including organic formula, formula made with A2 cow's milk, and formulas with added components intended to mimic human milk. The manufacturer's website is a good source of information to find the various formulas available and the premise behind each formula (Table 5.6).

Soy infant formulas are made with soy protein in place of cow's milk protein. They are lactose free and vegetarian. They are used for infants with galactosemia (see Chapter 23) or based on caregiver preference.

Extensively hydrolyzed (hydrolysate) infant formulas are made from cow's milk protein that is partially broken down. These formulas are considered hypoallergenic, and many infants with cow's milk protein allergy will tolerate these formulas (see Chapter 15). There are variations in the source of fat used in these formulas, and those with high MCT concentration may be used for infants with malabsorption.

TABLE 5.5
Term Infant Formulas

Formula Type	Protein Source	Indications
Standard	Cow's milk protein	Typically used as the first formula for infants without diagnosed allergies or other medical conditions
Rice-thickened	Cow's milk protein	Reflux. Thickens in the acidic environment of stomach[a]
Soy	Soy protein	Vegetarian, lactose intolerance, galactosemia
Hydrolysate	Hydrolyzed milk protein	Cow's milk allergy/intolerance
Elemental	Single amino acids	Hypoallergenic. Cow's milk allergy that does not respond to hydrolysate

[a] There is no evidence that these formulas decrease the incidence of reflux but may aid with symptom management.

TABLE 5.6
Infant Formula Manufacturers

Infant Formula Manufacturers (USA)	Website
Abbott Nutrition Maker of Similac® Products and Elecare®	https://abbottnutrition.com
Gerber® Maker of Good Start® Products	https://medical.gerber.com
Mead Johnson™ Maker of Enfamil® Products and Pure Amino™	https://www.hcp.meadjohnson.com
Nestlé Maker of Alfamino® Infant & NAN® 1 Pro	https://www.nestlemedicalhub.com
Nutricia Maker of Neocate®	https://www.neocate.com
PBM Nutritionals, LLC Maker of Generic/Store Brand Infant Formulas (Amazon, CVS, Sam's Club, BJ's, Rite Aid, Kroger, Target, Costco, Walmart, Walgreens, etc.)	https://www.perrigopediatrics.com

Elemental formulas are from single amino acids, making them hypoallergenic. Elemental formulas are recommended for infants with food allergy that do not tolerate extensively hydrolyzed formulas. They may also be recommended for infants with malabsorption.

Additional infant formulas are available for patients with specific metabolic, renal, or other medical conditions.

The interest in and popularity of infant formulas produced in other countries, including Europe, Australia, and New Zealand, has dramatically risen in the USA since 2015. This has stemmed from public distrust in domestic food regulation, fear of contamination, and perceived superiority of foreign ingredients and manufacturing practices. At the time of writing this chapter, there is no US agency or organization monitoring the nutrient content or the conditions in transport and storage of the products, and the FDA does not investigate complications that may be related to these formulas. Caregivers should be informed of the differences and potential contamination risks if they should choose an infant formula not made in the USA.

FOOD INTRODUCTION

Introduction of solid foods requires meeting age and developmental milestones for safe oral feeding. Food introduction is sometimes called complementary feeding as it complements, or adds to, the infant's human milk or formula feeding and is not yet the sole source of nutrition. Skills needed to start consuming solids include being able to sit with support, having good head and neck control, being able to push up with straight elbows from lying face down and having an interest in solid food by placing hands in the mouth or reaching for food when others are eating nearby, typically around 6 months of age (see Table 5.1). These skills are important to have started to develop before introducing solids in order to decrease the likelihood of choking and aspiration.

Infants do not need water for hydration. Their hydration needs are met by human milk or formula, and eventually water from food. Providing water may lead to false satiety and a decrease in energy intake from human milk, formula, or food. At the discretion of a primary care provider or pediatrician, small amounts of water or an oral-rehydration solution (less than 30 mL [1 oz] at a time) may be given to alleviate the symptoms of dehydration if an infant has prolonged diarrhea, develops an ongoing fever (greater than or equal to 100.4°F or 38°C), or is exposed to hot temperatures for an extended period of time.

With each new food introduction, the infant should be observed for signs and symptoms of allergic reaction such as a rash, increased work of breathing, emesis, or diarrhea. A wide variety of foods from all food groups should be introduced, and repeatedly offered every few days, weeks, and months – even if it is refused at the first offering. Refusal of unfamiliar foods is a normal part of development. Infant taste buds are partial to sweet and slightly salty tasting foods. Savory (umami), bitter, and sour flavors are important to provide in various different foods to develop a full palate. A majority of caregivers will describe their child as a "picky eater" and this may cause great concern and conflict in families. There is no consensus or definition of what exactly a "picky" eater is, and it is important to encourage repeated exposures to a variety of foods. It does not matter which food is an infant's first, as long as it is a safe consistency for the infant to swallow.

It is common to add human milk or formula to a puree mixture to help with the consistency, add energy and protein, and provide a familiar taste. Traditionally, families started with iron-fortified infant rice cereal; however, many caregivers choose to start with pureed vegetables. Infants receiving human milk should be advised to start with iron- and zinc-containing foods along with vitamin C containing foods to aid with absorption of non-heme iron. Historically, the advice was to not introduce common allergenic foods such as eggs and peanuts until 12 months of age; however, there is no evidence to support prolonging an infant's exposure will protect children from allergies. In fact, delayed introduction is now thought to be a risk factor for development of allergies for children with a first-degree relative with atopy (asthma, eczema, allergic rhinitis etc.). Early introduction of solids around 6 months of age, including foods considered allergenic, is now highly recommended by the AAP. Furthermore, based on the results from landmark studies it was concluded that introducing peanut-containing and egg-containing products to the diet of high-risk infants early (between 4 and 11 months) was very important in reducing future development of allergies to these foods (see Chapter 15). For healthy infants, it is recommended that a variety of foods, in developmentally appropriate textures, including highly allergenic foods be offered. Avoid giving honey, unpasteurized foods, and juice during infancy. Foods with added sugar and salt should also be avoided.

Baby-Led Weaning

Baby-led weaning has become a popular feeding strategy among caregivers over the last few years. Using this approach, infants are fed soft table foods as their first foods, skipping pureed foods. This allows the infant to self-feed. Potential advantages of baby-led weaning include self-regulation of feeding pace and volume, skill development including hand-eye coordination, and participation in family mealtimes by consuming texture-appropriate components of the family meal.

Perceived risks of baby-led weaning include:

- Iron deficiency, as infants are not consuming iron-fortified infant cereal and many food sources of iron are difficult textures for infants to eat
- Risk of choking if provided unsafe food textures
- Growth faltering if infant consumes less human milk or infant formula

If a family is using baby-led weaning, it is important to ensure that the infant is developmentally ready for solids. Caregivers should be counseled to avoid foods that are choking-risks (see Table 5.1). They should also be able recognize the signs of choking and should understand how to intervene if the infant chokes. The infant should be offered moist, tender foods that she can mash with her tongue and chew using bare gums. Examples include scrambled eggs, strips of avocado or banana, well-cooked vegetables such as sweet potatoes and squash. Food should be easy to pick up, often cut into strips about 6–7 cm (3″) in length. Families should also consider offering purees to the infant in addition to table foods so they can learn to accept food from a spoon. With proper supervision and caregiver knowledge, baby-led weaning may be a safe feeding strategy.

NUTRITION MANAGEMENT

Nutrition Assessment

A thorough nutrition assessment should be completed for all infants assessed by the dietitian. Anthropometric measurements are an important part of the nutrition assessment, and comparing weight gain to age-appropriate goals is essential to determine if the infant is meeting their energy needs (Chapter 1). The nutrition-focused physical examination (NFPE) can help identify nutrition problems and should be used in conjunction with anthropometric measurements (Chapter 2).

It is difficult to assess nutrient intake of breastfed infants, as the volume of human milk consumed is not easily measured. For infants with nutrition concerns, careful assessment of anthropometric data and weight gain is an important indicator of nutrient intake. The dietitian should also assess output, including the number and frequency of wet diapers, stool frequency and appearance, and frequency spitting up or vomiting. Breastfed infants can be weighed before and after a feeding to determine the volume of human milk consumed. This is more easily measured in the hospital setting than the home setting, as a calibrated infant scale is required.

The dietitian should assess nutrient intake by asking specific questions about volume of human milk, formula, and food consumed. Common questions for the infant nutrition assessment are listed in Table 5.7.

Developmental milestones are an important part of the nutrition assessment. Understanding the infant's stage of development helps the dietitian determine when an infant is ready for solid food introduction and when she can progress to different food textures (Table 5.1 and Chapter 3). The dietitian should also review the medication list and ask about nutrition supplements, including multivitamins with iron and vitamin D supplements.

Nutrition Diagnosis

Common nutrition diagnoses for infants include:

- Inadequate vitamin intake (specify)
- Inadequate mineral intake (specify)
- Inadequate oral intake

TABLE 5.7
Infant Nutrition Assessment

Breastfed Infants
How many feedings per day?
How frequent are the feedings?
How long does a typical feeding last?
Is the infant fed from both breasts at each feeding?
Does mother feel like her breasts are empty after each feeding?
Does infant seem hungry after a feeding?
Is mother expressing milk in addition to breastfeeding the infant? If so, how often and how much milk is expressed?
Formula-Fed Infants
Which formula is the infant drinking?
Have they tried different formulas? If so, which formulas and why was each formula used?
How is the formula prepared in the home? Ask for the specific mixing recipe to determine if formula concentration is appropriate.
Does the family have difficulty accessing or purchasing the formula?
Bottle-Fed Infants (formula or human milk)
How much volume does the infant consume at each feeding?
Does the infant finish the bottle? If not, how much is left?
Does the infant spit up after a feeding? If so, how often and how much volume?
Infants Consuming Solid Foods
How old was the infant when solid foods were introduced?
Which foods were introduced first? Did the infant accept the foods?
What foods does the infant eat now? How often and how much is consumed?

- Inadequate energy intake
- Inadequate protein intake

Nutrition Intervention

Nutrition Prescription

Energy requirements for healthy infants can be calculated using predictive equations. Protein requirements are calculated using the DRIs, and vitamin and mineral needs should be determined using the DRIs. See Chapter 3 for more information about determining nutrient needs for infants.

Common Nutrition Interventions

Oral Feedings

For breastfed infants, the dietitian can provide guidance on the recommended frequency and duration of feedings. Infants receiving expressed human milk or infant formula may be given volume goals to help ensure adequate intake.

Nutrition Education

Nutrition education should be provided for infants starting solid foods. The type, frequency, and volume of foods recommended should be included. The caregivers should be educated on choking hazards and provided with written information to guide them through the progression of solid foods.

If the caregivers are mixing formula incorrectly, thorough nutrition education should be provided to ensure that the patient receives appropriately concentrated formula. Visual aids, such as a bottle, water, and can of formula powder, can help ensure understanding.

Laboratory Monitoring

Infants receiving human milk or less than 1 L of infant formula per day are at risk of vitamin D deficiency. If the infant is not receiving a vitamin D supplement to meet the DRI for vitamin D, consider checking 25-OH vitamin D to assess for potential deficiency. Infants that are receiving human milk and are > 6 months of age are at risk of iron deficiency. If the infant is not consuming iron-rich solid foods, consider assessing iron status (see Chapter 2).

Supplements

Compare the infant's micronutrient intake to the DRI and supplement micronutrients that are not being met through human milk, infant formula, and solid foods. Vitamin D should be recommended for infants receiving human milk and formula-fed infants that are consuming less than 1 L of formula per day. Supplemental iron may be needed for infants > 6 months old that are receiving human milk and not consuming iron-rich solid foods.

Other Specialty Referrals

Lactation specialists can help with infants that are having breastfeeding issues, including feeding difficulties and low milk supply. A speech therapy referral for a feeding evaluation may be indicated in patients with feeding difficulties, swallowing difficulties, and slow progression to solid foods.

Consider a referral to the Women, Infants, and Children (WIC) program for families that are having difficulties affording food or formula. For patients that qualify, WIC can provide infant formula, including select specialty formulas, food for older infants, and food for pregnant women and mothers providing human milk to the infant. A social work referral can help identify additional resources for families that are experiencing financial and social difficulties.

Nutrition Monitoring and Evaluation

Nutrition monitoring and evaluation can aid the dietitian in determining if the nutrition intervention is meeting the infant's needs. Monitor anthropometric measurements, including weight gain per day, feeding volumes consumed, stool and urine output, and developmental and feeding milestones. Additional monitoring and reassessment may be needed for patients with nutrition concerns.

Nutrition during infancy is vital to promote age-appropriate growth and physical and cognitive development. The dietitian should understand the nutrient needs and developmental stages of infants in order to evaluate nutrient intake and provide recommendations for feedings. Human milk, infant formula, and solid foods provide important nutrients for infant growth and development. A thorough nutrition assessment is essential in providing nutrition interventions to meet the unique needs of the infant.

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6 Nutrition in the Older Child

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CONTENTS

As children grow and develop, their nutritional requirements evolve. Elements of independence and self-determination involve dietary intake through self-feeding and making their own food choices. Between ages 2 and 18 years, children start to form their individual dietary habits and patterns. The quality and quantity of food and beverages that children consume have a large impact on their overall health. The United States Department of Agriculture (USDA) and Department of Health and Human Service provide dietary guidelines with updates at least every 5 years for children and adults. These recommendations include incorporation of a healthy diet at every stage of life, consisting of nutrient-dense food and beverages to meet food group needs with important core elements for adequate protein, vitamins, minerals, and fat. Through development of healthy dietary patterns and habits, maintenance of a healthy lifestyle is achievable and this may diminish risk of developing chronic disease. Shared meals are helpful to encourage healthy eating and dietary patterns as well. Setting a routine is very important for all ages.

According to the 2020–2025 Dietary Guidelines for Americans, children in the USA are not meeting recommendations for diet quality. The Healthy Eating Index scores of children ages 2–4 is poor, and diet quality declines throughout childhood. Children of all ages do not meet recommendations for daily servings of fruit or vegetables, and teenage children consume about half of the recommended servings. Younger children meet recommended dairy intakes, but adolescents consume less dairy than recommended. Children of all ages do not meet recommendations for whole grains. However, protein intake typically meets recommendations, with the exception of adolescent females. Children typically exceed recommendations for added sugars, saturated fat, and sodium.

The overall goal of adequate nutrition is to achieve appropriate weight gain throughout childhood, followed by maintenance of an ideal weight to support normal growth and development at the

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end of adolescence. Children grow through all stages of development, with 60% of their total weight gain and height completed prior to the last stage of puberty during their teenage years. Dietary intake of food and beverages provides macronutrients and micronutrients that are vital for all cells and processes within the body.

TODDLERS

Toddlers are of a unique age group, as this is when eating behaviors and healthy habits are first established. Toddlers are transitioning to more structured meal times, and due to their young age, are still reliant on other people for their meals and snacks. Caregivers have a great influence on developing the palate of children at this age, and with exposure to a variety of nutrient-dense foods within each food group, they can help the child develop a healthy dietary pattern. This is important as children develop more control of their food and beverage intake as they get older. Taste preferences are established early in life, but have the ability to change and grow over time.

The diet of the child is reflective of the household and environment she lives in most often. It can be anxiety provoking at meal times as the child is learning to establish a routine and feed independently. The child may be distracted throughout mealtimes as well, which can be chaotic. Their preferences change and they may persistently eat a food for a while and then decide they do not like the food and reject it. This is called a food jag, and is a normal part of toddlerhood as the child is finding her independence. Eating together with toddlers can model a positive eating environment.

Children observe cues for appropriate feeding behaviors from their caregivers. This is why structured mealtimes and sitting at a table as a family unit are very important for the child's development.

Between the ages of 1 and 5, appetites tend to diminish in comparison to infancy. After the rapid growth of infancy, toddler growth is supported by less energy requirements per kilogram bodyweight, which is reflected in appetite. During this time, body mass index (BMI) also decreases as children transition from the higher fat stores of infancy to the lean body habitus of a preschooler. This can be of concern to caregivers as eating patterns change, fat stores decrease, and they may feel that their child is not eating enough. Caregivers should receive anticipatory guidance about this period of decreased appetite, which is not of concern if the child is following her growth curves.

When discussing nutrition and food intake with caregivers, identifying who decides the quantity of food consumed (the child or the caregiver) is important in understanding how mealtimes are viewed at home. It is important to educate the family on the division of responsibility for meal times in order to promote a structured and less-chaotic eating environment. Learning about the eating environment is also crucial in understanding the various mealtime behaviors. Toddlers should develop a structure of 3 meals/day with two to three nutritious snacks for adequate intake. If a child goes to daycare, caregivers should ask what the child is offered and what is consumed there.

PRESCHOOLERS

Preschoolers are starting to develop more autonomy with their eating habits, and this is when picky eating may first present. Caregivers should try not to cater to preferences, but rather to encourage trying a variety of new foods when offered at meals. Continuing to limit distractions and screen use during mealtime can encourage healthy eating environments. Structured family mealtimes continue to be very important for both modeling of good behaviors and encouraging healthy intake. This allows children to eat at a slower pace overall and chew food properly. Having conversations during mealtimes allows the length of eating time to increase and may help with appropriate intake.

Picky Eaters

Children go through periods of eager food acceptance followed by food refusal. Although this is normal, caregivers are often concerned that their child is a picky eater. When children are refusing

certain foods, it is important for caregivers to continue to offer a variety of foods but not force a child to continue to eat a food they do not like. Children have a natural preference for sweeter foods and will tend to choose them over other more nutritionally dense choices. Reluctance to try new foods is a common developmental stage that all children go through during their early years when they are gaining more control over feeding themselves. Encouraging new foods repeatedly is important to build upon their dietary intake. A new food should be introduced between 8 and 15 times for adequate exposure before a caregiver can determine the child will not accept the new food. The variety of preparations allows increased acceptance of foods. Due to a child's natural preference to choose sweet foods such as fruits, a useful strategy to increase consumption of often less preferred vegetables includes offering them first. After a child has eaten vegetables, fruits or other foods can be given to complete the meal.

It is essential that caregivers do not cater completely to the child to encourage picky eating habits, otherwise the child will continue with those behaviors. This again can cause stress in caregivers due to concerns of children not eating enough. Appropriate growth as assessed by growth charts can be very reassuring. Caregivers should try to ignore negative feeding behaviors unless there is concern for the safety of the child. Caregivers should always be present during eating times and distractions including television and screens should be limited.

Pediatric Feeding Disorder

It is important to distinguish between picky eating and a pediatric feeding disorder. A pediatric feeding disorder has been defined as impaired oral intake that is not age-appropriate, and is associated with medical, nutritional, feeding skill, and/or psychosocial dysfunction. From a nutrition perspective, picky eaters typically do not have any nutrition dysfunction. When children with feeding problems develop nutrition dysfunction as determined by malnutrition, significantly impaired dietary diversity, or the need for high-calorie beverage supplementation/tube feeding, then they have a pediatric feeding disorder. Other forms of dysfunction include: medical (aspiration or aspiration pneumonia), skill-based (where a child needs to be fed in a manner that is atypical for age [e.g., only pureed food to a 3-year-old]), and psychosocial (e.g., extreme anxiety during feeding in the child or the caregiver). Pediatric feeding disorders require the care of a multidisciplinary team including a dietitian, physician, speech-language pathologist, and psychologist.

SCHOOL-AGED CHILDREN

As children enter into school age, they become more capable of making their own food and beverage choices and are able to decide what to eat. The structure of the day is still present with standard mealtimes as designed by their caregivers; however, they have more access to obtaining their own snacks throughout the day. Another change at this time is the routine and structure of the day. Children are in school and have a different schedule than at home with a specific time for meals. While at home, continuing with structured family meals and limiting television or screen time during meals is helpful as children continue to strengthen their eating habits. For the dietitian, it may be difficult to determine the nutrient intake of foods consumed at school as well as to provide nutrition interventions that can be implemented at school.

ADOLESCENTS

Adolescents become even more independent with choosing their food and beverages. The environments in which meals are consumed are varied; it is still important to encourage family dinnertime around a table. Teens are also impacted by peer influences which can shape dietary preferences and encourage unhealthy habits or exploration of alternative diets. Increased dining out and fast-food consumption with more independence and accessibility can increase consumption of large portion

sizes of energy-dense and low nutrient-density foods. This is also a common age for special dietary practices to be established including vegetarianism and veganism. Caregivers should be aware of dieting and hiding foods with concern for eating disorders that occur more frequently in this age group (Chapter 22). Adolescents are more preoccupied with their weight and at risk for disordered eating habits. Alcohol and caffeine intake often is initiated during adolescence. Due to these factors, adolescents tend to have the greatest risk of dietary inadequacy compared to any other age group.

DIVISION OF FEEDING RESPONSIBILITY

Ellyn Satter has developed a Satter Division of Responsibility in Feeding that develops a partnership between caregivers and their children with meal times. Caregivers are responsible for providing the food (healthy and age-appropriate) and context in which meal time is set, while children are allowed to learn to feed themselves and decide how much or if to eat. This allows children to develop an understanding of the structure of meals as well as to help understand when to stop eating based on being satisfied and can be applied at all ages.

Creating a setting with mealtimes as a family as well as sit-down snacks allows children to understand the schedule. This allows caregivers to focus on creating meals that are healthy and well balanced and allows the child the autonomy of eating the correct amount and to develop their own relationship with food and choices. The foundation of this principle relies on a structure with scheduled mealtimes focused on sitting down to eat for both meal and snacks throughout the day. This can be difficult in a busy household, but it is important as a child develops his relationship with food. Eating regularly is important for adult health and is important to establish at a young age.

This method also encourages caregivers to learn to trust their child and to not create negative stigmas associated with mealtimes. Children are individuals and will take variable amounts of time to adjust to meals and contents. Reducing pressure and anxiety around mealtimes allows children to learn to explore. This can help to prevent picky eating as well.

MYPLATE

The US government has developed MyPlate which is a consumer translation of the Dietary Guidelines for Americans. MyPlate allows for cultural and traditional values to be reflected in mealtime along with personal preferences. The goal is to have half a plate of fruits and vegetables focusing on whole foods as opposed to alternatives such as juices. Variety is very important both for nutritional value and to encourage children to be open to new choices and options. The rest of the plate should include whole grains and protein that again should be varied. Foods and beverages with less added sugars, saturated fat, and sodium are also important. Dairy products including milk and yogurt should be low fat or fat free (Figure 6.1).

MyPlate is a basis for building an optimal diet for children and adults. It is aimed at the general population rather than healthcare providers and provides a nice visual representation of different food groups and portion sizes (Table 6.1).

NATIONAL SCHOOL LUNCH PROGRAM

The National School Lunch program and the School Breakfast Program provide low-cost meals for greater than 5 million children nationwide. Free and reduced-price meals are available for children that meet income guidelines. These programs provide age-based portion sizes and appropriate amounts of vegetables, fruits, and grains. There are minimum and maximum energy levels set with appropriate portions based on age and gender (Table 6.2). At breakfast, a fruit must be chosen, and at lunch it can be a fruit or a vegetable (Table 6.3). Bread and grain offerings should be whole grain. Milk options should be fat free if there is a flavor, and plain milk should be fat free or 1% fat.

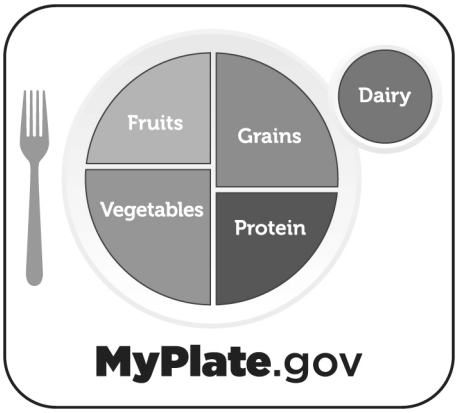

FIGURE 6.1 MyPlate.

TABLE 6.1
Recommended Serving of Food Groups

Food Groups	12–23 months	2–3 years	4–8 years	Age 9–13 years	Age 14–18 years
Dairy (cups/day)	1.7–2	2–2.5	2.5	3	3
Protein (oz/day)	2	2–4	3–5.5	4–7	5–7
Grains (oz/day)	1.75–3	3–5	4–6	5–10	5–10
Fruits (cups/day)	0.5–1	1–1.5	1.5–2	1.5–2.5	1.5–2.5
Vegetables (cups/day)	0.7–1	1–1.5	1.5–2.5	1.5–3.5	2–4

Source: Adapted from United States Department of Agriculture (choosemyplate.gov).

TABLE 6.2
National School Lunch Program

	Preschool	Grades K-5	Grades 6–8	Grades 9–12
Food Group		**Minimum per day**		
Fruit (cups)	¼	½	½	1
Vegetables (cups)	¼	¾	¾	1
Grains (ounce equivalents, unless otherwise noted)	½ Slice or ¼ cup	1	1	2
Meat/meat alternatives (oz)	1 ½	1	1	2
Fluid milk (cups)	¾	1	1	1
Minimum-maximum energy (kcal)	–	550–650	600–700	750–850

Source: Adapted from US Department of Agriculture National School Lunch Program Meal Pattern Chart.

TABLE 6.3
National School Breakfast Program

	Preschool	Grades K-5	Grades 6–8	Grades 9–12
Food Group		**Minimum per day**		
Fruit (cups)	½	1	1	1
Vegetables (cups)	May count towards fruit requirement			
Grains (ounce equivalents, unless otherwise noted)	½ Slice or ¼ cup	1	1	1
Meat/meat alternatives (oz)	May substitute for grains three times per week	May count towards grains requirement		
Fluid milk (cups)	¾	1	1	1
Minimum-maximum energy (kcal)	–	350–500	400–550	450–650

Source: Adapted from US Department of Agriculture School Breakfast Program Meal Pattern Chart.

COMMON NUTRIENTS OF CONCERN

Calcium is a micronutrient that is important for bone formation and calcification, muscle function and contraction, and blood clot formation. Calcium is found in dairy products. Calcium is added to many plant-based milks and is found in smaller amounts in some green vegetables including kale and broccoli. If children are unable to meet their calcium needs from food alone, calcium supplements may be needed to meet their needs.

Vitamin D helps intestinal absorption of calcium and phosphate and is important for bone development and strength. Vitamin D is found in dairy products including fortified milk, as well as fish and eggs. Vitamin D is also absorbed via the skin from sunlight. Patients with low vitamin D intake, and especially those with low vitamin D laboratory values, will benefit from vitamin D supplementation. Vitamin D deficiency presents with rickets or osteomalacia, with classic exam findings including frontal bossing, bowed legs, and costochondral beading.

Teenagers following a restricted diet, such as a vegan diet, may be at risk of vitamin B_{12} deficiency. Vitamin B_{12} (cobalamin) is important for making DNA through recycling tetrahydrofolate and is found in many meats and fish with smaller amounts in milk and eggs. Consider vitamin B_{12} supplementation for children following a vegan diet.

Iron is a part of hemoglobin and necessary for oxygen transport by the red blood cells. Iron is found in meat products and iron-fortified foods such as cereals. Toddlers are at higher risk of iron deficiency, especially if they drink large amounts of milk (which interferes with iron absorption) and consume low volumes of meat and iron-fortified foods. Children following a vegetarian or vegan diet are also at risk of iron deficiency if iron-rich foods are not part of the daily diet. Iron deficiency is associated with a microcytic anemia and can result in pallor or fatigue.

Water intake is very important to ensure adequate hydration. Intake is from consumption of various foods and beverages. Water loss occurs through excretion of urine and stool as well as insensible losses such as evaporative loss through skin and respiratory systems.

BEVERAGES

Milk and water are the recommended beverages for toddlers though adulthood. Milk is a good source of protein and calcium and is an important part of the diet to help meet nutrient needs. If a child is lactose-intolerant, lactose-free milk can be substituted. For children with a milk allergy,

fortified soy milk is recommended due to its comparable nutrition profile to cow's milk. Other milk substitutes are available but provide varying amounts of protein, vitamins, and minerals (See Chapter 15).

Juice is a common beverage offered to children. However, juice (even 100% fruit juice) is not a necessary part of the diet. Children should receive the majority of their recommended fruit servings from whole foods. If juice is included in the diet, it should not be offered until 2 years of age and then limited to 4 oz/day for younger children and no more than 10 oz/day for adolescents.

Sugar-sweetened beverages are not necessary in a child's diet. These include fruit drinks (not 100% juice), soda, sports drinks, and energy drinks. Sugar-sweetened beverages contribute to overall added sugar intake, do not contribute to meeting food group goals, and are a source of added energy intake.

NUTRITION MANAGEMENT

Nutrition Assessment

When doing an assessment of nutrition status of children, it should always begin with a detailed history of their typical food and beverage intake. Gathering this information allows caregivers and children to understand normal eating habits at home, and most of this information is gathered through interview.

Specific questions to ask during the assessment include the types and varieties of food consumed, including preparation method (baked, grilled, fried, etc.). Asking about where the child eats and the mealtime setting and behaviors is also important. Diet history is helpful by identifying a 24-hour food recall or keeping a food record for 3–7 days. In addition to the actual dietary intake, asking about different familial structures, religious associations, cultural practices, and beliefs is important. Medications, including various herbal supplements or vitamins, are necessary as part of the history. Identifying access to food and any food assistance program is also needed to better understand the food environment a child has at home.

In addition to obtaining a detailed history through interview, observation of a child can tell a lot about the nutritional status. This comes from the visual and/or physical assessment of the muscle content, skin and hair quality, and how the child is acting in the exam room (Chapter 2). Use of the medical record and notes from other providers are also helpful. Measurements are needed for weight and length or height, and monitoring the trend over time helps to identify over- or undernutrition (Chapter 1).

Standard screening for nutrition status, including measuring weight and length or height, and plotting on growth charts along with BMI, at every medical visit is important as well as routine lab monitoring done by the primary care physician. Testing for anemia is done at age 1 year and then subsequently repeated if a risk assessment is completed and there are concerns. Lipid screening for dyslipidemia is done first between ages 9 and 11 years and then repeated between ages 17 and 21 years; however, it can be done at any age above 2 years if there are concerns. Vitamin D testing is commonly done in patients who are at risk of deficiency including patients with diets low in vitamin D foods, obese children, and those with darker skin.

Nutrition Diagnosis

Common nutrition diagnoses in toddlers, children, and adolescents include:

- Inadequate energy intake
- Inadequate vitamin intake (specify)
- Inadequate mineral intake (specify)
- Undesirable food choices

- Overweight/obesity
- Malnutrition (undernutrition)
- Inadequate fluid intake

Malnutrition occurs when there is an imbalance of essential nutrients, or a nutritional deficiency – either from inadequate intake or increased requirements and needs. Children with malnutrition will often have lethargy and fatigue and may present with alterations in psychological function. Monitoring for malnutrition includes following serial weight and height measurements and should also include calculating and plotting the weight for length or BMI. It is important to recognize malnutrition in children, as it is associated with higher morbidity and mortality, and may lead to electrolyte disturbances and an increased risk of infection (Chapter 10).

Obesity is defined as an excessive accumulation of body fat and has a high risk of morbidity and mortality. Unfortunately, obesity is very common in the USA. One third of children and adolescents are classified as overweight or obese and is based on BMI. In children age 2–20 years, a BMI percentile is plotted and should be used for assessment. A BMI between 85th and 95th percentiles for age and gender is considered overweight, and a BMI greater than 95th percentile for age and gender is classified as obese. This is important to monitor over time. In children with rapidly rising BMI percentiles (even before these thresholds are reached) or once a child is classified as overweight, interventions can be done to improve the health of the child. This can include dietary changes as well as increased physical activity and in certain situations may benefit from various programs and clinics for obesity (Chapter 25).

Nutrition Intervention

Oral feeding starts during the first year of life with table food introduction. As children get older, they become more autonomous with their feeding habits and are in charge of what food and beverages they consume. Nutrition education is important to incorporate at all well-child visits and, if needed, at other visits with healthcare providers. Nutrition education on what is appropriate intake for adequate growth and energy requirements should first be addressed with the caregivers of infants. As children get older, they should start to engage in conversations and be able to discuss food preferences and intake more independently.

MyPlate may be used to educate children on age-appropriate portion sizes and discussion of food groups. Specific recommendations should be made for areas identified in the nutrition assessment, including calcium and iron intake.

In settings where there is concern for undernutrition or lack of weight gain, nutritional supplements such as high-energy nutrition shakes are used to help with weight gain. This can be helpful with growth and should be an addition to what they are eating, not to replace daily nutritious meals.

When there is concern for inadequate nutrition or poor growth, referral to pediatric subspecialists is warranted, including, but not limited to, a dietitian. If there is concern for poor weight gain or a malabsorptive process, referral to a pediatric gastroenterologist can be helpful. With concerns for overweight or obesity, referral to a pediatric gastroenterologist or a pediatric endocrinologist may be beneficial. Endocrinology referrals should also be considered in the setting of stunting, or poor linear growth.

Monitoring and Evaluation

Monitor growth regularly and plot on the appropriate growth chart to ensure a patient is following their growth pattern. Patients deviating from their growth pattern or with weight gain or loss outside of recommendations for age may require nutrition reassessment (Chapter 1).

A healthy, well-balanced diet is important for children. As children grow and develop, their eating patterns and feeding skills change. It is important to establish good eating habits early and

to address any feeding concerns quickly to prevent future problems. Childhood is a time of rapid growth and development, and adequate nutrient intake is essential in promoting development and preventing nutrient deficiencies.

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7 Enteral and Parenteral Devices

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CONTENTS

Managing nutrition support therapy is ideally orchestrated by a multidisciplinary team of nutrition support clinicians from the following disciplines: dietitian, pharmacist, physician, nurse, speech-language pathologist, occupational therapist, psychologist, and social worker.

The multidisciplinary nutrition support team (NST) evaluates the child's clinical condition, the indications for nutrition support therapy, and the anticipated duration of nutrition support therapy to be able to determine the most appropriate enteral or parenteral access device.

In 2013, there were over 400,000 patients receiving home enteral nutrition (EN) via enteral access devices (EADs), which is just over 1/1,000 U.S. inhabitants. Of these, almost 200,000 were pediatric patients. At the same time, there were ~25,000 patients receiving home parenteral nutrition (PN), which is 0.08/1,000 U.S. inhabitants. Of these, ~4,000 were pediatric patients. In 2001, it was estimated that 11,000 gastrostomy tubes are placed annually in U.S. children <18 years of age. One study reported that 24% of neonatal and pediatric hospitalized patients had an EAD.

ENTERAL ACCESS DEVICES

Short-Term Enteral Access Devices

Nasogastric (NG), orogastric (OG), and nasojejunal (NJ) tubes are classified as short-term (or temporary) EADs. NG tubes are inserted through the nares and the tip of the tube is in the stomach. OG tubes are inserted through the mouth with the tip of the tube in the stomach. NG and OG tubes provide nutrition, hydration, and/or medication directly into the stomach. In contrast, NJ tubes are

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inserted through the nares with the tip of the tube in the jejunum. NJ tubes bypass the stomach and provide nutrition, hydration, and/or medication directly into the small intestines (jejunum). Traditionally, NG tubes are placed at the bedside and NJ tubes are placed under fluoroscopy.

When the child's clinical condition warrants consideration for short-term EN, a multidisciplinary NST should assess the child's clinical condition to evaluate if there are contraindications to non-surgical tube placement. These short-term EADs are typically nasal or oral tubes which can provide enteral access during the initial 4–6 weeks and up to 12 weeks. These tubes are considered unsafe in patients with severe oro-maxillary congenital defects, or patients with tracheo-esophageal fistula, esophageal atresia, or basilar skull fracture as these conditions make blind tube placement unsafe. Similarly, trauma or burns to the face or pharynx can be contraindications to short-term EADs. Oncology patients experiencing pharyngeal or esophageal mucositis or low platelet counts warrant due diligence in weighing the benefits and risks associated with short-term EAD placement.

An NG tube is passed through the nose and into the stomach. An OG tube is passed through the mouth and into the stomach. The most common indication for using an OG tube is nasal trauma or birth defect and endotracheal intubation. These patients are typically in an intensive care setting where a trained nurse places the OG tube with the neonate or child being sedated.

Both OG and NG tubes are used when gastric emptying is adequate to allow EN and gastric contents to leave the stomach. Gastric feeding is the preferred method for initial feeding for most children. However, if there are concerns about aspiration of gastric contents into the lung or signs of delayed gastric emptying, a trans-pyloric tube (with the tip in the jejunum) may be indicated.

An NJ tube is a trans-pyloric tube. It is passed through the nose and into the jejunum. It is placed by an interventional radiologist under fluoroscopy or, in some cases, by a trained nurse at the bedside. The multidisciplinary NST then reassesses the child's clinical condition to evaluate if a longer-term EAD is needed.

Long-Term Enteral Access Devices

When the child's clinical condition is anticipated to require EN for a duration longer than 4–12 weeks, a more secure and more stable type of EAD is warranted. Long-term, or durable, EADs are placed through the skin (percutaneous) into the digestive system, using either endoscopic, surgical, or interventional radiologic techniques. The most common long-term EAD is the gastrostomy (G) tube. Other long-term EADs are the gastrojejunostomy (GJ) and jejunostomy (J) tubes. Progression of oral-motor skill development and oral intake should be included in the enteral nutrition plan when medically appropriate, despite dependence on an EAD for nutrition support therapy. The multidisciplinary NST should continue to reassess the child's clinical condition. When deemed appropriate, the team should encourage advancing oral feeding and weaning off EN, if indicated. Table 7.1 compares short-term tubes with long-term tubes in terms of clinical indications, advantages, and disadvantages.

Balloon Versus Non-Balloon Enteral Access Devices

This tube classification refers to the type of internal bolster that keeps the EAD in the correct place. Balloon gastrostomy tubes have an inflatable balloon that keeps these tubes in place; this makes them the most preferred EAD since the balloon facilitates easy replacement at the bedside and in the home setting. The use of non-balloon tubes is limited to situations where the balloon fails often or the balloon itself is too close to the pylorus and intermittently prevents gastric emptying, therefore resulting in vomiting and feeding intolerance. Figure 7.1 depicts balloon gastrostomy tubes and non-balloon tubes. Table 7.2 compares balloon gastrostomy tubes with non-balloon tubes in terms of indications, advantages, and disadvantages.

TABLE 7.1
Short-Term Devices Versus Long-Term Devices: Clinical Indications, Advantages, and Disadvantages

Enteral Nutrition Access Device	Indications	Advantages	Disadvantages
Short-term enteral access device (nasogastric [NG], orogastric [OG], nasojejunal [NJ])	• Duration anticipated 4–6 up to 12 weeks • Temporary	• Can be placed at the bedside • NG tubes can be replaced by a trained caregiver • No surgery required • No sedation required • Can be readily discontinued • Some older adolescents will opt for an NG tube (for nocturnal feeds) to avoid body image issues with a G tube. They self-insert their tube every night	• May be accidentally pulled • Dislodgement leads to interruption of feeds with consequent loss of energy and/or hydration • Excess retching or vomiting can cause dislodgement • May require X-ray to verify placement • NJ tubes require placement by a trained clinician and may require fluoroscopy
Long-term enteral access device (gastric [G], gastrojejunal [GJ], jejunal [J])	• Duration anticipated to be long-term (>4–12 weeks)	• More stable than short-term devices • Lower likelihood of dislodgement and hence or loss of energy and/or hydration	• Initially requires surgery and anesthesia to be surgically placed • May have surgical complications associated with initial placement

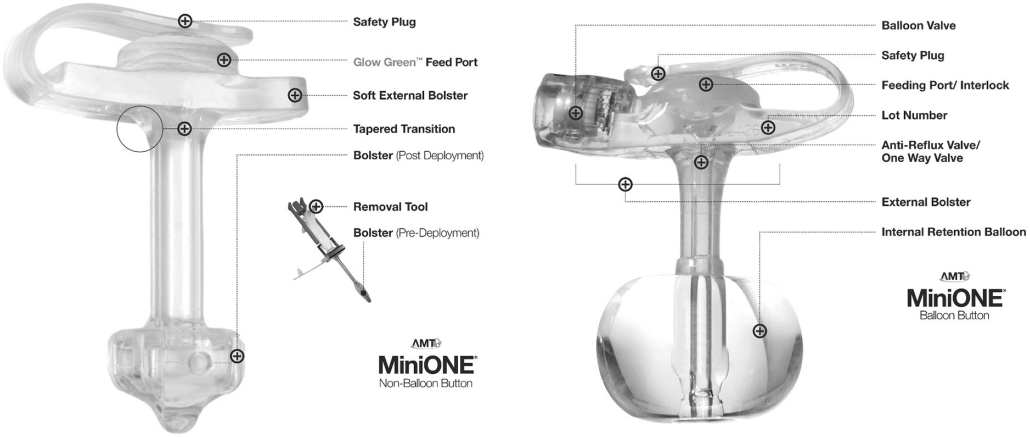

FIGURE 7.1 Balloon gastrostomy tubes and non-balloon tubes. (a) A non-balloon gastrostomy tube and (b) a balloon gastrostomy tube. (Images courtesy of Applied Medical Technology, Inc.)

TABLE 7.2
Balloon Gastrostomy Tubes Versus Non-Balloon Tubes: Indications, Advantages, and Disadvantages

Enteral Nutrition Access Device	Indications	Advantages	Disadvantages
Balloon gastrostomy tube	• Any age	• Balloon facilitates bedside replacement • A trained caregiver can replace the tube • Replacement involves minimal trauma, minimal discomfort, or bleeding • Can be routinely upsized as the child grows	• There may be possible risk of balloon obstructing the pylorus in neonates • If excess retching/vomiting, there may be higher chances of frequent balloon breakage
Non-balloon gastrostomy tube	• Children whom the balloon was noted to obstruct their pylorus on contrast imaging • Patients who have frequent balloon failures from excess retching/vomiting	• Lower dislodgement risk • May last 8–12 months	• Higher skin breakdown risk if not resized during growth spurts • Caregivers cannot replace • Difficult to replace at bedside and ideally sedation is used during replacement • Replacement may involve higher risk of trauma, discomfort, or bleeding

High-Profile Versus Low-Profile Enteral Access Devices

This classification refers to the external part of the EAD that is above the skin. A low-profile gastrostomy tube refers to the device that has its outer bumper at skin level. It often is referred to as a "button". Figure 7.2 depicts the high-profile and the low-profile tubes.

The high-profile tube is a long tube extending above the gastrostomy site and visible above the skin. While caregivers tend to prefer low-profile tubes (buttons) over high-profile tubes, the latter allow for more skin protection by providing flexibility to adjust the external bolster above the skin level to accommodate for abdominal distension or a large body habitus. Table 7.3 compares high-profile tubes with low-profile tubes in terms of indications, advantages, and disadvantages.

Gastric Versus Trans-Pyloric Enteral Access Devices

This classification refers to the location of the tube tip where enteral feeds are delivered. A gastric enteral access device delivers EN and enteral medications into the stomach. Examples include the NG tube, the OG tube, and the G tube. A trans-pyloric EAD delivers enteral feeds beyond the stomach. Examples include NJ tubes, the GJ tubes, and J tubes. Table 7.4 compares gastric tubes with trans-pyloric tubes in terms of indications, advantages, and disadvantages.

Enteral Access Device Issues and Recommended Troubleshooting

Leakage at Gastrostomy Site

Leakage around the gastrostomy tube site is one of the most common symptoms that caregivers describe. This may occur due to an overstretched stoma from excessive tube pulling, a deflated

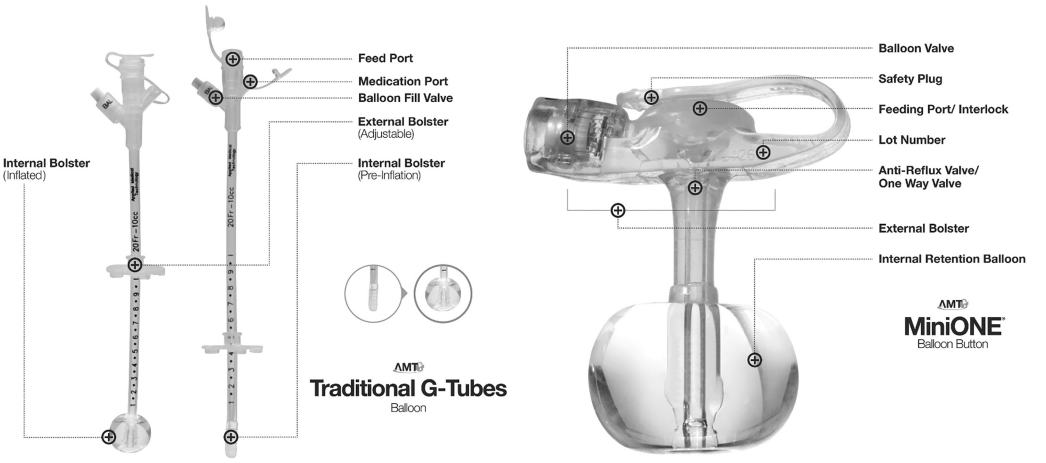

FIGURE 7.2 High-profile and low-profile tubes. (a) A high-profile gastrostomy tube and (b) a low-profile gastrostomy tube. (Images courtesy of Applied Medical Technology, Inc.)

TABLE 7.3
High-Profile Tubes Versus Low-Profile Tubes: Indications, Advantages, and Disadvantages

Enteral Nutrition Access Device	Indications	Advantages	Disadvantages
High-profile tube	• Anterior abdominal wall thickness >5 cm • Intermittent abdominal distension • Fluctuations in weight • Older teen, adolescent, adult • Large body habitus	• Adjustable outer disk/bolster is wide and cushioned • The silicon grade of the bolster is skin-friendly • The balloon facilitates bedside replacement by the trained clinician • There is lower risk of skin breakdown since the adjustable disk facilitates frequent resizing	• Long tube is visible above skin level • There is a risk of accidental avulsion or trauma if tube catches or snags on something • Patients may pull on the tube • Patients with larger body habitus likely to require fluoroscopy-guided replacement • Caregivers are instructed to not replace it at bedside and to have a trained clinician replace it
Low-profile tube	• Anterior abdominal wall thickness <5 cm • Any age	• Less visible under clothes • Preferred for positive body image • Balloon facilitates bedside replacement by the trained caregiver • Lower dislodgement risk	• No adjustable outer disk/bolster • Requires tube length resizing during growth spurts or significant weight loss • There is higher risk of skin breakdown if not appropriately sized in comparison to the high-profile tube

TABLE 7.4
Gastric Tubes Versus Trans-Pyloric Tubes: Indications, Advantages, and Disadvantages

Enteral Nutrition Access Device	Indications	Advantages	Disadvantages
Gastric tube	• Any age	• Most tubes can be inserted at bedside as well as by trained caregivers	• Risk of aspiration compared to trans-pyloric feeds • There is risk of not tolerating feeds in dysmotility or gastroparesis
Trans-pyloric tube	• Recurrent aspiration • Chronic or worsening lung disease • Duodenal hematoma • May be considered in severe acute pancreatitis, depending on clinical setting	• There is lower risk of aspirating feeds, but risk is not entirely eliminated • Better chances of tolerating feeds in gastroparesis or dysmotility • May last 4–6 months	• Cannot be exchanged at the bedside by the caregiver • With surgically placed jejunostomy tubes, there is risk of volvulus around jejunal segment that contains the tube • For nasojejunal and gastrojejunal tubes, there is a risk of dislodgement back into stomach or kinking of tube • There is risk of clogging • Requires fluoroscopy-guided interventional radiology and/or endoscopic replacement

balloon, feeding intolerance, or a delay in gastric emptying. Another common cause is scoliosis of the spine, which leads to the tube sitting above the skin at an angle that prevents a proper seal at the junction of the tube with the skin. Rarely, the leak is severe enough to cause the child to lose large volumes of enteral formula or gastric juices. Consistent leakage from the site may contribute to malnutrition, dehydration, skin breakdown, and electrolyte abnormalities.

While there are many ways to attempt remedy a leaking tube, it is never appropriate to place a larger diameter tube as that will simply enlarge the stoma and worsen leakage. The amount of water in the balloon should be checked. If the water in the balloon is low, it should be inflated to the recommended amount. If the leak is noted to occur after bolus feeds, a slower feeding pump rate may be tried or a prokinetic agent may be added to help the stomach empty more effectively. Venting the tube prior to and after feedings may also be effective. Finally, a tube change may be warranted. Work with the NST to determine the cause of tube leakage and the best course of action to prevent further leakage.

Granulation Tissue at Gastrostomy Site

Granulation tissue is excess tissue that appears around the stoma site. Some children are more prone to granulation tissue. This complication is more likely to occur with increased movement and pulling on the tube. It is further exacerbated by excess moisture around the site. If not treated, granulation tissue may become infected or may continue to increase in size, causing bleeding and discomfort. If the granulation tissue develops an epithelialized layer above it, this will leave a raised ridge above the skin. For these reasons, it is important to manage and eliminate the development of

granulation tissue. To minimize the chances of developing granulation tissue, the extension tubing should be disconnected from the EAD when not in use, and the peristomal skin should be kept clean and dry with a moisture wicking dressing. Depending on the severity, granulation tissue may be treated by a provider or nurse with moisture wicking dressing, topical medication, or silver nitrate. Work with the NST to determine the best course of treatment for granulation tissue.

Clogged Enteral Access Devices

Prevention of EAD clogging or occlusion is of paramount importance to minimize interruption of feeds, fluids for hydration, or enteral medications. This is best achieved by properly flushing the tube after medication administration and, whenever possible, separating medications from feeds. Tubes should be flushed with water after every bolus feed and at least every 8 hourly with continuous feedings. Prompt attention to pump alarms is also important; if an occlusion is discovered, it should be dealt with as quickly as possible. Small syringes create high intraluminal pressures and may damage the EAD. In order to reduce the risk of rupturing the structure of the EAD, the largest functional syringe size should be used; 30–50 mL syringes are recommended. Use 15–30 mL water, in a 50 mL syringe, and a pull/push action. Other liquids that used to be used including carbonated beverages, cranberry juice, or other solutions with an acidic pH lack evidence and should not be used.

Factors that can contribute to tube clogging include the use of long tubes, small bore tubes, tube composition and lack of routine flushing especially in trans-pyloric tubes, drug-nutrient interactions, or drug-drug interactions. Routine flushing with water is considered the best method to prevent tube clogging and the use of a pulsatile motion with a large syringe of water is the first-line treatment to unclog tubes. Polyurethane tubes have been shown to be better at maintaining patency than silicone tubes. Another contributing factor to tube clogging is checking gastric residual volumes where acidic fluid is aspirated into the tube mixing with formula in the narrow bore tube leading to the coagulation of formula.

The inability to flush the tube does not always mean that it is clogged. Tubes can kink and stop formula or medication administration. Troubleshooting involves placing a syringe on the end of the tube and attempting to instill water. If unable to instill water, gently pulling the tube back 1–1.5 cm while simultaneously attempting to instill water will often unkink the tube.

Other preventive measures to maintain tube patency involve careful attention to detail when giving medications. It is not recommended that medications be added to enteral formula. Flushing with water before and after each medication is administered is recommended but not always done in neonatal or pediatric practice due to fluid restrictions. If flushing with water is done, it is performed using the least amount of water to clear the tube. Tablet medications should be finely crushed and dissolved in water prior to administration. Enteric-coated or extended-release medications should never be crushed. Trans-pyloric tubes must be flushed every 4–6 hours with enough water to clear the tube. Medications should be scheduled in such a way to avoid the administration of multiple medications at one time if possible. Routine checking of gastric residual volumes should be avoided.

Dislodgement of Enteral Access Devices

While new, or primary, EADs often require replacement by the medical team, some established EADs can be replaced by trained caregivers. Consult the NST to determine if an EAD can be replaced at home or requires medical intervention. A description of the action plan for dislodgement based on the type of EAD is described in Table 7.5.

PARENTERAL ACCESS DEVICES

Like EADs, when determining the type of parenteral access device (choice of central vascular catheter) to be utilized to provide PN, the multidisciplinary NST evaluates the child's clinical condition, indications for PN, and the anticipated duration of nutrition support therapy.

TABLE 7.5
Action Plan of Tube Dislodgement Based on the Type of Enteral Access Device (EAD)

Dislodged Tube	Intervention
Nasogastric tube	Caregiver is trained to re-insert nasogastric tubes and verify placement
Low-profile balloon tube	Caregiver can re-insert the tube, but if the re-insertion faces resistance, bleeding, or inability to aspirate gastric contents after placement, have the child seen at the hospital
Low-profile non-balloon tube	
High-profile balloon tube	Caregiver should have the child seen at the hospital so that an EAD can be inserted at the bedside and placement be verified
All trans-pyloric tubes	

Peripheral venous access devices can be used to provide hydration, some intravenous medications, and partial PN. However, the provision of complete parenteral nutrition requires central venous access. Central venous access delivers PN to the distal vena cava or the right atrium (Figure 7.3). This central venous access ensures that caloric provision is optimized, since the provision of PN through a peripheral intravenous catheter limits the osmolality of the parenteral nutrition solution and hence the energy that can be provided.

Types of Central Lines and Indications for Each Type

Non-tunneled catheters are intended for short-term use and are often used in the hospital setting. They are typically placed at the bedside. Peripherally inserted central catheters (PICCs) often have an exit site in an extremity (antecubital or femoral), which may impact freedom of movement (Figure 7.3). For other non-tunneled catheters, the exit site may be at the jugular or subclavian (Figure 7.4). PICCs are often placed by interventional radiology and can be used for several months; they are often a good choice for children that require PN for up to several months.

Tunneled catheters are intended for long-term PN (Figure 7.5). They are placed in the operating room or interventional radiology suite and have a lower infection risk compared to non-tunneled catheters.

Implanted ports are another type of central access device, where the exit site is placed under the skin. They are not intended for daily PN administration. Instead, they are often used for patients requiring intermittent access such as patients with intravenous chemotherapy.

Table 7.6 compares the types of PN vascular access devices in terms of their clinical indications, advantages, and disadvantages.

Preventing Central Vascular Catheter infections

Catheter-Related Blood Steam Infection (CRBSI) is the most common complication in children receiving PN, leading to prolonged hospitalizations and added cost, risk of developing microbial strains that are multidrug resistant, risk of losing central vascular access, and mortality. CRBSI is defined as bacteremia or fungemia in a patient who has an intravascular device and >1 positive blood culture result obtained from the peripheral vein with clinical manifestations of infection (e.g., fever, chills, and/or hypotension) and no apparent source for the infection other than the central venous catheter.

Central Line-Associated Blood Stream Infection (CLABSI) is the term used by the Centers for Disease Control and Prevention's (CDC's) National Healthcare Safety Network (NHSN) and is defined as primary blood stream infection in a patient that had a central line within the 48-hour period before the development of the infection and is not related to an infection at another site.

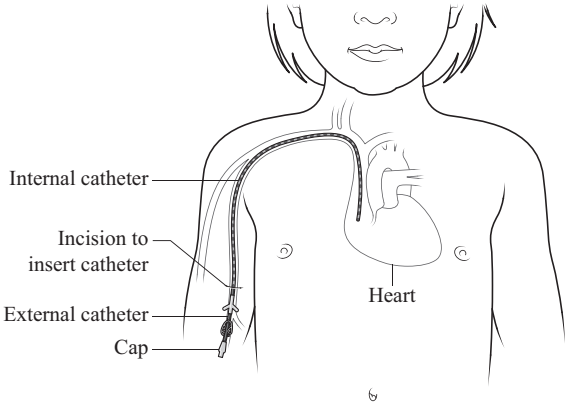

FIGURE 7.3 Peripherally inserted central catheter.

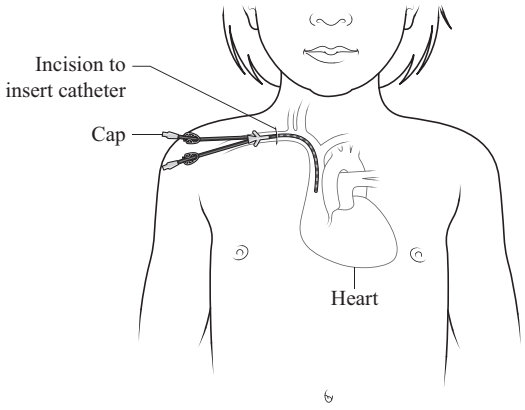

FIGURE 7.4 Non-tunneled catheter.

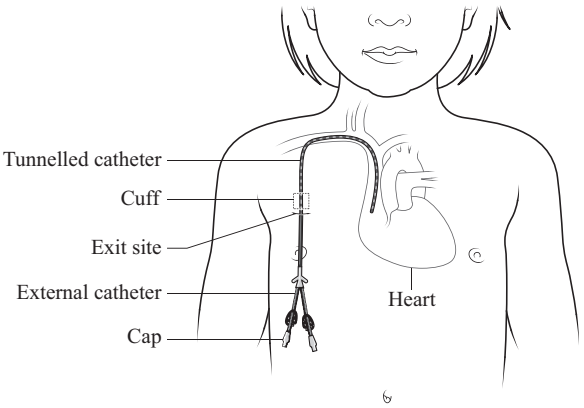

FIGURE 7.5 Tunneled catheter.

TABLE 7.6
Types of Parenteral Nutrition Vascular Access Devices, Clinical Indications, Advantages, and Disadvantages

Parenteral Nutrition Vascular Access Devices	Indications Clinical Setting	Advantages	Disadvantages
Non-tunneled catheters (Figures 7.3 and 7.4)	• Short-term, acute setting • Jugular, subclavian, antecubital, femoral • Peripherally inserted central catheter (PICC)	• Lower cost • Easy removal and exchange over guide wire • Placed at the bedside	• Non-repairable • Requires sutures • No cuff • Higher infection risk (exchange over guide wire) • Antecubital may impact arm freedom of movement
Tunneled (Figure 7.5)	• Long-term, home care • Percutaneous jugular, subclavian, cephalic • Subcutaneous anchor, Dacron cuff facilitates fibrous ingrowth	• Repairable (silicone only) • Infection risk lower • Polyurethane more durable (not repairable) • Single lumen silicone • Ethanol-lock-compatible (silicone only)	• Operating room for placement and removal or Interventional Radiology suite
Implanted port	• Port via subclavian, jugular	• Long-term, intermittent access (not to be used for daily PN administration) • No external segment • Positive body image	• Needle dislodgement • Malfunction • Operating room or interventional radiology for placement & removal

What Is the Difference between CRBSI and CLABSI?

CRBSI is a clinical definition used when diagnosing and treating patients and requires specific laboratory testing that more thoroughly identifies the catheter as the source of the BSI, so is not typically used for surveillance purposes; while CLABSI is a surveillance definition and overestimates the true incidence of CRBSI as some blood stream infections are secondary to other sources other than the central line that may not be easily recognized. Nevertheless, both terms are often used interchangeably even though the meanings differ.

In addition to morbidity and mortality, half a million cases of CRBSIs in the USA each year are directly linked to increased costs. Preventing line infections is achieved with meticulously following central line care instructions and when indicated, the use of ethanol lock therapy in appropriate candidates.

Managing Central Venous Catheter Occlusion

Catheter occlusion is a common mechanical complication of central venous catheters. Depending on the cause, catheter occlusions may be treated with repositioning the extremity or with a medication such as a thrombolytic. Contacting the vascular access team can help troubleshoot this complication.

Enteral and parenteral access devices are necessary to provide nutrition support therapy. It is important for the dietitian to understand the patient's access device in order to recommend an appropriate nutrition prescription for that device. In general, short-term EADs (NG, OG, NJ) are to be used for 4–6 weeks, up to 12 weeks. Patients requiring longer enteral access should have a long-term access device placed. Pediatric PN is best administered using a central (not peripheral) venous catheter. The dietitian should work with the NST to troubleshoot and resolve enteral and central access device issues quickly so the patient can receive the prescribed nutrition support

therapy. For enteral and parenteral access devices in the home setting, proper training and education is required in order for caregivers to properly care for the device.

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8 Enteral Nutrition

Stephanie G. Harshman, RD, PhD and
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CONTENTS

Enteral nutrition (EN) is the use of a liquid nutrition delivered via tube directly to the gastrointestinal tract. EN is used in patients who are unable to meet their nutrient needs orally. EN is preferred over parenteral nutrition (PN) and is used in patients with a functional gastrointestinal tract. Formula selection, delivery method, and feeding schedule are dependent on the child's age, medical condition, tolerance, and location of the tube. As patients grow and develop, their nutrient needs and feeding schedules change, resulting in the need for frequent reassessment and adjustment of the EN plan. Pediatric EN may require a multidisciplinary approach including physicians, dietitians, speech-language pathologists, occupational therapists, and psychologists in order to evaluate oral feeding skills and help the child advance toward oral feedings.

INDICATION AND ADMINISTRATION OF ENTERAL NUTRITION

EN is preferred over PN due to its ability to preserve gut barrier function, mucosal integrity, and mucosal immunologic function, thus, reducing risk of infection. It causes fewer metabolic complications and is significantly more cost effective. Indications for EN are varied and include:

- Inadequate oral intake (due to poor oral feeding skills, fatigue, increased energy needs, medical causes of inadequate intake including sedation)
- Dysphagia or aspiration resulting in unsafe oral feedings
- Decreased gastric emptying (resulting in need for post-pyloric feedings)
- Malabsorption (resulting in need for continuous feedings)

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To better define inadequate oral intake, definitions include:

- Children younger than 1 year who are unable to meet ≥60%–80% of individual requirements for ≥3 days
- Children older than 1 year who are unable to meet ≥60%–80% of individual requirements for ≥5 days
- Children who meet criteria for malnutrition (Chapter 10), wasting, or stunting and are unable to meet nutrient needs with oral supplementation

EN is also appropriate in a child with developmental delay who needs to be fed orally for more than 4–6 hours/day. EN can also be an option when diet modification is used as a treatment of a disease, food intolerance, and metabolic disorders.

Enteral Nutrition Access

EN can be administered into the stomach (gastric feedings) or into the small intestines (jejunal feedings). Short-term access is used for patients requiring EN for 4–12 weeks and is delivered via a temporary tube (nasogastric [NG], orogastric [OG], or nasojejunal [NJ]). Long-term access is recommended for patients who will require EN for >4–12 weeks (gastrostomy tube [G-tube], jejunostomy tube [J-tube], or gastrojejuostomy tube [GJ-tube]). See Chapter 7 for more information about enteral access devices.

Administration

Method of delivery is dependent on the patient, condition, and location of the tube (Table 8.1). Bolus feedings are delivered directly into the stomach, typically in 60 minutes or less. Bolus feedings may be administered using a syringe, using a gravity feeding bag, or using a feeding pump set at a rate that limits feeding time to <60 minutes. Continuous feedings may be used for gastric feeding and are mandatory for jejunal feeding. They are delivered using a feeding pump, typically over a prolonged period of time (8–24 hours). Bolus delivery is contraindicated for post-pyloric tubes due

TABLE 8.1
Summary of Enteral Nutrition Delivery

Type	Indications	Advantages	Disadvantages
Bolus	• Dysphagia • Anorexia • Supplementing oral intake	• Physiologic method • Increase patient mobility • Use pump or syringe for feeds • Flexible feeding schedule • Decreased hang time resulting in reduced risk of microbial contamination	• May increase risk of aspiration • May be poorly tolerated in patients with volume intolerance
Continuous	• Delayed gastric emptying • Increased risk of aspiration • Patients with limited absorptive area (e.g., short bowel syndrome)	• Preferred method for post-pyloric feeds • Improved tolerance due to low rate • Can be provided overnight to lessen daytime interruption and increase time available for oral feeds	• Requires feeding pump • Limited mobility due to length of feeds and use of pump

to the large hyperosmotic volume delivered to the jejunum causing hyperperistalsis, cramping, and diarrhea.

Pediatric feeding plans may include a combination of bolus and continuous feedings, where bolus feedings are delivered throughout the day and continuous feedings are delivered overnight to allow the patient and family to rest.

Formula Selection

Once delivery of EN is determined, it is important to consider formula selection that is based on gut function and tolerance (Table 8.2). Significant care must be taken when selecting a formula and/or modular additives to meet estimated needs for macronutrients, micronutrients, electrolytes, and fluid. Considerations in formula selection include:

- **Age**: The age of the patient informs formula selection. Infants will require human milk or infant formula, children 1–12 years old typically transition to pediatric formulas, and children 13 years and older may transition to an adult enteral formula.
- **Medical Conditions**: Start with a polymeric formula unless patients has a medical contraindication, such as food allergy or impaired absorption that indicates need for an alternative formula.
- **Nutrient Needs**: Given that all standard formulas used post infancy are 1 kcal/mL, patients with low energy needs may benefit from a reduced-energy formula (~0.6 kcal/mL). Patients with high energy needs or fluid restrictions may benefit from an energy-dense formula (1.2, 1.5, or 2.0 kcal/mL).
- **Formula Tolerance**: Patients with intolerance to polymeric formula may benefit from transition to alternative formulas, such as partially hydrolyzed, elemental, or blenderized formulas.
- Appropriate potential renal solute load (PRSL) and osmolality.

TABLE 8.2
Pediatric Enteral Formulas

Formula Type	Protein Source	Energy (kcal/mL)	Indications	Notes
Polymeric, standard concentration	Cow milk	1.0	Normal bowel function, normal fluid requirements	May contain soy. Products available with pea protein
Polymeric, concentrated volume	Cow milk	1.5	Fluid restricted, volume intolerance	May contain soy
Polymeric, reduced energy	Cow milk	~0.6	Low energy needs	Helps meet protein, micronutrient, and fluid needs in patients with low energy requirements
Soy	Soy	1.0	Milk allergy, vegan	–
Peptide-based	Hydrolyzed milk protein	1.0–1.5	Malabsorption	Not hypoallergenic
Elemental	Amino acids	1.0	Food allergy, malabsorption	Powder formulas may be mixed to higher concentration
Commercial blenderized	Food ingredients	Varies	Normal bowel function, normal fluid requirements	Nutrient composition and ingredients vary by product. Some products are not a sole source of nutrition

Blenderized Tube Feedings

Prior to commercialization of food-based formulas, blenderized tube feedings prepared in hospital kitchens were the primary source of EN but their use declined with the advent of commercial formulas. More recently, blenderized tube feedings have gained popularity particularly in pediatric populations. Blenderized tube feedings come in two forms: commercial blenderized formulas that are prepared by a manufacturer and include real food ingredients (see Table 8.2) and homemade blenderized tube feedings that are made at home from whole foods.

Families choose blenderized tube feedings for a variety of reasons, including intolerance to commercial formulas, food allergies, purportedly improved bowel function, psychosocial reasons, or personal preference. Putative benefits of blenderized tube feedings include exposure to real foods and tastes (from burping), adherence to dietary restrictions or preferences (e.g., dairy free, vegetarian), and improved gastrointestinal symptoms. Studies have shown that blenderized tube feedings can significantly help manage some complications of EN including gagging and retching, as well as improving oral intake.

While there are benefits to blenderized tube feedings, the disadvantages must be considered. Specifically, they tend to be of thicker consistency and are best administered as a bolus feeding by syringe, especially homemade blenderized tube feedings. Additional water may need to be added to thin out the consistency, which could be a challenge for a volume-intolerant patient. Commercial blenderized tube feedings come in a variety of preparations, all with different ingredients, energy content, protein sources, and viscosity.

Homemade Blenderized Tube Feedings

Prior to initiating homemade blenderized tube feedings, there are important factors to consider:

- Age (may provide partial nutrition from foods starting at 4–6 months of age, full nutrition at 12 months of age)
- Medical stability (only medically stable patients should be initiated on them)
- Strong medical support team in place
- Dietitian support and availability
- Patient/caregiver demonstrating understanding of safe food handling practices
- Size of gastrostomy tube ≥ 14 French
- Patient tolerates bolus feedings
- Stable on a commercial formula (unless severe intolerance and blenderized tube feeding is next intervention)
- Patient/caregiver motivation to commit to preparing blenderized tube feeding
- Patient/caregiver demonstrating ability to follow recipe and instructions for preparation
- Adequate financial and material resources
- For patients with jejunal access, seek medical permission prior to initiation

The dietitian is an essential part of homemade blenderized tube feeding recipe development. Once it is determined that the patient is a candidate for blenderized tube feedings, a thorough nutrition assessment should be completed by the dietitian, including a discussion of family preferences of foods to be included or avoided. Then the dietitian can prepare a blenderized tube feeding recipe. Ideal recipes allow for variety in foods used in the blenderized tube feeding recipe, which increases dietary diversity and allows for family participation in the process.

The dietitian should utilize nutrient analysis software during recipe development. Start with MyPlate recommendations for recommended portion sizes of foods for age from all food groups, using variety when entering in nutrient analysis software. Then assess nutrient intake to determine where recipe adjustments and supplementation are needed. Common supplements used are infant and pediatric multivitamins with iron, calcium, salt, and a blend of oils to meet essential

fatty acid needs. Guides for creating a homemade tube feeding recipe are available for dietitians (Walia et al. 2016).

Homemade blenderized tube feeding is not an option for all patients receiving EN. Patients with nasogastric or nasojejunal tubes, complicated medical and gastrointestinal issues, immunocompromised individuals, and those who require frequent hospitalization may not be appropriate for a homemade blenderized tube feeding regimen. Additionally, patients who require continuous feeding are not ideal candidates since bolus by syringe is the preferred method of feeding homemade blenderized tube feedings and it is not recommended that the duration of each feed last more than 2 hours due to food safety. The process of initiating a home blenderized diet regimen can be overwhelming for the patient family but it can be safely implemented with the involvement of a dietitian to educate, assess, and monitor progress for this EN option. Frequent reassessment is required to determine patient tolerance to blenderized tube feeding and ensure adequate growth. Routine lab monitoring including standard chemistry profile, complete blood count, vitamin D, zinc, and iron panel should be considered in addition to supplemental labs based on medical condition. Finally, it is important to note that one should identify a commercial formula for emergency situations for families when traveling or when refrigeration of homemade blenderized tube feeding is not available. Patients that are not candidates for homemade blenderized tube feedings should consider commercial blenderized tube feeding products.

Initiation and Progression of Enteral Nutrition

In pediatrics, EN initiation most often occurs in the inpatient setting. EN should be started with a small volume and monitored closely to ensure tolerance. Feedings are advanced slowly to goal feeding volumes and rate. It is recommended that only one variable at a time be changed when manipulating EN. More specifically, increase volume, or concentration, or schedule of feeds, and monitor tolerance.

Formula Safety

Commercial enteral formulas are shelf stable. However, once the formula cans or bottles are opened, they are at risk of microbial contamination. Open liquid formula cans or bottles can be covered and refrigerated for up to 24 hours. The hang time for formulas depends on the type of formula (powder or liquid), the location (hospital or home), and if additives are used:

- Nonsterile powder formula and additives: 4 hours
- Sterile formula (hospital): 8 hours
- Sterile formula (home): 12 hours

ENTERAL NUTRITION IN INFANTS

Human milk and infant formula are the primary sources of nutrition during the first year of life (Chapter 5). When an infant is unable to meet his needs by mouth, these products can be provided through a feeding tube. For all infants, feeding (orally or enterally) should start on the first day of life if medically able. Initiation and advancement of EN is dependent on the individual including their age, weight, and medical stability.

Vitamin and mineral supplementation should be considered depending on the nutrition source. The two nutrients often prioritized include iron and vitamin D. For infants receiving human milk, supplementation of vitamin D is necessary and iron supplementation is indicated at 4–6 months of age (Chapter 5). Supplementation can be provided as an infant multivitamin that includes iron and vitamin D or either can be supplemented individually. For patients receiving infant formula, supplementation of vitamin D may be indicated if consuming less than 1 L of formula

per day. Additional supplementation is often not needed, unless indicated by the specific medical condition.

Use of concentrated formula or fortified human milk is often needed in the case of infants who have slow growth; have abnormal biochemical indices (e.g., low serum phosphorus, high alkaline phosphatase activity, or low blood urea nitrogen [BUN]); or require a restricted volume or have a medical condition (e.g., bronchopulmonary dysplasia, congenital heart disease) that requires increased energy density to maintain growth trajectory. See Chapter 10 for recipes for fortifying human milk and concentrating infant formula.

For all infants receiving EN, the initiation rate varies from 15 to 20 mL/kg/day (for very low birth weight infants) up to 50 mL/kg/day (for stable infants with a birth weight >2,000 *g*). This will vary further depending on medical conditions. Advancing feeds can occur as quickly as daily or after 5 days tailored to the individual infant (e.g., gestational age, birth weight, medical conditions), at a rate of 10–40 mL/kg/day. Feedings can be administered by bolus, continuously, or a combination of both depending on the patient's medical status.

Generally, bolus feedings should mimic typical infant feeding volumes schedules (Chapter 5). Recommended feeding schedules should ideally mimic that of age-appropriate peers, starting with feeds every 2–3 hours and increasing time between feeds to 4 hours with age and concomitant increase in feed volume. Feedings should ideally be administered in less than 30 minutes. For infants who may present with a feeding intolerance, length of the feed can be increased; however, it is recommended that bolus feeds be delivered in less than 60 minutes.

Continuous feedings are typically delivered over 24 hours, but may be condensed to fewer hours as tolerated to allow time off of the feeding pump. Breaks from tube feedings should not exceed typical fasting times for their age. For example, newborn infants that typically feed every 2–3 hours should have no more than 2–3 hours off the feeding pump at a time. Due to the fat loss from expressed human milk in tubing, continuous feeds are not recommended, unless severe feeding intolerance is observed.

For patients working on oral feedings, coordinated care with a speech-language pathologist is necessary to assist in timing these additional exposures either immediately prior to a feed or in between feeds. For example, if oral stimulation or exposures are a priority, bolus feedings can be provided by mouth first, with remainder given by feeding tube. Another option is to deliver overnight continuous feeds to meet nutrient needs and increase the daytime window for oral exposures. As infants transition from inpatient to home, it is important to ensure that parents receive training in feeding management and techniques including formula mixing, how they will receive formula and EN supplies, and follow-up with providers. The infant's tube feeding schedule should be adjusted to match the family's schedule at home.

Given the rapid growth of infants, tube feeding volumes need to be adjusted frequently to meet nutrient needs and fluid needs as the infant grows. In the inpatient setting, frequent nutrition reassessment is indicated and feeding plan adjustments should be made to promote continued growth. In the outpatient setting, tube feeding plans should include a schedule for advancing feeding volumes at home to promote continued growth between nutrition assessments. Although feeding advancements for infants should be tailored to the needs of each individual patient, general guidelines for advancements in infancy are as follows:

- 0–3 months: increase total volume by 1 ounce every week
- 3–6 months: increase total volume by 1 ounce every other week
- 6–9 months: increase total volume by 1 ounce every 3 weeks
- 9–12 months: increase total volume by 1 ounce every month

ENTERAL NUTRITION IN CHILDREN AND ADOLESCENTS

EN adaptations are necessary as infants transition into childhood. The most important transition is to an age-appropriate pediatric formula. Standard pediatric formulas are available for children

TABLE 8.3
Initiation and Progression of Enteral Nutrition for Children

	Bolus Feeds			Continuous Feeds		
Age	Initiation	Advancement	Suggested volume	Initiation	Advancement	Suggested volume
1–6 years	5–10 mL/kg every 2–3 hours	30–45 mL/feed	15–20 mL/kg every 4–5 hours	1 mL/kg/hour	1 mL/kg every 2–8 hours	1–5 mL/kg/hour
>7 years	90–120 mL every 3–4 hours	60–90 mL/feed	330–480 mL every 4–5 hours	25 mL/hour	25 mL every 2–8 hours	100–150 mL/hour

1–13 years of age (Table 8.3). Beyond 13 years, adult EN formulas can be considered. Standard pediatric formulas are 30 kcal/oz (1 kcal/mL) and are often milk-based and available with or without fiber. As a rule, they are gluten free and lactose free. Specialty pediatric formulas including partially hydrolyzed protein formulas are considered in cases of malabsorption or gastrointestinal impairment. Caution should be used in patients with milk allergy as these formulas will contain a small amount of milk protein. Elemental formulas are also available and indicated for multiple food allergies/intolerances, eosinophilic esophagitis, malabsorption, and history of intolerance to standard and partially hydrolyzed formulas. Although beneficial, they have decreased palatability. Commercial blenderized tube formulas are also available. The composition of these formulas varies greatly by brand. Typically, commercial blenderized formulas are higher in fiber and some may be more energy dense than standard pediatric formulas.

The palatability of pediatric formulas varies greatly. Some formulas are intended solely for enteral use, while others are intended to be used orally or enterally. Modular additives are also available to alter the nutrient composition of formulas. These products include energy supplements (from carbohydrate and/or fat), protein supplements, fiber supplements, and electrolyte solutions.

EN delivery methods, schedules, and rates for children and adolescents are patient dependent (Table 8.3). Adjustments to volume and energy density are dependent on growth trajectory and changes in energy needs due to a medical condition.

For children and adolescents transitioning home with EN, discussing the plan well before discharge is necessary to identify home caregivers and their learning style to ensure a successful and safe transition. The care team can provide insight on optimizing the feeding schedule around the child's home schedule, including medications, sleep schedule, school schedule, medical appointments, and oral feedings. The care team can further simplify the home feeding plan by preparing formula in large batches and simplifying recipes to a round number of cans/scoops for ease of preparation.

MONITORING AND MANAGING COMPLICATIONS

When a patient has transitioned home on EN, special attention needs to be paid to monitoring electrolytes, fluid, micronutrient imbalances, increased macronutrient needs, and tolerance as the feeding plan progresses. Consistent follow-up with a dietitian and medical provider (i.e., gastroenterologist) is necessary. For infants receiving EN, labs often considered include alkaline phosphatase, phosphorus, and hemoglobin as clinically indicated. In all patients receiving EN, independent of age or life stage, various symptoms/problems can occur, which are summarized in Table 8.4.

Often, the primary outcome evaluated with all pediatric patients is growth. It is important to consider appropriate time intervals between measures to best capture change. See Chapter 1 for recommended measurements and time intervals for monitoring growth in pediatrics that can be applied to patients receiving EN.

TABLE 8.4
Common Problems and Potential Strategies for Prevention and Intervention

Problem	Prevention/Intervention
Diarrhea/abdominal cramping	• Decrease rate • Recognize or avoid drugs that may be contributing to diarrhea particularly liquid medications that may contain sorbitol • Evaluate fiber content of formula, consider blenderized formula • Consider osmolality and addition of modulars • Change to a mixed-fiber containing formula • Consider peptide-based formula in patient with refractory diarrhea or malabsorption
Vomiting/nausea	• Ensure formula is at room temperature • Elevate head of bed/crib or have patient seated • Consider continuous feeding • Reduce feeding volumes and concentrate formula • Consider trial of hydrolyzed or elemental formula • Consider post-pyloric tube placement
Hyperglycemia	• Decrease rate • Use formulas with reduced sucrose
Constipation	• Ensure optimal fluid intake • Consider laxative or fiber supplement
Delayed gastric emptying	• Change to low-fat or isotonic formula • Decrease rate of infusion • Change to room temperature formula • Consider continuous feeds • Consider post-pyloric tube placement • Position patient upright
Clogged tube	• Ensure tube is flushed with water before and after every bolus feed or every 4–8 hours with continuous feeds • Check tubing size for appropriateness with specific formulas • Use lukewarm water to flush tube, avoid acidic or carbonated liquids
Oral aversion	• Provide oral stimulation • Initiate early speech and/or occupational therapy • Rearrange feeding schedule to optimize hunger

ADVANCING TO ORAL FEEDINGS

Children requiring EN often meet criteria for pediatric feeding disorder (Chapter 6). Infants, children, and adolescents with pediatric feeding disorder present as a complex clinical challenge because of the heterogeneous underlying etiologies. Thus, a multidisciplinary team approach is essential for prompt interventions, management, and monitoring. When physically and physiologically appropriate and safe, children requiring EN should work toward increasing oral intake. As part of the multidisciplinary team, the speech-language pathologist (SLP) or occupational therapist (OT) has an integral role in determining a child's skills and working with the team to develop and coordinate an appropriate intervention. SLP/OT collaboration and education with team members and caregivers is essential for intervention success. Additional support may be provided by a behavioral psychologist dependent on the patient's needs.

Patients working on oral feedings should have frequent nutrition reassessment. As oral intake increases, the dietitian should assess the amount and quality of foods consumed orally and decrease EN accordingly. In the inpatient setting, EN feedings can be stopped when a patient is taking ~80% of their nutrient needs by mouth. The patient should be monitored closely to ensure adequate oral intake and growth prior to tube removal. In the outpatient setting, tube feedings can be stopped

when the patient is taking 100% of their nutrient needs by mouth. Outpatients should demonstrate adequate oral intake and adequate growth for at least 3–6 months prior to removal of a long-term enteral tube (Chapter 7).

EN is the preferred method for nutrition support therapy if energy needs cannot be met by oral feeding. Attention must be paid to formula selection, delivery, and feeding schedule. Complications should be minimized through routine monitoring and follow-up to advance feedings in accordance with goals set by care team and the patient and family/caregivers.

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9 Parenteral Nutrition

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CONTENTS

Parenteral nutrition (PN) is the delivery of nutrition directly into the venous system, bypassing the gastrointestinal tract. The science and application of parenteral nutrition have evolved such that PN has become a common life-saving therapy in children. It is widely used in neonates, older pediatric patients, and adults with impaired gut function. PN should be considered a high-risk medication with several components that require trained clinicians to carefully prescribe and monitor. It is best done under the supervision of a multidisciplinary nutrition support team that includes physicians, advanced-level providers, pharmacists, dietitians, and nurses. This chapter is designed to provide the necessary information to prescribe, calculate, and monitor pediatric patients receiving PN and help manage potential PN-related complications.

INDICATIONS FOR PN

PN is costly and has associated complications. Its use is recommended only when enteral feeding is contraindicated or inadequate. The first step in determining whether PN is indicated is to assess the

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nutritional status of the patient. This should include several aspects including patient age, anthropometric data, growth history, medical history, clinical diagnosis, biochemical assessment, medical devices/access, severity of illness, degree of inflammation, and a nutrition-focused physical exam. The decision of when to start PN should not be based on a single diagnosis but should be made after looking at several factors that indicate there is a benefit to starting PN. Specific indications for PN are based on intestinal function, disease severity, and the inability to tolerate enteral feeding. PN should be used when the gastrointestinal tract is not functional and/or enteral access cannot be obtained. Common conditions that warrant PN support include intestinal failure, chronic liver disease awaiting transplant, children with single ventricle physiology pre- and early post-surgery, cancer and bone marrow transplant patients with treatment complications including severe mucositis, typhlitis, intestinal obstruction and intractable vomiting, critically ill patients who are severely malnourished or at risk of nutrition deterioration and unable to advance past low volumes of enteral nutrition (EN), and premature infants.

TIMING OF PN INITIATION

In older infants and children, just as in neonates, metabolic reserves are more limited, and energy requirements are higher than in adults. A key difference between the pediatric and the adult patient is the requirement for sufficient nutrients for growth. Specifically, protein, lipid, and glycogen stores are lower in infants and children as compared with adults. The energy and protein requirements based on each kilogram of body weight are higher in infants and children than in adults. Because of this, the importance of providing nutrition early in a child's course is more critical.

For the infant, child, or adolescent with a self-limited illness, it is reasonable to delay consideration of starting PN for 7 days. However, PN should be initiated within 1–3 days in infants and within 4–5 days in older children and adolescents when it is evident that they will not tolerate full oral intake or EN for an extended period. This should also be balanced with the fact that children will likely need central venous access to initiate PN and that giving a child PN for <3–5 days is considered unhelpful. Hence, a great deal of subjectivity and skill is needed when deciding to initiate PN. Also, in critically ill children that can be at least partially enterally fed, PN should be delayed for 1 week as that has been shown to be associated with better outcomes.

CONTRAINDICATIONS

The decision to withhold or delay PN is largely dependent upon whether PN administration will likely improve the patient's clinical outcome and the benefits outweigh the potential risk of PN-related complications such as severe metabolic disruptions or infection. Conditions where PN should not be initiated include:

- Severe, unstable hemodynamic instability
- Severe metabolic bnormalities
  - Serum glucose >180 mg/dL
  - Blood urea nitrogen (BUN) >100 mg/dL
  - Serum triglycerides >200 mg/dL
- Severe electrolyte abnormalities
  - Na <130 mEq/L or >150 mEq/L
  - K < 3 mEq/L
  - Mg <1.6 mEq/L
  - Cl < 85 mg/dL or >115 mg/dL
  - Phosphorous <2 mg/dL
- End-of-life care

Electrolyte and metabolic abnormalities should be corrected prior to the initiation of PN.

WRITING THE PN PRESCRIPTION

Pediatric PN may be supplied as a 3:1 or 2:1 solution. 3:1 PN contains all PN components (including the three macronutrients: carbohydrates, protein, and fat) in one PN bag. 2:1 PN provides lipid separate from all other PN components (the two macronutrients carbohydrate and protein are in one PN bag with all other PN components, while lipid is administered separately). 2:1 PN is commonly used in the hospital setting, while 3:1 PN is commonly used in the home setting. 2:1 and 3:1 PN have different requirements to achieve PN solubility and prevent precipitation of PN components. A PN pharmacist should be consulted to ensure the PN prescription meets safety guidelines.

Typically, pediatric PN is tailored to the needs of the patient. This requires a series of calculations and an individualized PN prescription. Target ranges for macronutrients when initiating and advancing PN are found in Tables 9.1–9.4.

Fluid and electrolyte content of PN can be customized to the individual patient. However, PN should not be used as the sole fluid source in metabolically unstable patients, nor should it be used to correct electrolyte abnormalities. Instead, any significant fluid and electrolyte disturbance should be corrected with separate intravenous fluids administered separately from PN.

It is also important to recognize that PN requirements are often different than those for EN. Absorption of nutrients from the gastrointestinal tract is dependent upon several variables, whereas PN bypasses this process.

Fluids

Parenteral fluid recommendations are based on estimates of needs to maintain adequate hydration and adjusted for increased losses as necessary. The Holliday-Segar method is commonly used to calculate maintenance fluid needs (Chapter 3). When calculating the fluid goal of an individual, it is important to consider the many factors that can affect fluid needs such as age, disease state, hydration status, gastric and/or ostomy output, stool losses, insensible water losses, and changes in metabolic and respiratory rate. It is also important to account for any other sources of fluid, including oral intake, EN, intravenous fluids, and intravenous medications that may account for a significant portion of a patient's fluid requirements.

Appropriate fluid management also requires ongoing monitoring and adjustment according to the patient's fluid losses and level of hydration. Fluid losses should be measured frequently and replaced.

Specific issues that affect fluid needs include:

- Gastrointestinal losses through a stoma, fistula, or from short bowel syndrome, which can reach 1–3 L daily. For most patients, this fluid should be measured and replaced separately from the PN prescription, unless the fluid loss is small and consistent.
- Renal maturity and function. The ability to concentrate urine increases as a child gets older allowing for less free water loss. Any injury to the kidneys, whether acute or chronic, may also result in decreased urine output and affect overall fluid needs.
- Insensible fluid losses are higher in infants as compared with older patients, and the maintenance fluid calculation accounts for these differences. Certain conditions can increase insensible losses. For example, fever, extensive burns, high respiratory rate, high ambient temperature, and low humidity increase fluid needs. An instance where insensible fluid losses are decreased would be the use of a humidified ventilator for respiratory support.
- Fluid restriction may be necessary for patients who have cardiac disease, bronchopulmonary dysplasia, head trauma, and renal failure. In such patients, PN composition can be concentrated to optimize the provision of nutrients.

TABLE 9.1
Parenteral Nutrition Dosing Recommendations for Preterm Infants

	Initiation	Daily Advancement	Goal
Macronutrients			
Protein (g/kg per day)[a]	1–3	–	3–4
Dextrose (mg/kg per minute)	6–8	1–2	10–14 (max 14–18)
Injectable lipid emulsion (g/kg per day)[b]	0.5–1	0.5–1	3
Electrolytes			
Sodium	2–5 mEq/kg		
Potassium	2–4 mEq/kg		
Calcium	2–4 mEq/kg		
Phosphorous	1–2 mmol/kg		
Magnesium	0.3–0.5 mEq/kg		
Acetate	As needed to maintain acid-base balance		
Chloride	As needed to maintain acid-base balance		

Manufacturer Recommendations[c]		NAG-AMA Recommendations[d]	
Weight (kg)	**Dose (mL)**	**Weight (kg)**	**Dose (mL)**
Pediatric Multivitamins[e]			
<1 kg	1.5	<2.5 kg	2 mL/kg
1–3 kg	3.25	≥2.5 kg	5 mL
≥3 kg	5		
Trace Elements			
Zinc	400 mcg/kg		
Copper	20 mcg/kg		
Manganese	1 mcg/kg		
Chromium	0.05–0.3 mcg/kg		
Selenium	2 mcg/kg		

Source: Adapted from ASPEN. Appropriate Dosing for Parenteral Nutrition: ASPEN Recommendations. 2019. Available from nutritioncare.org.

[a] Protein does not need to be titrated; protein needs are increased with critical illness.

[b] Intravenous lipid emulsion dosing based on soybean oil-based emulsion; should not be provided at a rate > 0.15 g/kg/hour.

[c] Infuvite Pediatric (Baxter) and M.V.I. Pediatric (Hospira).

[d] Nutrition Advisory Group – American Medical Association.

[e] Assumes normal age-related function.

Energy

Accurate determination of a patient's energy needs for the PN prescription can be challenging. Energy needs vary with age, weight, activity level, and disease state. Traditional energy expenditure equations can over- or underestimate a hospitalized patient's energy needs by a large margin and thus, if available, the use of indirect calorimetry is the gold standard for determining a patient's energy requirements. When indirect calorimetry is not available, standard

TABLE 9.2
Parenteral Nutrition Dosing Recommendations for Term Infants

	Initiation	Daily Advancement	Goal
Macronutrients			
Protein (g/kg per day)[a]	2.5–3	–	2.5–3
Dextrose (mg/kg per minute)	6-8	1–2	10–14 (max 14–18)
Injectable lipid emulsion (g/kg per day)[b]	0.5–1	0.5–1	2.5–3
Electrolytes			
Sodium	2–5 mEq/kg		
Potassium	2–4 mEq/kg		
Calcium	0.5–4 mEq/kg		
Phosphorous	0.5–2 mmol/kg		
Magnesium	0.3–0.5 mEq/kg		
Acetate	As needed to maintain acid-base balance		
Chloride	As needed to maintain acid-base balance		
Multivitamins[c]			
Pediatric multivitamin mixture (patients > 3 kg)	5 mL pediatric multivitamin		
Trace Elements			
Zinc	250 mcg/kg		
Copper	20 mcg/kg		
Manganese	1 mcg/kg		
Chromium	0.2 mcg/kg		
Selenium	2 mcg/kg		

Source: Adapted from ASPEN. Appropriate Dosing for Parenteral Nutrition: ASPEN Recommendations. 2019. Available from nutritioncare.org.

[a] Protein does not need to be titrated; protein needs are increased with critical illness.

[b] Intravenous lipid emulsion dosing based on soybean oil-based emulsion; should not be provided at a rate > 0.15 gm/kg per hour.

[c] Assumes normal age-related function.

equations can be used to estimate energy requirements (Chapter 3). For patients receiving 100% of their nutrient needs from PN, consider initiating PN at 10%–15% below their estimated energy needs as PN bypasses the gastrointestinal tract and thus does not require energy for digestion. The use of the Schofield or FAO/WHO/UNU equations for pediatrics may also be beneficial when working with critically ill patient populations, particularly when indirect calorimetry is unavailable. After determining the overall energy goal, it is important to monitor the patient's growth response to PN with regular anthropometric monitoring (including weight, length, head circumference, and mid-upper arm circumference) and adjust the energy prescription as needed.

Macronutrients

Carbohydrates

The source of carbohydrate in PN is dextrose with an energy yield of 3.4 kcal/g. Dextrose generally provides 40%–55% of the energy requirements. To avoid hyperglycemia, dextrose is started

TABLE 9.3
Parenteral Nutrition Dosing Recommendations for Children Age 1–10 Years

	Initiation	Daily Advancement	Goal
Macronutrients			
Protein (g/kg per day)[a]	1.5–2	–	1.5–2.5
Dextrose (mg/kg per minute)	3–6	1–2	8–10
Injectable lipid emulsion (g/kg per day)[b]	1–2	0.5–1	2–2.5
Electrolytes			
Sodium	2–5 mEq/kg		
Potassium	2–4 mEq/kg		
Calcium	0.5–4 mEq/kg		
Phosphorous	0.5–2 mmol/kg		
Magnesium	0.3–0.5 mEq/kg		
Acetate	As needed to maintain acid-base balance		
Chloride	As needed to maintain acid-base balance		
Multivitamins[c]			
Pediatric multivitamin mixture	5 mL pediatric multivitamin[d]		
Trace Elements[e]			
Zinc	50 mcg/kg (max 5000 mcg/day)		
Copper	20 mcg/kg (max 500 mcg/day)		
Manganese	1 mcg/kg (max 55 mcg/day)		
Chromium	0.2 mcg/kg (max 5 mcg/day)		
Selenium	2 mcg/kg (max 100 mcg/day)		

Source: Adapted from ASPEN. Appropriate Dosing for Parenteral Nutrition: ASPEN Recommendations. 2019. Available from nutritioncare.org.

[a] Protein does not need to be titrated; protein needs are increased with critical illness.

[b] Intravenous lipid emulsion dosing based on soybean oil-based emulsion; should not be provided at a rate > 0.15 g/kg/hour.

[c] Assumes normal age-related function.

[d] This dose is recommended until 11 years of age.

[e] These doses are used up to 40 kg of body weight; above that weight, use the guidelines for adolescents.

at a rate that mimics endogenous glucose production and advanced over the course of 3–5 days depending upon patient age and glucose tolerance with desired glucose levels less than 180 mg/dL (Tables 9.1–9.4). The rate at which dextrose is infused is commonly referred to as the glucose infusion rate (GIR).

The acceptable GIR varies with the patient's age and clinical condition. Acceptable quantities of glucose are important because at glucose infusions less than basal production, hypoglycemia may occur. It is also important to avoid excessive glucose; an excessive GIR can cause hyperglycemia, hyperosmolarity, and osmotic diuresis, and increase the risk of hepatic steatosis. A healthy infant can tolerate a GIR of 12–14 mg/kg per minute, but an ill- or malnourished child may not. Thus, the glucose concentration must be carefully advanced in a malnourished or critically ill patient. Lower GIR targets are used for ventilated patients to avoid excessive CO_2 production, as well as in patients with hyperglycemia, and sepsis. Tables 9.1–9.4 outline recommended GIR ranges for infants, children, and adolescents. Figure 9.1 provides example calculations for dextrose and GIR.

TABLE 9.4
Parenteral Nutrition Dosing Recommendations for Children Age > 10 Years

	Initiation	Daily Advancement	Goal
Macronutrients			
Protein (g/kg per day)[a]	0.8–2	–	0.8–2
Dextrose (mg/kg per minute)	2.5–3	1–2	5–6
Injectable lipid emulsion (g/kg per day)[b]	1	1	1–2
Electrolytes			
Sodium	1–2 mEq/kg		
Potassium	1–2 mEq/kg		
Calcium	10–20 mEq		
Phosphorous	10–40 mmol		
Magnesium	10–30 mEq		
Acetate	As needed to maintain acid-base balance		
Chloride	As needed to maintain acid-base balance		
Multivitamins[c]			
10–11 years	5 mL pediatric multivitamin		
>11 years	10 mL adult multivitamin[d]		
Trace Elements[e]			
Zinc	2–5 mg		
Copper	200–500 mcg		
Manganese	40–100 mcg		
Chromium	5–15 mcg		
Selenium	40–60 mcg		

Source: Adapted from ASPEN. Appropriate Dosing for Parenteral Nutrition: ASPEN Recommendations. 2019. Available from nutritioncare.org.

[a] Protein does not need to be titrated; protein needs are increased with critical illness.

[b] Intravenous lipid emulsion dosing based on soybean oil-based emulsion.

[c] Assumes normal age-related function.

[d] Adult multivitamins may not contain vitamin K. Consider addition of vitamin K to PN prescription.

[e] These requirements may be different from what can be provided using the multi-trace element products currently available in the US.

GIR= milligrams of dextrose / kg body weight per minutes of infusion

Example: D12.5% at 60 ml/hr x 20 hours for at patient weighing 14 kg

Dextrose: 60 ml/hr x 20 hours = 1200 mL/day
1200 mL/day x .125 = 150 g of dextrose
150 g dextrose x 1000 mg/g = 150,000 mg dextrose

Minutes: 20 hours x 60 minutes/hour = 1200 minutes

GIR = 150,000 mg / 14 kg per 1200 minutes = 8.9 mg/kg per minute

FIGURE 9.1 Dextrose and GIR calculations.

Amino Acids

The source of protein in PN is crystalline amino acids with an energy yield of 4 kcal/g. Protein generally provides 15%–20% of PN calories. Targets for protein intake for pediatric patients with normal organ function are listed in Tables 9.1–9.4.

Protein needs depend on severity of illness. Stress factors such as sepsis, thermal injury, surgery, trauma, and stoma losses increase protein requirements. Urinary excretion of nitrogen related to steroids, diuretics, or primary renal disease also can increase the protein requirement. Indications for protein restriction may include renal disease (Chapter 20), hepatic failure (Chapter 18), and inborn errors of metabolism (Chapter 23).

Standard amino acids are a combination of essential amino acids (those that cannot be synthesized by the human body) and nonessential amino acids (those that can be synthesized). A third category of amino acids referred to as conditionally essential amino acids are those that can be synthesized but, under certain conditions, may have increased demand. Examples of conditionally essential amino acids include cysteine, tyrosine, and glutamine. Cysteine is an amino acid that is conditionally essential for premature and term neonates. Cysteine is not included in crystalline amino acid solutions, because it is unstable. It can be added separately at the time of PN infusion with usual dosing of 40 mg/g of amino acid.

Specific pediatric amino acid solutions (Aminosyn-PF®, Premasol®, Trophamine®) contain a higher concentration of branched chain amino acids and decreased amounts of methionine and phenylalanine. They were designed to produce a similar amino acid profile to term breast-fed infants and are commonly used in preterm and term infants. They also have a lower pH to allow for higher calcium and phosphorous delivery through improved solubility. For children 1 year of age and older, adult amino acid solutions are used.

Special amino acid formulations for renal and hepatic failure are available. Renal formulations are composed of essential amino acids and have not been demonstrated to provide a clinical advantage over standard formulations and may actually result in metabolic complications. Amino acid solutions designed for hepatic encephalopathy contain primarily branched chain amino acids with limited amounts of aromatic amino acids. Recent evidence suggests that protein restriction is not indicated in hepatic encephalopathy. Therefore, the indications for renal and hepatic formulations are limited and generally do not provide a clinical advantage.

Fat

Fat in PN is delivered in the form of intravenous fat emulsions, called injectable lipid emulsions (ILE). ILE provides between 20% and 30% of energy needs. ILEs provide a dense source of calories and essential fatty acids (EFA) (α-linolenic acid and linoleic acid). Components of ILEs include the type of oil used, egg yolk phospholipid (emulsifier), glycerol to make the formulation isotonic, and sodium hydroxide to adjust the final pH of the solution. The total energy supplied by fat is shown in Table 9.5.

TABLE 9.5
Energy Provided by Lipid Injectable Emulsions (ILE)

% Lipid	kcal/mL	kcal/g
10	1.1	11
20	2	10
30	3	10

Like dietary fat, each gram of fat provides 9 kcal but the glycerol component can be metabolized as energy, thus increasing the energy per gram (Table 9.5). The ideal ILE is one that would promote growth and reverse or prevent essential fatty acid deficiency without leading to hepatic steatosis, hypertriglyceridemia, or the elevation of liver enzymes. There have now been three generations of ILEs in the USA that are attempting to achieve this.

Types of Lipid Injectable Emulsions

Soybean oil-based ILEs are the most common form of ILE used in the USA and most other countries. They are manufactured under the brand names Intralipid® or Nutralipid®. They are rich in omega-6 fatty acids, which have the advantage of supplying EFAs and phytosterols. However, accumulating evidence suggests that soy-based ILE also may be associated with increased inflammation and liver injury, especially in infants on long-term PN, in a pattern known as intestinal failure-associated liver disease (IFALD).

Mixed oil-based lipid emulsions such as SMOFlipid® are a combination of several oils including soybean oil (30%), medium chain triglycerides (30%), olive oil (25%), and fish oil (15%). This composition of lipids has more anti-inflammatory properties by including higher omega-3 fatty acids and vitamin E, while decreasing potential pro-inflammatory/hepatotoxic properties of omega-6 fatty acids and phytosterols. Given the lower omega-6 content, caution should be taken when lipid restriction is indicated as this would place the patient at risk of developing EFA deficiency. It has promising applications in improving laboratory markers of liver disease in long-term PN use as well as reducing inflammatory markers in instances of sepsis, trauma, or other high inflammatory process. SMOFlipid® is not FDA approved for use in children but is frequently used off label.

Fish oil-based lipid emulsions (FOLE) such as Omegaven® are comprised of 100% fish oil. Preliminary evidence suggests that fish oil-based ILE may be useful for treating infants with IFALD. However, fish oil-based ILE provides minimal amounts of EFA, so patients are at risk for developing EFA deficiency and should be monitored (Figure 9.2).

Electrolytes

Electrolytes are essential and must be provided in PN. Electrolyte needs are dependent upon several factors including organ function, medication interactions, nutritional status, and baseline serum concentrations. Usual doses for sodium, potassium, calcium, magnesium, and phosphorus are included in Tables 9.1–9.4. The chloride content of the PN solution is determined by the patient's acid-base status. Acetate acts as a buffer and can help correct metabolic acidosis, if present, since bicarbonate is not compatible with PN mixtures.

Special attention should be paid to instances of renal dysfunction where potassium and phosphorous may need to be reduced or omitted from the PN prescription. Refeeding syndrome is also a

Example 1: 5 ml/hr x 24 hr of 20% lipid emulsion in a 12 kg patient
Total Volume of lipid emulsion = 5 ml/hr x 24 hours = 120 mL

Option 1:	Option 2:
120 mL x 2 kcal/mL = 240 kcal 240 kcal ÷ 10 kcal/gm = 24 gm of lipid 24 gm lipid ÷12 kg = 2 gm lipid per kg	120 mL x 0.2 (20% emulsion) = 24 gm lipid 24 gm lipid x 10 kcal/gm = 240 kcal 24 gm lipid ÷12 kg = 2 gm lipid per kg

Example 2: Goal of 1 gm/kg of lipid in a 15 kg patient
15 kg x 1 gm/kg = 15 total grams of lipid
15 grams ÷ 0.2 (20% emulsion) = 75 mL of lipid emulsion
75 ml ÷24 hours = 3.1 ml/hr

FIGURE 9.2 Lipid calculations.

time where potassium, phosphorous, and magnesium should be closely monitored, and replacement doses provided to keep serum levels normal (Chapter 22).

Premature infants need increased amounts of calcium and phosphorus in their PN to prevent metabolic bone disease. The calcium to phosphorous ratio in PN should be 1.7 mg calcium to 1 mg phosphorus. Ratios lower than 1:1 result in elevated serum and urine phosphorus, possibly due to inadequate calcium and hence decreased utilization of phosphorus. Premature infants have high requirements for calcium and phosphorus, which must be balanced against limited solubility of these nutrients in the PN solution.

Vitamin Preparations

Multivitamins should be routinely included in the PN prescription. Pediatric preparations are commercially available in the USA under the brand names MVI Pediatric® and Infuvite Pediatric®. Both preparations contain the same quantities of 13 vitamins. The composition of pediatric multivitamin products can be found on the manufacturer website. Tables 9.1–9.4 provide multivitamin dosing guidelines for infants and children.

The guidelines for pediatric vitamins were developed in the late 1970s and 1980s. The current vitamin formulations do not match the requirements for many special conditions including premature infants, renal disease, liver disease, and short bowel syndrome. These populations may be prone to vitamin excesses or deficiencies.

For patients who require long-term PN, vitamin levels should be monitored (see related section on laboratory monitoring). Children with severe renal failure who are receiving hemodialysis or peritoneal dialysis should receive 50% of the recommended dose of MVI as they may develop vitamin A toxicity even if they receive the recommended dose of retinol. Levels of Vitamin A in patients with chronic renal failure should be monitored and if elevated, supplementation should be reduced accordingly.

Trace Elements

The five recommended trace elements to be supplemented include zinc, selenium, copper, manganese, and chromium. No substantial changes have been made in trace element formulations during the past 30 years. Dosing of pediatric multitrace elements products is problematic in that the weight-based dosage recommendations underestimate the recommended daily intake for some trace elements, while intake is excessive for others such as chromium and manganese. Single-entity trace elements based on age-specific and disease-specific needs, especially in those receiving long-term PN are recommended. Tables 9.1–9.4 outline dosing recommendations PN trace elements.

Special considerations for individual trace minerals include:

- Zinc is frequently supplemented in patients who have excessive gastrointestinal fluid losses via ostomy output or diarrhea. There is no good parameter to monitor for zinc status, but serum zinc levels and alkaline phosphatase are used clinically.
- Selenium is an essential nutrient. Patients who require PN for 2 months or more must receive selenium. Selenium is not included in some standard packages of trace elements. Patients on long-term PN need selenium added to their trace element preparation, or need to change to a trace element preparation that includes selenium.
- Decreased doses of copper and manganese may be required for patients with cholestasis. However, in this case, serum levels should be monitored. Manganese can accumulate in patients with liver disease because it is normally excreted in bile. It is speculated that manganese accumulation can contribute to the development of PN cholestasis. Levels should

be checked in patients receiving PN for greater than 30 days. If high levels are found, the amount of manganese should be decreased and levels monitored.
- Chromium is a contaminant in PN solutions. Serum and urine levels should be monitored in patients on long-term PN with renal impairment.
- Aluminum is a contaminant of PN solutions. Since crystalline amino acids have replaced protein hydrolysates, aluminum contamination has decreased. However, it remains a concern. The U.S. Food and Drug Administration requires disclosure of aluminum content and concentration on labels of parenteral compounding supplies. Some components of PN including calcium gluconate and phosphate salts still include significant amounts of aluminum. There is no consensus to define "safe" levels of parenteral aluminum intake. Intakes of less than 4–5 μg/kg per day were recommended by the U.S. Food and Drug Administration in 2004. However, it is often difficult to achieve exposures under these limits using available products, particularly for preterm infants who typically have high calcium needs.
- Iodine is generally not included in PN; it is not provided in most trace element solutions or added to the PN. As a result, infants and children on chronic exclusive PN may develop iodine deficiency. Children who receive PN as their sole source of nutrition should undergo periodic monitoring of iodine status by checking serum thyroid-stimulating hormone (TSH) every 6 months. If serum TSH is elevated, then iodine status can be evaluated by measurement of either 24-hour urinary iodine or spot urinary iodine.
- Iron is not compatible with 3:1 PN and hence, not added to PN solutions. Instead, it must be administered orally or intravenously. Iron status should be monitored every 3–4 months while on PN. Patients on long-term PN are at risk for iron deficiency and need repeated intravenous infusions of iron.

Other PN Additives

Carnitine

Carnitine is necessary for the transport of long-chain fatty acids into the mitochondria. It can be added to help with lipid metabolism when receiving ILEs. It can also be added for patients with a documented carnitine deficiency or those at risk of developing carnitine deficiency such as those on continuous renal replacement therapy. Common daily dosing is 5–10 mg/kg.

Heparin

Heparin can be added at doses of 0.5–1 unit/mL to a PN solution. Its benefits are limited in preventing thrombophlebitis but there are some potential benefits in stimulating lipoprotein lipase and improving lipid clearance in neonates.

Medications

Medications added to PN solutions may present issues with compatibility and therefore consulting with a pharmacist is advised. Common medications that can be added include H_2-receptor antagonists (ranitidine/famotidine) or insulin for the treatment of hyperglycemia.

COMPLICATIONS OF PARENTERAL NUTRITION

Complications of PN are largely categorized into three groups including mechanical, metabolic, and infectious. Complications may appear within the first 24 hours of starting PN or take months to years to develop. Those complications that present later may take much longer to correct and treat. Therefore, patients that are on PN require routine monitoring and assessment as described in the next section.

Mechanical Complications

Mechanical complications are related to the vascular access device used for PN delivery. Common complications include displacement of the catheter tip, occlusion of the line, thrombosis, and phlebitis. In each of these scenarios, PN would need to be stopped and the line assessed for placement and integrity. Medical treatment may be needed, and the line replaced (Chapter 7).

Metabolic Complications

Metabolic complications are the most prevalent when using PN. They can be a result of over- or under-prescribing macronutrients, micronutrients, electrolytes, or fluid or as the result of medications or clinical status.

Complications from PN carbohydrate intake include hypoglycemia and hyperglycemia. Hypoglycemia may result from providing a GIR less than the exogenous rate of glucose production in the body; abrupt discontinuation of PN infusion resulting in rebound hypoglycemia; or excessive administration of insulin. To treat these complications, increase or resume the dextrose infusion and stop insulin if being administered. Hyperglycemia may result in glycosuria and osmotic diuresis. It is often the result of stress-associated hyperglycemia in acute illness and sepsis, but also may be from the use of corticosteroids or excessive glucose infusion. Treatment of hyperglycemia depends on the root cause. In all instances, a reduction in the GIR may be warranted. However, if persistent hyperglycemia limits calorie intake, cautious administration of insulin may be needed.

Complications from PN protein administration include azotemia. Excessive protein load with inability to process the urea by-products may result in a rise in BUN. This is most common in patients with hepatic and renal disease. Protein restriction is not indicated in these instances unless there is a need for dialysis or evolution to hepatic encephalopathy. Ensuring appropriate protein dose based on age and disease severity along with ensuring adequate non-protein energy are important tools when managing these patients.

Complications from PN fat administration include hypertriglyceridemia and EFA deficiency. Hypertriglyceridemia, defined as serum triglycerides >200 mg/dL in premature infants or >400 mg/dL in older infants/children, may be related to excessive doses of ILE, especially in neonates or malnourished patients as they have a reduced ability to clear triglycerides. However, the dose of ILE should be reduced if the triglyceride levels are consistently more than 200 mg/dL. If levels rise above 400 mg/dL, hold lipids for 24–48 hours.

To prevent EFA deficiency, the requirement for EFA in a premature infant is 0.5–1 g/kg/day with Intralipid® and Omegaven® or 2 g/kg/day with SMOFlipid®. After 5 days of fat-free PN, most premature infants have biochemical evidence of EFA deficiency. In older infants and children, the EFA requirement is 2%–4% of calories as linoleic acid or approximately 0.5–1 g/kg/day with Intralipid® and Omegaven®, 2 g/kg/day with SMOFlipid®. Older infants and children can become EFA deficient after 2 weeks of fat-free PN or sooner in a critically ill child or child with preexisting malnutrition.

Acid-base disorders or electrolyte disturbances are also complications of PN. Electrolyte monitoring should occur daily until the PN solution is at goal and stable. Changes to electrolytes as well as alterations in chloride and acetate content should be made as clinically indicated.

Metabolic bone disease is a PN complication that may occur in infants and children. Premature infants and children dependent upon PN for long periods of time are at risk for developing metabolic bone disease. This can be discovered by physical exam, radiography, or by biochemical evidence (elevated alkaline phosphatase). Provision of adequate calcium, phosphorous, and vitamin D are necessary to prevent this complication.

IFALD is diagnosed when direct bilirubin is greater than 2 mg/dL for two consecutive weeks. There are several risk factors for developing IFALD including PN administration for greater than 2 weeks, low gestational age and birth weight, inability to tolerate EN, short bowel syndrome/intestinal failure, and recurrent episodes of sepsis. It has been identified that if anticipating a patient

to require PN for greater than 2 weeks, a mixed-oil lipid emulsion should be considered as it has been shown to delay the increase in bilirubin levels. The gold standard for reversing IFALD is EN. If this is not feasible, lipid minimization, use of alternative lipids, avoiding exceeding maximum GIR, avoiding overfeeding, and initiating enteral feeds as soon as possible are all recommended treatments. In the instance of rising direct bilirubin levels with the use of a mixed-oil lipid emulsion, the use of fish-oil lipid emulsion may be indicated.

Infectious Complications

Ensuring aseptic techniques for PN compounding and line care are important in reducing the risk of infection. Patients and providers will monitor for local signs of infection such as redness and swelling at the catheter site and systemic signs of infection such as fever. Once infection is suspected, medical intervention is needed to rule out bacteremia/fungemia or other line complications (Chapter 7).

MONITORING AND EVALUATION

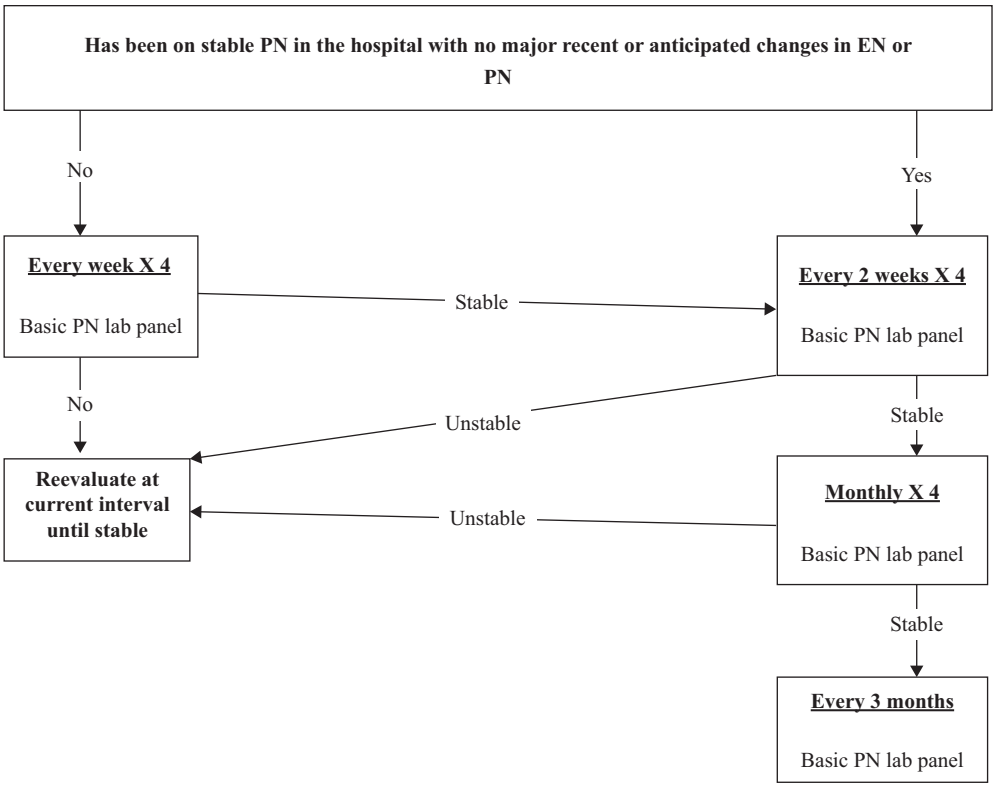
Routine monitoring of patients on PN allows clinicians to identify if the prescribed therapy is meeting the nutrition goals of the patient, if those goals are supporting desired outcomes such as growth and development, and if there is a return of gastrointestinal function to allow for weaning from PN. It is also essential in identifying potential complications and correcting those issues early and prior to any clinical manifestation. The frequency of monitoring should be individualized based upon the severity of illness and duration of therapy. Patients that are either initiating or weaning from PN may need more frequent follow-up than a patient that is stable and established on their PN regimen. Anthropometric and laboratory measures must be obtained at baseline and repeated periodically after PN treatment is begun to monitor the patient and adjust the PN prescription as needed. Tables 9.6 and 9.7 and Figure 9.3 outline recommendations for anthropometric and laboratory monitoring for pediatric patients receiving PN.

Transitioning to Enteral or Oral Feedings

While PN may be the sole source of nutrition for some patients, other patients are receiving PN in addition to oral feedings and/or EN. As oral or enteral feedings are increased, PN should be decreased to continue to meet the patient's nutrient needs when all sources are considered. In the hospital setting, PN can be discontinued when oral intake and/or EN achieves 50%–75% of requirements for energy, protein and micronutrients, unless impaired gastrointestinal function precludes 100% absorption of nutrients. In the outpatient setting, PN can be discontinued when a patient is meeting >75% of requirements for energy, protein and macronutrients from oral and/or enteral feedings. However, the central venous catheter should not be removed until the patient demonstrates appropriate growth without the use of PN. Consider using a weaning protocol during the transition from PN to EN.

TABLE 9.6
Anthropometric Monitoring During PN Initiation

Physical exam	Particular attention should be paid to body temperature, presence/absence of edema, liver size, jaundice, cardiac status, neurologic status, and central venous catheter insertion sites
Daily monitoring	Weight, intake and output. Check serum glucose with increases in dextrose infusion and aim for euglycemic range. Check serum triglyceride with increases in lipid dose
Weekly monitoring	Length, height, and head circumference. Growth parameters should be plotted at least weekly



Basic PN Lab Panel

Complete blood count with auto differential, Sodium, Potassium, CO_2, Chloride, Blood Urea Nitrogen, Creatinine, Glucose, Calcium, Magnesium, Phosphorus, AST, ALT, Triglycerides, Albumin, Alkaline phosphatase, Direct bilirubin

PN Micronutrient Panel

Every 6 months: Copper, Selenium, Zinc, Vitamins A, E, D, B_{12}, Merthylmalonic Acid, Prothrombin Time, Iron, Total Iron-Binding Capacity, RBC Folate, Carnitine if < 1 year of age
Annually: DEXA Scan

FIGURE 9.3 Laboratory monitoring for patients receiving home parenteral nutrition. (Reprinted with permission from Smith A, Feuling MB, Larson-Nath C, et al. Laboratory Monitoring of Children on Home Parenteral Nutrition: A Prospective Study. *JPEN J Parenter Enteral Nutr.* 2017;42(1):148–155. doi: 10.1177/0148607116673184. Copyright 2016 American Society for Enteral and Parenteral Nutrition.)

TABLE 9.7
Laboratory Monitoring for Inpatients Receiving Parenteral Nutrition

			After Day 7	
Parameter	**Baseline**	**Days 1–7**	**Weekly**	**Periodically**
Glucose, blood urea nitrogen, creatinine, electrolytes, calcium, magnesium, phosphorous	✓	Daily×3 until stable	✓	
Complete blood count with auto differential	✓	Daily×3 until stable	✓	
Total bilirubin, direct bilirubin, alkaline phosphatase, AST, ALT, albumin, gamma glutamyltransferase	✓		✓	
Prothrombin time/INR	✓			✓
Serum triglycerides	✓	Daily until stable	✓	
PN micronutrient panel (Figure 9.3)				✓

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10 Malnutrition

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CONTENTS

Malnutrition in children has short-term and lifelong implications for both children and the health-care system as a whole. The term malnutrition (undernutrition) is most often associated with a net energy and/or protein deficit, which is the focus of this chapter. It is important to realize that malnourishment from a micronutrient standpoint may also occur without an energy deficit. While malnutrition is most often discussed in patients who are underweight, overweight and obese patients who lose significant weight can also be malnourished.

The prevalence of malnutrition varies depending on the definition of malnutrition used and the patient population being examined. In a large database study looking at codes for malnutrition in hospitalized children, the rates of malnutrition ranged from 2.6% of the entire hospitalized population to 26% in children admitted with cystic fibrosis. These and other reported malnutrition data likely underestimate the true prevalence of malnutrition given the need for a documented malnutrition diagnosis code. Another study using the National Health and Nutrition Examination Survey (NHANES) reported the prevalence of malnutrition in children in the USA to be around 3%. In low- and middle-income countries, overall rates of malnutrition are around 7%.

Terms often associated with the concept of malnutrition include: failure to thrive, growth faltering, inadequate growth, poor weight gain, and growth failure, among others. Children with chronic disease are at particular risk of developing malnutrition. In 2013, the American Society for Parenteral and Enteral Nutrition (ASPEN) developed a conceptual definition for malnutrition in pediatric patients defining it as "an imbalance between nutrient requirements and intake that results in cumulative deficits of energy, protein, or micronutrients that may negatively affect growth, development, and other relevant outcomes". They laid out a framework that describes malnutrition in five domains: chronicity, etiology, cause of nutrient imbalance, severity, and impact. In 2015, the

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Academy of Nutrition and Dietetics (The Academy) joined ASPEN to develop objective diagnostic criteria for pediatric malnutrition in clinical practice which allows for diagnostic clarity when assessing children for malnutrition. It is important to recognize that while malnutrition has defined diagnostic criteria, malnutrition is not the end diagnosis, instead it is a symptom of another underlying process or processes that requires identification.

IMPACT OF MALNUTRITION

The consequences of pediatric malnutrition are far reaching with lifelong implications. Much of the outcome data in pediatric malnutrition come from children with chronic disease and those from low- and middle-income countries. In addition, most data related to consequences of malnutrition are corollary due to the heterogeneity of the underlying causes and complexity of the patient populations studied.

Impacts on Linear Growth

Nutritional, hormonal, and inflammatory factors all impact normal linear growth. In the setting of chronic malnutrition, decreased energy and protein intake lead to decreased linear growth velocity. The impact of inadequate energy and protein provision on linear growth is potentiated by inflammation and hormonal alterations. Hormones that affect linear growth include growth hormone, thyroid hormone, insulin-like growth factor 1 (IGF-1), estrogens, and androgens. It is important to note that with long-term stunting, BMI-for-age (or weight-for-length) may appear normal. Recovery of linear growth velocity occurs with appropriate nutritional rehabilitation and follows weight gain recovery.

Development

The impact of malnutrition on developmental outcomes is complex. Developmental outcomes associated with malnutrition arise from protein and energy deficits and micronutrient deficiencies, and are also influenced by social, environmental, and cultural factors. Many studies assessing the effect of interventions on malnutrition not only impact nutrition but also impact social and environmental factors. Given the multiple confounding factors impacting neurocognitive development, the exact relationship between early malnutrition and later development is murky. Nutrients whose deficiencies can have a clear impact on long-term development include protein, zinc, iron, choline, folate, iodine, vitamins A, D, B_6, and $B_{12,}$ and long-chain polyunsaturated fatty acids (e.g., docosahexanoic acid [DHA]).

Other Consequences

Malnutrition impacts the course of hospitalized children. In these children, malnutrition is associated with increased length of stay in the pediatric intensive care unit, increased duration of mechanical ventilation, higher risks of infection, delayed wound healing, and loss of lean body mass. In a 2018 report, children with a coded diagnosis of malnutrition had a mean length of stay of 10.2 days compared to children without this diagnosis who had a mean length of stay of 5.4 days. In addition, in this report, the authors found that children had increased mortality and increased cost of hospitalization. It is clear that malnutrition negatively impacts children with other chronic diseases and the medical system as a whole.

DIAGNOSING PEDIATRIC MALNUTRITION

The first step in diagnosing malnutrition is nutrition screening (Chapter 3). Patients identified as being at nutrition risk during screening warrant dietitian involvement to determine if nutrition

intervention is indicated. Diagnosis of pediatric malnutrition includes identification and documentation of standardized indicators as outlined by The Academy and ASPEN. When only single data points of anthropometric measurements are available, weight-for-length *z*-score (WFLZ), body mass index (BMI)-for-age *z*-score (BMIZ), length/height-for-age *z*-score, and mid-upper arm circumference-for-age *z*-score should be evaluated for the identification of malnutrition. When more than one data point is available, deceleration of WFLZ or BMIZ, inadequate nutrient intake, weight gain velocity (<2 years of age), or weight loss (2–20 years of age) should be evaluated for the identification of malnutrition (Table 10.1). These indicators may be applied to term infants 1 month of age or older, infants with a corrected gestational age of 37 weeks or greater, and children up to 18 years of age. Pediatric patients are required to meet 1 criterion for the diagnosis of malnutrition.

Accurate anthropometric measurements are essential in diagnosing malnutrition. See Chapter 1 for detailed steps for accurate anthropometric measurements. While nutrition-focused physical exam (NFPE) findings are not currently indicators for the diagnosis of pediatric malnutrition, the NFPE is an important part of the nutrition assessment. NFPE can be used to support a malnutrition diagnosis and help the dietitian determine if the malnutrition diagnosis matches the clinical picture. NPFE findings can be present, particularly in moderate to severe malnutrition. See Chapter 2 for further discussion of the NFPE.

Mechanisms of Malnutrition

Once diagnosed, the chronicity and underlying etiology of malnutrition should be determined and documented. Acute malnutrition is defined as occurring for less than 3 months. Chronic malnutrition is defined as occurring for greater than 3 months. The etiology of malnutrition generally is defined as illness related or non-illness related and may coexist in the same patient at the same time. Both illness- and non-illness-related malnutrition are caused by nutrient imbalance.

TABLE 10.1
Diagnosis Criteria for Pediatric Malnutrition

Primary Indicators	Mild Malnutrition	Moderate Malnutrition	Severe Malnutrition
Primary Indicators When Only a Single Data Point Is Available			
Weight-for-height *z*-score	−1 to −1.9 *z*-score	−2 to −2.9 *z*-score	−3 or greater *z*-score
BMI-for-age *z*-score	−1 to −1.9 *z*-score	−2 to −2.9 *z*-score	−3 or greater *z*-score
Length/height *z*-score	No data	No data	−3 *z*-score
Mid-upper arm circumference	Greater than or equal to −1 to −1.9 *z*-score	Greater than or equal to −2 to −2.9 *z*-score	Greater than or equal to −3 *z*-score
Primary Indicators When Two or More Data Points are Available			
Weight gain velocity (<2 years of age)	<75% of the norm for expected weight gain	<50% of the norm for expected weight gain	<25% of the norm for expected weight gain
Weight loss (2–20 years of age)	5% usual body weight	7.5% usual body weight	10% usual body weight
Deceleration in weight-for-length/height *z*-score	Decline of 1 *z*-score	Decline of 2 *z*-score	Decline of 3 *z*-score
Inadequate nutrient intake	51%–75% estimated energy/protein need	26%–50% estimated energy/protein need	≤25% estimated energy/protein need

Source: Becker P, Carney LN, Corkins MR, et al. Consensus Statement of the Academy of Nutrition and Dietetics/American Society for Parenteral and Enteral Nutrition: Indicators Recommended for the Identification and Documentation of Pediatric Malnutrition (Undernutrition). *Nutr Clin Pract*. 2015;30:147–161. Copyright 2014 by the Academy of Nutrition and Dietetics and the American Society for Parenteral and Enteral Nutrition.

Understanding the mechanism of malnutrition helps narrow the differential diagnosis for the etiology of malnutrition. Mechanisms leading to malnutrition include: (1) inadequate energy intake, (2) increased losses, (3) increased energy expenditure, and (4) dysfunctional nutrient utilization (Table 10.2).

Marasmus and kwashiorkor are specific processes associated with severe acute malnutrition most often seen in low- and middle-income countries. Clinical characteristics of marasmus include wasting without edema. Marasmus is associated with fat and muscle loss and stunting without edema. In marasmus, serum albumin remains normal. Kwashiorkor is characterized by the presence of symmetric peripheral edema (and ascites), muscle wasting, and low serum albumin. Traditionally, marasmus has been considered the end result of severe inadequate energy intake and kwashiorkor has been thought to be the end result of inadequate consumption of protein in the face of relatively

TABLE 10.2
Mechanisms and Causes of Pediatric Malnutrition

Inadequate intake	*Non-Illness Related*	
	Inadequate provision	Improper formula mixing
		Inadequate human milk supply
		Interruption of feeds
		Food insecurity
		Neglect
	Behavioral	Sensory issues
		Oral aversion
		Disordered eating (anorexia, avoidant restrictive food intake disorder)
	Illness Related	
	Mechanical	Cleft lip or palate
		Hypotonia
Increased losses	Malabsorption	Pancreatic insufficiency
		Congenital diarrhea
		Short bowel syndrome
		Protein losing enteropathy
		Chronic liver disease
		Celiac disease
		Infection
	Other	Vomiting
		Enterocutaneous fistula
Increase caloric expenditure	Cardiac disease	
	Malignancy	
	Infection	
	ENT/pulmonary	Cystic fibrosis
		Tracheomalacia, laryngomalacia
	Renal	Chronic Kidney Disease
		Bartter or Gitelman syndrome
		Renal Tubular Acidosis
	Endocrine	Hyperthyroidism
	Neuro	Seizures
	Other	Burns
Dysfunctional nutrient utilization	Eosinophilic disease	
	Metabolic disease	
	Endocrine	Diabetic ketoacidosis
	Other	Inflammation

adequate energy intake. However, the actual causes of each of these presentations are complex and involve inadequate nutrition and the intestinal microbiome.

Often, the cause of malnutrition is multifactorial and therefore it is important to recognize that the most obvious cause of malnutrition may not be the only contributing factor. For instance, a child with cardiac disease and trisomy 21 who has increased energy needs from her cardiac disease may also have decreased oral intake due to hypotonia and difficulties with swallowing. This is why a detailed history and exam are critical when a child presents with malnutrition.

Malnutrition Documentation

The nutrition diagnosis of malnutrition may be present along with additional nutrition diagnoses. The PES (problem, etiology, signs, and symptoms) statement should contain the severity, cause, and chronicity of malnutrition. Common nutrition diagnoses include:

- Illness-related pediatric malnutrition
  - Acute or chronic
  - Mild, moderate, or severe
- Non-illness-related pediatric malnutrition
  - Acute or chronic
  - Mild, moderate, or severe

Documenting a diagnosis of malnutrition allows the dietitian to share this information with the entire medical team. Identifying and diagnosing malnutrition is the first step in treating malnutrition. The dietitian should work closely with the medical team to ensure that all causes and consequences of malnutrition are addressed.

Other Diagnostic Considerations

Malnutrition diagnosis criteria as they currently exist may exclude some patients that do not meet the defined criteria but have malnutrition present. On the other hand, some children who meet criteria for mild malnutrition may not be malnourished. One reason malnutrition may not be accurately identified is if anthropometric measurements are not available or are inaccurate. Inaccurate measures may result from poor technique when obtaining measurements, difficulty measuring length or height measures in children who are unable to stand or lie straight, or from medical conditions which result in edema or fluid accumulation. Other contributing factors to missing the diagnosis of malnutrition include lack of appropriate equipment to obtain measurements, patient refusal, critical illness, and lack of information about nutrient intake. In addition, patients who have both linear growth stunting and suboptimal weight gain may be more difficult to diagnose with malnutrition as the weight-for-age z-score may appear normal. Using anthropometric data alone may also lead to the misdiagnosis of malnutrition in certain situations as laid out in Table 10.3.

The World Health Organization (WHO) criteria for malnutrition differ from The Academy and ASPEN standards (Table 10.4). The WHO criteria are used throughout the world and have been shown to be associated with an increased risk of morbidity and mortality. The WHO definition of pediatric malnutrition differs from The Academy and ASPEN criteria for pediatric malnutrition in the following ways:

- The WHO criteria uses an absolute mid-upper arm circumference (MUAC) value to define malnutrition, while The Academy and ASPEN criteria uses MUAC *z*-scores
- The WHO criteria includes length- or height-for-age *z*-score data as a criteria for moderate malnutrition while The Academy and ASPEN criteria does not

TABLE 10.3
Normal Variants Masquerading as Poor Growth

Cause	Possible Clues
Genetic short stature	• Short parents (Can be determined using mid-parental height. See Chapter 1) • Low percentiles that do not cross percentiles • Other genetic cause of short stature
Former premature infant	• Normal weight, if corrected for gestational age • Demonstrating catch-up growth • A portion of small-for-gestational-age infants will not have catch-up growth
Constitutional delay	• Initial drop in percentiles then following their own line • Family history of constitutional delay
Catch-down growth	• Large-for-gestational-age infant • Initial fall in percentiles, then following new percentiles

TABLE 10.4
WHO Criteria for Malnutrition (6–60 Months)

Criteria	Moderate Malnutrition	Severe Malnutrition
	Acute Malnutrition	
Weight-for-length or BMI-for-age z-score	–2 to –3	<–3
Mid upper arm circumference	11.5–12.4 cm	<11.5 cm
Symmetrical edema	Absent	Present
	Chronic Malnutrition	
Length- or height-for age *z*-score	–2 to –3	<–3

Source: Adapted from WHO Child Growth Standards and the Identification of Severe Acute Malnutrition in Infants and Children. A Joint Statement by the World Health Organization and the United Nations Children's Fund. World Health Organization and UNICEF, 2009.

- The WHO criteria includes assessment of edema, while The Academy and ASPEN criteria does not
- The WHO criteria traditionally are applied to children between 5-60 months of age while The Academy and ASPEN criteria can be applied across all ages in pediatrics

Although The Academy and ASPEN criteria for malnutrition are widely used in the USA, it is important for the dietitian to understand the WHO criteria as it is associated with morbidity and mortality. One important difference between the WHO and The Academy and ASPEN criteria is that the presence of symmetrical edema caused by nutritional deficiency automatically places a child in the severe malnutrition category. This should be remembered when using The Academy and ASPEN criteria, as children with nutritional edema have weights that may be artificially elevated and hence may not be diagnosed with malnutrition.

Wasting and Stunting

Wasting and stunting are defined using *z*-scores. Wasting is defined as weight-for-height *z*-score less than –2. Stunting is defined as height-for-age *z*-scores less than less than –2. Wasting is usually a symptom of acute undernutrition, while stunting is seen as a result of chronic nutrition deprivation.

Wasting and stunting in children are associated with health consequences. The severity of consequences is congruent with worsening *z*-scores.

Neonatal Malnutrition

The ability to evaluate malnutrition in the youngest pediatric patients has improved with the recent addition of established criteria to identify malnutrition in preterm and neonatal populations. Table 10.5 describes the criteria needed to diagnose neonatal malnutrition using 1 and 2 indicators.

TABLE 10.5
Primary Indicators of Neonatal Malnutrition – One Indicator Present

Indicators	Mild Malnutrition	Moderate Malnutrition	Severe Malnutrition	Use of Indicator
		Primary Indicators Requiring 1 Indicator		
Decline in weight-for-age *z*-score	Decline of 0.8–1.2 SD[b]	Decline of >1.2–2 SD	Decline of >2	Not appropriate for first 2 weeks of life
Weight gain velocity[a]	<75% of expected rate of weight gain to maintain growth rate	<50% of expected rate of weight gain to maintain growth rate	<25% of expected rate of weight gain to maintain growth rate	Not appropriate for first 2 weeks of life
Nutrient intake	≥3–5 Consecutive days of protein/energy intake ≤ 75% of estimated needs	≥5–7 consecutive days of protein/energy intake ≤ 75% of estimated needs	>7 Consecutive days of protein/energy intake ≤ 75% of estimated needs	Preferred indicator during the first 2 weeks of life
		Primary Indicators Requiring 2 or More Indicators		
Days to regain birth weight	15–18	19–21	>21	Use in conjunction with nutrient intake
Linear growth velocity[a]	<75% of expected rate of linear gain to maintain expected growth rate	<50% of expected rate of linear gain to maintain expected growth rate	<25% of expected rate of linear gain to maintain expected growth rate	Not appropriate for first 2 weeks of life May be deferred in critically ill, unstable infants Use in conjunction with another indicator when accurate length measurement available
Decline in length-for-age *z*-score[a]	Decline of 0.8–1.2 SD	Decline of >1.2–2 SD	Decline of >2 SD	Not appropriate for first 2 weeks of life May be deferred in critically ill, unstable infants Use in conjunction with another indicator when accurate length measurement is available

Source: Reprinted from Goldberg DL, Becker PJ, Brigham K, et al. Identifying Malnutrition in Preterm and Neonatal Populations: Recommended Indicators. *J Acad Nutr Diet*. 2018;118:1571–1582, Copyright 2018 with permission from Elsevier.

[a] Expected weight gain velocity, expected linear growth velocity, and *z*-scores can be determined using the online calculator PediTools (www.peditools.org).

[b] SD = standard deviation.

CORRECTING MALNUTRITION

After malnutrition is identified and diagnosed in the pediatric patient, a nutrition care plan can be developed and implemented. The goal of nutrition intervention is to correct malnutrition. The dietitian should work closely with the medical team to ensure that medical factors related to malnutrition are identified and addressed along with the nutrition intervention.

Nutrition Prescription

Indirect calorimetry provides the most accurate assessment of energy needs. When indirect calorimetry is not available, predictive equations can be used to estimate energy needs (Chapter 3). However, these equations predict energy needs required to maintain current growth trends and do not account for the additional energy needed to correct weight and height deficits. Energy needs for catch-up growth can be as much as 1.5–2 times maintenance energy needs. The dietitian should estimate energy needs using predictive equations and clinical judgment, and monitor the patient's growth to determine if adjustments are needed to promote nutrition rehabilitation.

Patients with malnutrition may also have increased protein requirements. Although the DRIs are typically used to calculate protein requirements (Chapter 3), additional protein may be required due to increased demands for catch-up growth. Fluid and micronutrient needs can be calculated using standard methods (Chapter 3). However, if micronutrient deficiencies are suspected, they may need to be confirmed with laboratory values and/or supplemented (Chapter 2).

Infants

Non-illness-related malnutrition in infants may be corrected by a regular feeding schedule providing human milk or standard-concentration infant formula in appropriate volumes.

Illness-related malnutrition will likely require further intervention that includes targeting the underlying disease process. To begin correcting malnutrition in young infants and neonates who can tolerate oral or enteral nutrition the use of fortification of human milk and/or concentration of formula should be considered to increase the energy density of the infant's feedings.

Infants who consume human milk as their main source of nutrition will benefit from the addition of formula to increase the energy density of the human milk (Table 10.6). This can be done with formula powder using prescribed recipes for desired energy concentration.

Infants who are reliant on formula feedings can be provided with increased energy density formula by adjusting the ratio of water and either formula powder (Table 10.7) or concentrate (Table 10.8). While recipes may vary slightly depending on the kilocalories per gram of formula powder, these recipes can be used for most standard infant formulas.

TABLE 10.6
Human Milk Fortification Recipes

Concentration (kcal/oz)	Human Milk (mL)	Powder
22	60	½ teaspoon
24	75	1 teaspoon
27	40	1 teaspoon
30	30	1 teaspoon

Recipes may vary slightly depending on the kilocalories per gram of formula powder. These recipes can be used for most standard infant formulas.

TABLE 10.7
Infant Powder Formula Recipes

Concentration (kcal/oz)	Water (oz)	Powder
22	5.5	3 scoops
24	6.5	4 scoops
27	7	5 scoops
30	5	4 scoops

Recipes may vary slightly depending on the kilocalories per gram of formula powder. These recipes can be used for most standard infant formulas.

TABLE 10.8
Formula Concentrate Recipes

Concentration (kcal/oz)	Concentrate	Water (oz)	Final Volume (oz)
22	1 can (13 oz)	11	24
24	1 can (13 oz)	9	22
27	1 can (13 oz)	6	19
30	1 can (13 oz)	4	17

In addition to increasing the concentration of the infant's human milk or formula, older infants who consume pureed or table foods can consume increased energy with the addition of nutrients to foods consumed. In general, foods before the age of one are thought to be supplementary energy and protein intake while the child learns to consume various flavors and textures. Many infant foods such as pureed fruits and vegetables are low in energy at baseline. To increase the energy density of pureed foods, one teaspoon of any oil that is liquid at room temperature can be mixed into 4 oz (~120 g) of pureed food. For example, 4 oz (~120 g) of pureed green beans provides approximately 40 kilocalories. With the addition of one teaspoon of canola oil, which contains 40 kcal, the energy density can be doubled to 80 kcal/4 oz (~120 g).

Older infants who have moved on to table foods may benefit from being fed high-energy foods or the addition of high-energy foods to the foods they consume. High-energy food recommendations for infants may include whole-milk yogurt, avocados, thinly spread nut or seed butters on toast or crackers, cheese, whole-milk cottage cheese, ground or diced meats. The addition of high-energy foods like gravy, sauces, butter, oils, or cheese may further increase the energy density of food already in an infant's diet.

Children and Adolescents

The use of evidence-based standardized nutrition interventions and protocols have been shown to decrease the severity of malnutrition in children. The following nutrition interventions should be individualized based upon the specific nutrition diagnoses for each child that presents with malnutrition. While certain nutrition interventions may be successful for some children, they may not be as effective in others. It remains important to utilize those interventions most appropriate for the individual child.

Mild malnutrition treatment protocol:

- High-energy and protein nutrition therapy. Provide oral nutrition supplements to meet 25%–50% of energy and protein needs.

- Track energy and protein intakes for a determined period of time.
- Education on high-energy and protein nutrition therapy for patient and/or caregivers.

Moderate malnutrition treatment protocol:

- Initiate mild malnutrition treatment protocol.
- Assess response to interventions after 7–10 days. If inadequate, progress to implementation of severe malnutrition treatment protocol.

Severe malnutrition treatment protocol:

- Enteral nutrition via feeding tube should be initiated for children who are unable to meet 100% predicted energy/protein needs by mouth.
- Initiate parenteral nutrition in children with impaired gut function or non-functional gut to meet 100% energy/protein needs.
- Assess response to interventions after 7–10 days. If acuity of malnutrition has improved, implement mild malnutrition treatment protocol.
- Take steps to avoid refeeding syndrome (see below).

When providing enteral nutrition via a feeding tube, consideration should be given to type of formula, route of delivery, and feeding regimen to provide the most appropriate intervention to treat the etiology of malnutrition. For children whose main cause of malnutrition is inadequate oral intake, a standard formula is likely appropriate. A partially hydrolyzed or amino acid-based formula may be appropriate for children whose cause of malnutrition is related to altered gut function or intolerance to standard formula or foods. Enteral nutrition may be used to supplement oral intake or provide 100% of the patient's nutrition needs for treatment of malnutrition. In the acute setting, the use of a nasogastric or nasojejunal tube is recommended to provide tube feeding formula. If the duration of malnutrition is chronic and/or not improving with previous interventions and if tube feeding is required for a longer period of time, a gastrostomy or gastrojejunostomy tube may be more appropriate. Feeding regimen should be determined for each patient individually based upon clinical condition and history. Bolus tube feeding schedules are the most physiologic; however, patients with malabsorption or intolerance of gastric feeding as a cause of malnutrition may require continuous feedings. See Chapter 8 for more information on enteral nutrition.

Parenteral nutrition may be indicated in patients with impaired gut function as the etiology of malnutrition or patients who are unable to meet 100% of nutrition requirements from oral or enteral nutrition. See Chapter 9 for more information on parenteral nutrition.

Refeeding syndrome may occur in infants and children with moderate to severe malnutrition after the initiation of treatment with oral, enteral, or parenteral nutrition. A comprehensive nutrition assessment revealing a risk of refeeding syndrome should result in a nutrition intervention with slow, deliberate introduction of nutrients and fluid, close monitoring of fluid and electrolytes, and adjustments of the nutrition regimen based upon the patient's tolerance. See Chapter 22 for more information on refeeding syndrome.

Illness-related malnutrition is often associated with an inflammatory condition. Critical illness, acute injuries, and chronic conditions are associated with varying levels of inflammatory response. Acute phase inflammatory response is associated with elevated resting energy expenditure, rapid catabolism, and anorexia. When evaluating for malnutrition, it is important to note the presence or absence of inflammation. Biomarkers such as C-reactive protein or cytokines should be considered in the evaluation of inflammation, if available. If inflammation is present, the effectiveness of nutrition interventions may be limited resulting in further deterioration of malnutrition severity. Without inflammation present, nutrition interventions may be more successful in treating malnutrition.

MONITORING AND EVALUATION

The goal of nutrition rehabilitation is to optimize short- and long-term developmental and clinical outcomes. For any intervention, there should be an outcome measure to assess the impact of the intervention. The measurement outcomes for nutrition rehabilitation and recovery are documented through improvements in anthropometric z-scores for weight, height, BMI-for-age (weight for length if <2 years), head circumference (OFC), MUAC, and triceps skinfold thickness (TSFT). Other signs of recovery include improvement in physical exam findings associated with malnutrition such as improvements in muscle wasting, resolution of edema, and increases in subcutaneous fat, and improvement in functional outcomes.

Expected Weight Gain

With appropriate nutrition intervention and treatment of underlying disease, if indicated, growth recovery is expected with weight being the main immediate measurement outcome. Weight represents the most rapid anthropometric measurement to change with nutritional rehabilitation. The expected degree and pace of change depends on the age of the child. Infants will have more rapid changes that can be seen on a day-to-day basis whereas it may take days to weeks to see improvements for older children and adolescents. When measuring the degree of gains, it is important to monitor for age-appropriate weight gains and catch-up growth. Catch-up growth occurs when weight gain velocity or linear growth velocity exceed what is expected for age. For children with malnutrition, catch-up growth is the growth needed to bring them back to their growth potential (Chapter 1).

Other Anthropometric Measurements

Weight gains alone do not describe the full impact of the nutritional rehabilitation process. While weight may rapidly recover, increases in height/length, OFC, and improvements in overall functional status take longer to appear. When monitoring children for their response to nutritional interventions, length should be assessed in all children <2 years of age, height should be assessed in all children >2 years of age, and OFC should be assessed in all children <2 years of age.

Many factors may impact changes in weight. Weight is impacted by gains in fat, muscle, and fluid. Therefore, in some instances, weight will not accurately reflect nutritional status such as in chronic liver disease which is complicated by ascites and edema. In these cases, increases in TSFT and MUAC should be monitored to assess response to nutritional intervention as surrogates for total body fat and muscle mass, respectively.

Since as a measurement weight is relatively generic, it does not delineate the amount of fat and muscle accretion for a given increase in weight. This is important as increases in fat-free mass in infants are associated with improved developmental and metabolic status. As stated previously, TSFT and MUAC at times are used as surrogates of fat and muscle mass since they can be performed at the bedside and there are defined age- and sex-specific norms (Chapter 1). Other reference standards to assess the quality of weight gain through assessment of body composition are not practical to use at the bedside (dual-energy X-ray absorptiometry scan (DEXA), air-displacement plethysmography, total body potassium, CT, and MRI) or are yet to be validated in general pediatric populations (bioelectrical impedance and ultrasonography).

Long-Term Monitoring

In the long term, once recovered from malnutrition, it is important that adequate nutritional status is maintained. Children with underlying chronic disease and those who are at risk for malnutrition due to social determinants of health may require more frequent monitoring of their growth and overall

nutritional status than the general pediatric population. At a minimum, growth should be followed per established guidelines for age, but many children will require more frequent assessments due to underlying risk factors.

Malnutrition is a prevalent problem worldwide and in children with underlying chronic disease. Malnutrition impacts children acutely and chronically and also impacts the health system as a whole. Identification, treatment, and prevention of malnutrition are critical for overall childhood health.

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11 Care of the Hospitalized Child

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CONTENTS

This chapter focuses on children that require inpatient care, from both medical and surgical etiologies. This does not include children in intensive care units (Chapters 12 and 13). Pediatric patients have unique nutrition needs because they have their daily metabolic needs plus the nutrition needed for growth. Children that require hospitalization often have an underlying medical diagnosis with malnutrition being more common in this population. Thus, hospitalized children commonly will require some sort of nutrition intervention. The literature suggests that appropriate nutrition support therapy can potentially prevent complications and improve outcomes.

COMMON MEDICAL CONDITIONS THAT AFFECT NUTRIENT INTAKE

There are basically three problems that lead to undernutrition in children: inadequate intake, significant losses, and increased nutrition needs. Intake is altered by factors such as dysphagia or

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neurologic disorders. Losses can occur through vomiting or malabsorption (manifested by diarrhea). Increased needs are due to oncologic, metabolic, or inflammatory conditions. Many childhood diseases are complicated by inflammation, which utilizes a high level of energy and quickly leads to malnutrition.

Commonly, the hospitalized child has an acute condition which results in a brief hospitalization. However, children with chronic conditions can require hospitalization as part of the care for that condition. Since the underlying condition can both predispose to and worsen malnutrition, they often have chronic malnutrition. Finally, children with chronic malnutrition can have acute worsening of malnutrition during the hospitalization.

Similarly, in surgical conditions, many children have brief hospitalizations for procedures such as appendectomies. However, complications of these procedures can result in inadequate intake and acute malnutrition. On the other hand, children with chronic disease sometimes undergo both planned and unplanned surgeries. Part of the planning for surgery in children with chronic medical conditions (e.g., child with severe cerebral palsy undergoing spinal surgery or the child with inflammatory bowel disease undergoing bowel resection) includes optimizing nutrition status prior to surgery. When the surgery is urgent or emergent, children with chronic disease may require postoperative nutrition rehabilitation as may children who have had planned surgery. Common indications for pediatric hospital admission and nutrition considerations are discussed in the following sections.

Bronchiolitis

Bronchiolitis is a frequent cause of hospital admission among young children and accounts for 15% of all hospitalizations in children under 2 years. It is typically caused by a virus in the winter months and causes breathing difficulties. It is usually treated with supportive care and most infants recover without problems though rarely the condition is severe enough to warrant intensive care unit admission.

The supportive care for patients with bronchiolitis involves providing appropriate fluid support while children receive respiratory treatment and oxygen. Traditionally, there has been reluctance to orally feed children with bronchiolitis due to concerns about respiratory deterioration when children are breathing at higher respiratory rates and/or when they need higher rates of oxygen support. Data now shows that these children can be safely fed orally despite these concerns. In rare instances, where the child cannot be fed by mouth, nasogastric feeds are well tolerated without leading to further respiratory deterioration. Hence, these children should be continued on oral feeding whenever possible and also, this feeding should likely commence as soon as possible after admission.

Acute Gastroenteritis

In the USA, gastroenteritis accounts for about ~10% (220,000) of admissions to the hospital. Frequently, children who are admitted to the hospital with acute gastroenteritis require intravenous hydration.

Apart from rehydration, principles of nutrition management of infants with gastroenteritis include: the continuation of breastfeeding throughout the course of treatment and resumption of normal diet (without restriction of lactose intake) immediately after rehydration. Ideally, the diet for older infants should include milk and solids including complex carbohydrates, lean meats, yogurt, and vegetables, but foods high in fat and sugars should be avoided. In formula-fed infants, there is no need to dilute formula when it is reintroduced. If diarrhea returns with each feed of milk, lactose may be temporarily withheld (for up to 2 weeks).

Surgical Patients

Patients undergoing surgery may undergo the procedure unexpectedly (emergent procedures) or may have a planned procedure that is done electively. When the procedure is done electively, any procedure that is likely to need hospitalization for >48–72 hours should be considered differently, particularly if much of this time will be with the child unable to eat or tolerate enteral nutrition (EN). If malnutrition is detected preoperatively in these patients, it is best that it is corrected prior to surgery. This malnutrition can be resolved by using oral supplements for 4–6 weeks prior to surgery. If the child is unable/unwilling to take these supplements, short-term EN to address the malnutrition may be indicated. It would be unusual for children to require parenteral nutrition (PN) to address the malnutrition in the absence of significant intestinal dysfunction (e.g., intestinal stricture needing surgery in Crohn's disease). When the surgery cannot be delayed for 4–6 weeks, it may be beneficial to either use high-energy supplements or nasogastric tube feeding for 2 weeks prior to the surgery. This may not serve to resolve the malnutrition but may make the child more anabolic and likely reduce surgical complications.

In the case of emergent surgery, if the child is malnourished and there is likely a prolonged nil per os (NPO) time of >5–7 days (or 3–5 days in younger children), the child should be started on nutrition support right after the procedure. If the child has a functioning gastrointestinal tract, this should be EN. Patients with a nonfunctioning GI tract will require PN. If the child is not malnourished but remains NPO for >5–7 days (3–5 days in younger children) after surgery, a similar approach should be taken.

INITIATING FEEDINGS IN THE HOSPITAL SETTING

Nutrition support therapy is indicated when a patient has insufficient oral intake to meet energy or nutrition requirements for age, regardless of the presence of acute or chronic malnutrition. Malnutrition is prevalent in hospitalized patients and may be more severe in patients with a poor nutrition status at admission.

In children younger than 1 year of age, it is recommended that nutrition support therapy be initiated within 3 days if it is anticipated that adequate oral intake will not be possible within that time frame. In children older than age 1 year, nutrition support therapy should be initiated within 5 days if it is anticipated they will have inadequate oral intake within this time. Nutrition support therapy should be initiated within 7 days for older adolescents and young adults. Regardless of age, if children are malnourished, it is recommended that nutrition support therapy be initiated earlier in the hospital course, not only to provide adequate nutrition but to prevent further nutrient deficit. The European Society for Pediatric Gastroenterology, Hepatology, and Nutrition (ESPGHAN) also recommends that nutrition support therapy is indicated if the patient demonstrates an inability to meet 60%–80% of their individual requirements for 10 days or more. Figure 11.1 provides an algorithm for determining the need for nutrition support therapy in the hospitalized patient.

Oral Feeding Considerations

Feeding by mouth or per oral (PO) feeding is the preferred route of nutrient administration whenever possible, if it is medically safe to do so. If the hospitalized patient can consume oral feedings to meet her daily nutrition intake and show optimal growth, oral feedings should be continued. On occasion, nutrition support therapy in the form of EN may be required due to inadequate oral nutrition intake. A 3-day calorie count may be utilized to evaluate the need for and estimate the amount of nutrition supplementation needed in addition to the oral diet. Oral feeding, even in small mounts, should be continued if safe to do so to preserve oral skills, especially in infants, even if oral feeding is inadequate to meet their nutrition needs.

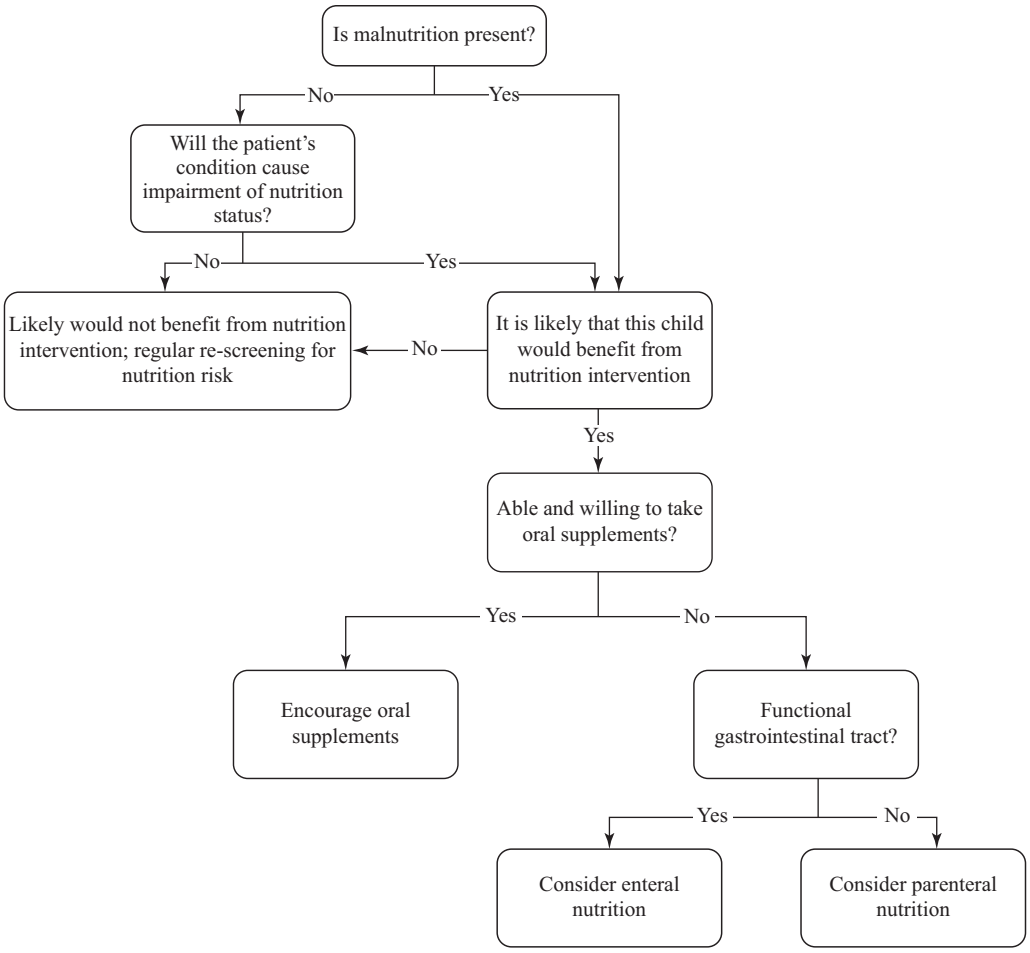

FIGURE 11.1 Nutrition support algorithm for pediatric hospitalized patients.

When malnutrition is present but the condition is unlikely to cause impairment of nutrition status, it suggests that the child will not require prolonged hospitalization. Plans must be made to address this malnutrition likely using oral supplements. When malnutrition is absent and the condition is likely to cause impairment of nutrition status, repeated reassessment is needed as well as a thorough risk-benefit analysis to decide the timing and optimal method of nutrition support.

Clear liquids are often used as a method to evaluate whether a child will tolerate EN. These fluids, such as juices and broths, are low in nutrition quality and energy density and typically extend the time before which the child can consume adequate energy and protein. Apart from the use of oral rehydration solutions that are used for the management of acute gastroenteritis, clear-liquid diets should generally be avoided.

If a hospitalized patient is unable to meet nutrient requirements via an oral diet alone, nutrition supplements should be considered as an adjunct to the diet. Age should be considered when choosing oral nutrition supplements. In certain disease states, such as Crohn's disease (Chapter 16), in addition to optimizing nutrition status, oral nutrition supplements may be used as a therapeutic option as well.

The type of oral nutrition supplement indicated depends on many factors, including patient age, medical conditions, food allergies, and tolerance to previous oral nutrition supplements. Standard

formulas are the preferred option when medically safe. Feeds may be initiated with an elemental or peptide-based formula when it is indicated for conditions such as milk-protein intolerance or delayed gastric emptying. In patients with oropharyngeal dysphagia, recommendations may be made regarding addition of thickening agents to oral feeds based on swallow evaluations, typically performed by speech-language/occupational therapists. Oral feedings may be contraindicated in patients with severe dysphagia and aspiration.

Enteral Feeding Considerations

EN is indicated when a patient is unable to meet nutrition and/or fluid needs orally. It is also indicated when oral intake is limited secondary to a disease process such as dysphagia, short bowel syndrome, gastrointestinal dysmotility, as well as neurological conditions that affect oral intake.

In pediatric patients with at least a partially functional gastrointestinal tract, it is recommended that EN use be maximized in preference to PN. In contrast to PN, EN has several advantages, including preservation of gastrointestinal function by maintaining mucosal integrity and fewer complications as compared to PN (Chapter 8). Clinical guidelines and recommendations advocate for the use of EN over PN whenever possible as the preferred form of providing nutrition. Providing even minimal or trophic amounts of EN when possible is beneficial. Prior to abandoning EN for PN, post-pyloric EN should be considered and/or attempted.

Parenteral Nutrition Considerations

PN is needed when a non-functional gastrointestinal tract precludes the use of EN or when EN alone is not sufficient to meet nutrient needs. Although it has proven to be a successful treatment for maintenance and promotion of nutrition, PN is associated with risks such as central line infections, liver disease, and fluid/electrolyte imbalances in addition to the cost of treatment and prolonged hospitalization. Thus, the use of PN should be justified based on an evaluation of risks and benefits. In addition to disease state or medical diagnosis, other factors that should be taken into account when considering PN include but are not limited to integrity and function of gastrointestinal tract, safe intestinal tract access to promote EN, severity of disease, baseline nutrition status of the patient, and anticipated duration of therapy. Administration of EN may be temporarily affected in conditions such as severe inflammatory bowel disease, intractable diarrheal illnesses, intestinal obstruction, or even severe motility disorders and these conditions are an indication for PN until the gastrointestinal tract is ready for EN.

PN may be initiated within 3 days of no nutrient intake in infants and 5 days in older children; dependent on if they have acute/self-limited illnesses and are unable to tolerate adequate oral or enteral fluid and/or nutrition intake. PN should be considered in children with chronic conditions that affect the ability to tolerate adequate EN for optimal growth and/or when energy needs are higher secondary to their disease pathology. However, the duration of need of PN should also be considered. In general, use of PN for fewer than 3–5 days is considered unhelpful. Also, central venous access should be present or obtained prior to commencing PN.

NUTRITION MANAGEMENT OF HOSPITALIZED CHILDREN

Nutrition Assessment

A nutrition assessment conducted by a dietitian is a crucial first step during a hospital admission. The assessment should be performed on patients identified during nutrition screening, which typically occurs within 24–72 hours of admission. During the nutrition assessment, the dietitian should conduct a thorough review of the patient's chart to identify any underlying medical conditions or pertinent background which could affect nutrition status. Factors affecting nutrition status can

include gastrointestinal malabsorption, EN/PN at home, and socioeconomic factors. The patient's estimated needs for energy, protein, and fluids should be documented in order to allow for proper nutrition delivery. Micronutrient needs may also be documented based on abnormal laboratory values indicating the need for repletion of certain vitamins and minerals. A malnutrition diagnosis upon admission can indicate the need for nutrition repletion prior to surgery in order to improve outcomes for the patient.

Anthropometric Measurements

A weight should be obtained at the time of admission and discharge. See Chapter 1 for measurement techniques. Bed scales can be used for patients who are unable to stand. The scale used should always be noted in the chart to achieve consistency with these important measurements. Signs of edema should also be noted as this affects the weight. Frequency of weight measurements is dependent on the patient's age and nutrition status (Chapter 1). Patients with malnutrition or at risk of malnutrition will need more frequent weight measurements. If a patient is unable to gain weight after surgery or shows weight loss, further nutrition intervention is warranted as proper nutrition is vital for surgery recovery.

An accurate height/length can be a good indication of nutrition status and should be obtained upon admission. See Chapter 1 for appropriate length/height measurement techniques.

Head circumference should be measured in infants and toddlers (Chapter 1). Mid-upper arm circumference (MUAC) and triceps skinfold thickness (TSFT) can provide a good measure of nutrition status without the influence of fluid fluctuations.

Tracking weight gain in an acute care setting can help navigate the need for nutrition support therapy. A clinician should keep in mind the effect an NPO status and intravenous fluids over several days can have on weight gain/cause weight loss.

Nutrition-Focused Physical Exam

The nutrition-focused physical exam (NFPE) should be a part of any nutrition assessment, even in an acute care setting. An experienced dietitian should examine the patient's muscle/fat stores, hair, nails, and skin. See Chapter 2 for more details about the NFPE. NFPE findings can identify underlying macro- and/or micronutrient deficiencies which could be affecting nutrition status and growth. Those deficiencies (i.e., vitamin C) could also lead to delayed wound healing or recovery from surgery, so early detection and correction is key.

Nutrient Intake

The dietitian can take the lead in verifying regular food intake and/or feeding regimens at home. A thorough feeding history such as a 24-hour recall can help navigate the feeding plan during admission. For example, if the recall shows a large gap in energy and protein in an orally fed child who is a selective eater, a nutrition supplement may be indicated. EN regimens should be verified by asking about formula mixing, volume and quantity of bolus feeds, rate and time on continuous feeds, and free water flushes. Food insecurity can be a real concern and relevant to a child's nutrition status. Asking questions about food availability in the household should be part of a dietitian's interview as well. The dietitian should assess nutrient intake from all sources, including oral foods and supplements, EN, PN, intravenous fluids, and supplements.

Common Medications and Drug-Nutrient Interactions

Although a patient's medications can be reviewed in the electronic medical record, the dietitian should also ask about non-formulary herbal supplements and vitamins a patient is taking. Certain supplements/medications are affected by foods or timing of meals so usual times for medications should also be recorded. See Table 11.1 for the list of common drug-nutrient interactions.

TABLE 11.1
Common Drug-Nutrient Interactions

Drug	Drug-Nutrient Interaction
Antacids	• Decreased iron absorption • Decreased phosphate absorption (with aluminum-containing antacids)
Cholestyramine	• May decrease the absorption of fat-soluble vitamins, especially of vitamin K to increase the risk of bleeding
Digoxin	• High doses of supplemental calcium can increase the side effects of digoxin and predispose to arrhythmias • Digoxin can predispose to hypomagnesemia, and hypomagnesemia can in turn increase risk of digoxin toxicity; also, magnesium-containing antacids decrease digoxin absorption
Histamine-2 (H2) receptor antagonists (famotidine, ranitidine)	• Long-term use might result in vitamin B_{12} deficiency • Long-term use might decrease iron status • May decrease calcium absorption
Ketoconazole	• Inhibits the enzyme that converts vitamin D into its active, dihydroxylated form
Levothyroxine	• Concomitant intake of levothyroxine and calcium or iron supplements may decrease levothyroxine absorption
Loop diuretics	• May result in hypokalemia • Longer term use may result in magnesium and thiamine depletion
Metformin	• Interferes with the absorption of vitamin B_{12}
Methotrexate	• Can lead to folate deficiency
Orlistat	• May decrease the intestinal absorption of carotenoids and fat-soluble vitamins
Phenytoin	• Decreases absorption of folate • Decreases serum concentration of 25-hydroxyvitamin D
Proton-pump inhibitors	• Long-term use can result in vitamin B_{12} deficiency
Quinolone antibiotics	• Concomitant administration with calcium, iron, magnesium, or zinc will decrease absorption of both the antibiotic and the nutrient
Rifampin	• Decreases serum concentration of 25-hydroxyvitamin D
Sulfasalazine	• Can decrease intestinal absorption of folate
Tetracycline-class antibiotics (doxycycline)	• Concomitant administration with calcium, iron, magnesium, or zinc will decrease absorption of both the antibiotic and the nutrient
Thiazide diuretics	• Decrease urinary excretion of calcium • Increase urinary excretion of magnesium, potassium, and zinc
Trimethoprim/Trimethoprim-sulfamethoxazole	• Its use may increase the risk of folate deficiency
Valproic acid	• May decrease carnitine status with long-term use
Warfarin	• Vitamin K will counteract the effects of warfarin • Possible interaction with grapefruit where grapefruit could potentiate the effects of warfarin • Consumption of large quantities of green tea could decrease the effects of warfarin • May interact with a variety of herbal supplements which could potentiate the effects of warfarin (high-dose ginger, gingko biloba, sweet clover, turmeric) or decrease them (echinacea, St. John's wort, ginseng)

Source: Adapted from Micronutrient Information Center, Linus Pauling Institute. 2021. Drug-Nutrient Interactions. https://lpi.oregonstate.edu/mic/drug-nutrient-interactions Accessed October 3, 2021 and from Asher GN, Corbett AH, Hawke RL. Common Herbal Dietary Supplement–Drug Interactions. *Am Fam Physician*. 2017;96:101–107.

Nutrition Diagnosis

Nutrition diagnoses in the hospital setting depend on multiple factors, including nutrition status, reason for admission, and current medical and surgical issues affecting nutrition status. A diagnosis of malnutrition is common in the hospital setting and should be identified and addressed early to improve outcomes. Common nutrition diagnoses in the hospital setting include:

- Increased energy expenditure
- Inadequate energy intake
- Predicted inadequate energy intake
- Inadequate oral intake
- Increased nutrient needs
- Inadequate vitamin intake (specify)
- Inadequate mineral intake (specify)
- Malnutrition (undernutrition)

Nutrition Intervention

The most appropriate mode of nutrition intervention is based on multiple factors including but not limited to age of the patient, anatomical and functional gastrointestinal integrity, safety, and ability to take oral feeding and disease pathology. Nutrition therapy has a significant role in hospitalized malnourished patients, especially those undergoing surgery. Surgical processes can add to the physiological stress in already sick and malnourished patients. In addition, suboptimal nutrition in the perioperative period is associated with poorer surgical outcomes with regard to wound healing, infection, fluid-electrolyte imbalances, and increase duration of hospitalization. Initial nutrition assessment is important to delineate the degree of malnutrition and identify patients that require nutrition therapy pre- and postoperatively.

Nutrition Prescription

Nutrient needs will vary depending on the reason for hospital admission and the patient's medical diagnoses. For many patients, standard equations can be used to estimate nutrient needs. Acute conditions may increase energy and protein needs, including wound healing and surgical recovery. The dietitian should communicate with the medical team to ensure the best nutrition prescription in the setting of the acute medical management.

Oral Feedings

Oral feeding is always preferred and recommended if the swallowing mechanism and the gastrointestinal tract are intact. Certain circumstances may limit oral nutrition intake. Oropharyngeal dysphagia with concerns for aspiration, neurological abnormalities affecting deglutition, and gastrointestinal dysmotility may make oral feedings unsafe.

A regular balanced diet should be continued if it is sufficient to provide adequate nutrition. Dietitian assessment to establish energy needs and evaluate optimal intake early on in hospitalization is helpful to formulate a nutrition plan. Nutrition supplementation may be indicated secondary to baseline nutrition state and effect of disease. Standard pediatric polymeric formulations (30 kcal/oz [1 kcal/mL]) can be utilized for this purpose in addition to regular diet in patients > 1 year of age. Higher energy/concentrated formulations are also available and can be used in volume-sensitive patients. In infants, concentration of infant formulas may be modified to meet needs and should be done with careful monitoring (Chapter 10). Extensively hydrolyzed and elemental formulations are available when intact proteins are not tolerated; for example, in cow milk-protein intolerance. These formulations may have the added benefits of better emptying from the stomach and improved

absorption. Infants and younger children may tolerate these formulations fairly well by mouth; however, EN may be required as these tend to be less palatable than standard supplements. Some disease states such as Crohn's disease may require intake of polymeric formula exclusively as therapy (Chapter 16). Older children are at times able to tolerate this orally, however, may also need EN if the formula is not palatable for the patient in the volumes recommended.

Enteral Nutrition

Enteral formulas are designed to provide a balanced combination of essential nutrients required to meet requirements and promote growth and can act as the sole nutrition source. In some cases, supplemental feeds may be utilized to ensure provision of adequate nutrition in addition to what is consumed by the patient at baseline.

Enteral Formulas

EN may be offered as ready-to-feed liquid formulation or powdered formulations that require mixing prior to administration. Formulations with variable energy concentrations are available. Routinely, formulations that provide 1 kcal/mL are considered standard in the pediatric population. Energy dense formulations are also available that provide more calories (~1.5 kcal/mL) if indicated. The choice between polymeric formulations with intact protein versus peptide-based or elemental formulas is based on indication, clinical condition, and disease pathology (Chapter 8).

Disease-specific formulas may be required in certain cases. Formula with increased medium chain triglyceride (MCT) content is preferred in severe cholestasis, liver disease, short bowel syndrome, and other malabsorptive states. Patients with galactosemia or other forms of carbohydrate malabsorption may require modified carbohydrate formulations. Hydrolysate or elemental formulations are used in any type of allergic enteritis. Incorporation of fiber in the formula can help with both constipation and diarrhea.

Enteral Access Devices

When indicated, EN can be provided by several different routes and choice of route is based on age of patient, anticipated duration of EN, anatomy/integrity as well as functionality of the gastrointestinal tract and disease state.

Gastric feeds are preferred to post-pyloric feeds as they are more physiological and management of gastric tubes is less cumbersome and associated with fewer complications. Gastric feeds may be administered via orogastric (OG), nasogastric (NG), or gastrostomy tubes (GT). OG and NG routes are most often utilized when EN is perceived as a short-term (4–6 weeks and up to 12 weeks) requirement, mainly in hospitalized patients. The OG/NG can be placed bedside by trained medical personnel. Accurate positioning should always be confirmed prior to use.

A GT is indicated when need for EN is required chronically as may be the case with certain disease states. Anticipated need for EN support > 4–12 weeks is an indication for GT placement. GTs are generally a safe and straightforward method of providing EN. Gastric tubes can provide continuous as well as bolus feeds into the stomach. Bolus feeds are more physiological and hence, if tolerated are preferred.

Certain clinical conditions such as aspiration and functional or mechanical gastric outlet obstruction necessitate post-pyloric feeding. Post-pyloric feeds can be provided via nasojejunal (NJ) or surgically placed long-term enteral access devices such as gastrojejunal (GJ) or jejunostomy (J) tubes. Nasoenteral devices may be placed at bedside but are most commonly placed with fluoroscopic assistance. Proper positioning needs to be confirmed prior to use, especially if placed at bedside. Position of the tube should also be confirmed on an ongoing basis. Potential issues include inadvertent dislodgement, blockage, and misplacement of the device. Surgically placed enterostomy tubes are also prone to dislodgement and rarely can cause intestinal obstruction.

Post-pyloric feedings should be administered continuously with cautious, gradual increments in rate, especially when using energy dense and/or hyperosmolar formulations.

Weaning EN

Patients receiving EN should be started on an oral diet as soon as possible. As their oral intake improves, EN can be decreased accordingly. The dietitian should assess the EN regimen and adjust the feeding schedule accordingly to prevent satiety and improve acceptance of oral feedings. When a hospitalized patient is able to meet 80% of nutrient needs by mouth, EN can be discontinued. Patients unable to meet their needs by mouth can be discharged on EN with close outpatient dietitian follow-up to work on weaning EN in the home setting.

Parenteral Nutrition

PN should be used when the intestinal tract is not functional or cannot be accessed or when nutrient needs to provide for growth are greater than that which can be provided through oral intake or EN support alone. PN may be provided via a peripheral or central device.

Peripheral PN is intended for short-term purposes, in pediatric patients who are well nourished at baseline or have mild malnutrition and when it is anticipated that patient will progress to full EN in 7–10 days. Peripheral PN may at times be used as a bridge to central PN. The osmolarity of the peripheral PN solution is limited, which may result in inadequate nutrient intake if the patient is fluid restricted. If a patient is not progressing as expected on EN in 5–7 days, centrally administered PN should be considered. Centrally administered PN allows for the delivery of adequate fluid and nutrients in a high-osmolarity solution.

Components of PN

Chapter 9 outlines macronutrient and micronutrient PN recommendations for infants and children. Specific PN considerations for the hospitalized patients are described here. Protein needs are higher in critical illness and protein content should be optimized in the perioperative period. When chronic PN is required, as in the case of intestinal failure, lipid minimization strategies or alternate lipid injectable emulsions (ILE) are utilized to prevent PN-associated liver disease. In order to prevent essential fatty acid (EFA) deficiency, infants and children should receive a minimum of 0.5–1 g/kg per day of ILE.

Micronutrients in PN include electrolytes, minerals, vitamins, and trace elements. Additional vitamin D supplementation may be needed in addition to PN multivitamin. In the case of liver pathology, patients may require additional supplementation of fat-soluble vitamins (A, D, E, and K).

Cycling and Weaning PN

PN is usually initiated as a continuous infusion over 24 hours. Cycling PN indicates running the PN over a shorter time period allowing the patient time off the PN infusion. Working toward cycling is done by gradually reducing the infusion duration over a period of days/weeks once a patient is clinically stable and able to maintain blood glucose for a period without PN. Cycling PN is better tolerated in older children as compared to neonates due to immature pathways of glucose metabolism in contrast to high glucose needs. The infusion duration may be shortened by 1–2 hours every 1–2 days to reach the desired infusion duration goal. This is ideally established prior to discharge to ensure the patient is able to tolerate it without any complications which may include hyperglycemia, hypoglycemia, and respiratory distress. Cycling PN has shown to have a protective effect against intestinal failure associated liver disease (IFALD). When cycling PN, it is important to monitor glucose infusion rate (GIR) and lipid infusion rate to ensure that the PN prescription remains within acceptable ranges (Chapter 9).

It is always recommended that feeds be restarted using EN as soon as clinically possible. While providing EN, even minimal amounts of trophic feeding, if tolerated, should be continued to promote intestinal adaptation and maintain mucosal integrity. EN should be increased gradually as tolerated, making only one change at a time. Every attempt should be made to encourage and promote even minimal oral intake when deemed safe to avoid oral aversion. PN should be decreased

gradually as EN is increased. EN may be introduced as continuous feeds and then gradually condensed into bolus feeds over time.

Nutrition Education

If hospitalized patients will require continued nutrition intervention at home (oral nutrition, EN, or PN), nutrition education is essential prior to discharge. This will prepare them for success at home. In addition, the care team should consider the patient's home schedule and adjust the hospital nutrition therapy to meet the home schedule prior to discharge. Condensing tube feedings to fewer feedings per day or adjusting feeding times to match home routine, school schedule, and sleep schedule will set the patient up for success after discharge. Outpatient follow-up with a dietitian should also be discussed prior to discharge.

With respect to EN, this includes training regarding appropriate mixing of the enteral formula, care of the enteral access device, administration of EN via the enteral access device, and common problems/issues that may arise with EN administration at home.

Education related to home PN is more complicated involving aseptic precautions when accessing central lines, safely administering the PN formulation, and recognizing potential complications. In both scenarios, caregivers should be made aware of the situations that require immediate medical attention. Ideally, the parent or caregiver should independently demonstrate appropriate care of the child while in the hospital and be supervised by skilled staff to certify that they are able to successfully perform the tasks required prior to discharge.

In addition to education of the families, education of the healthcare team is critical as well. Ongoing nutrition-related education directed toward healthcare teams is essential to ensure appropriate nutrition rehabilitation of hospitalized patients. This may include regular in-service modules, easy reference guides/pocket cards, and regular quality improvement initiatives. Education should be directed toward identification of at-risk patients, assessing needs and deficits with the assistance of nutrition support teams, and safe EN and PN prescribing and monitoring practices as an integral part of the trainee core curriculum.

Laboratory Monitoring

Pediatric nutrition support therapy is individualized, and monitoring is thus tailored specific to each patient. It is important to establish goals for each patient at the initiation of nutrition support therapy and regularly modify the goals based on progress. Routine lab monitoring may not be required and is not typically recommended for EN in patients who are medically stable and meeting growth standards while on the prescribed EN. When nutrition support is initiated in a severely malnourished patient, electrolyte levels (especially phosphorus, potassium, and magnesium) are obtained to monitor for and prevent refeeding syndrome (Chapter 22). Electrolyte abnormalities may also be seen with EN-associated diarrhea secondary to excessive losses and may be an indication for intravenous electrolyte replacement.

It is important to obtain baseline lab parameters prior to initiation of PN. Lab values that are significantly out of range should be corrected prior to initiation of PN. Chapter 9 provides recommendations for lab parameters to monitor and frequency of monitoring. Frequency of lab monitoring is gradually decreased once values stabilize, and the patient is clinically stable. For patients on chronic PN, periodic assessment of micronutrient status is recommended (Chapter 9).

Supplements

Modular additives are available as macronutrients that may be added to increase energy density of enteral formulas. These products include energy supplements (from carbohydrate and/or fat), protein supplements, fiber supplements, and electrolyte solutions. Care should be taken with final osmolarity of the product especially when using carbohydrate or protein modulars.

Other Specialty Referrals

A multidisciplinary approach has proven to be highly effective in tailoring care to each individual patient by catering to specific needs and concerns. The dietitian works closely with other team members to ensure coordination of care during the hospital admission. Attending rounds or communicating with the attending provider ensures the nutrition interventions align with the medical and surgical goals of the hospital admission.

Establishment of a pediatric nutrition support team (NST) is shown to be highly effective in managing nutrition support therapy and rehabilitation of hospitalized patients. Ideally, the NST is composed of multidisciplinary experts including pediatricians, dietitians, pharmacists, and nutrition-focused nursing staff as its core members. Sub-specialists such as pediatric gastroenterologists with specific interest in nutrition can prove to be valuable assets, especially when managing patients with inherent intestinal issues such as short bowel syndrome and dysmotility. Other members that may serve on the NST as experts include pediatric surgeons, rehabilitation team members such as occupational therapists, speech-language therapists, physical therapists, psychologists, wound and stoma care teams, and vascular access teams. Some other specialty referrals that may be considered for specific patients include to pediatric endocrinologists, geneticists, experts in metabolic disorders, and palliative care teams.

TABLE 11.2
ADIME Summary for Hospitalized Children

- Assessment
  - Growth assessment
    - Ensure accurate and timely measurements
  - Nutrition-focused physical exam
  - Nutrient Intake
    - Consider all sources: Parenteral nutrition, intravenous fluids, enteral nutrition, oral, supplements
  - Labs
  - Gastrointestinal Findings
  - Medications/Side Effects
- Diagnosis
- Intervention
  - Nutrition Prescription
    - Consider acute medical conditions that may affect nutrition prescription
  - Common nutrition interventions
    - Oral
      - Provide oral feedings whenever medically feasible
      - Avoid prolonged clear-liquid diets
    - Enteral Nutrition
      - Infants: initiate within 3 days of inadequate oral intake
      - Children: initiate within 5 days of inadequate oral intake
    - Parenteral Nutrition
      - Initiate within 3 days for infants and 5 days for children
      - Consider duration of need
      - Consider central venous access
    - Education
    - Laboratory Monitoring
    - Supplements
      - Consider oral nutrition supplements
    - Other specialty referrals
      - Speech therapy
      - Nutrition support team
- Monitoring and Evaluation

Nutrition Monitoring and Evaluation

The nutrition care plan should state how often the recommended nutrition interventions will be monitored. The patient's anthropometric measurements are monitored on a regular basis dependent on prematurity, postnatal age, disease state, malnutrition status, and the level of metabolic stress. Lab values should also be followed to help determine the effectiveness of the nutrition intervention. Patients on PN require frequent lab monitoring to ensure a proper concentration of electrolytes, minerals, vitamins, trace elements, and carnitine in the PN solution. However, essential lab work should be conducted at appropriate intervals in order to avoid causing deficiencies (i.e., iron) from excessive blood draws. Intake and output are followed to determine the patient is receiving the correct amount of formula, PN, and/or fluid. It is also important to track electrolyte status if there are excessive losses from ostomies, drains, and fistulas.

Certain medications can influence tolerance to feeds and/or gastrointestinal status so a thorough review of medications is crucial. Changes in gastrointestinal status such as increase/decrease in bowel movements, abdominal distention, and blood/fat in the stool may warrant a change in the nutrition plan. Changes in the care plan should be discussed with the care team, patient, and patient's family. The dietitian should continue to provide frequent nutrition reassessment in the hospital setting until nutrition diagnoses are resolved (Table 11.2).

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12 Care of the Premature and Ill Neonate

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CONTENTS

One of the challenges of neonatal nutrition is that the infants admitted to the neonatal intensive care unit (NICU) comprise a unique population within the field of pediatrics that spans a wide range of disease states. For instance, the nutrient needs of an extremely preterm infant born at 23-weeks gestation are very different from the nutrient needs of a term infant with intestinal atresia, but both rely heavily on nutrition interventions to support their growth and development. In this chapter, we will cover specific considerations for high-risk infants, including growth assessment, parenteral and enteral management, and approaches to nutrition after discharge.

COMMON MEDICAL CONDITIONS THAT AFFECT NUTRIENT INTAKE

There are a number of conditions that can present challenges for optimal growth in newborns either through limits in amount of intake or increased demands in energy and nutrient requirements. An infant born before 37-completed weeks gestational age is considered preterm. Preterm infants are at risk of a variety of medical complications and are at increased nutrition risk. Preterm infants born before 34 weeks gestation will require nutrition support therapy as they have not yet developed safe coordination of sucking, swallowing, and breathing. Premature infants born between 28 and 38 weeks usually do not have adequate subcutaneous fat, muscle tissue, or tissue stores of iron and calcium as these stores are acquired during the third trimester of pregnancy. Infants born at this gestation will require nutrition interventions to meet these needs.

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An infant born weighing less than 1,500 g is considered very low birth weight (VLBW). An infant born weighing less than 1,000 g is considered extremely low birth weight (ELBW). Among VLBW and ELBW preterm infants, the incidence of acute and chronic respiratory disease such as respiratory distress syndrome (RDS) and bronchopulmonary dysplasia (BPD) can be significant due to the immaturity of the lungs. Increased work of breathing, seen in both these conditions, contributes to increased energy expenditure and elevates the need for more nutrient and energy intake. It is important to make routine clinical assessment of respiratory effort and factor this into the overall calculation of daily nutrient requirements as standard recommendations may be insufficient to support growth.

The surgical neonate may be born preterm or term. The need for surgery may be due to congenital or acquired conditions. Common neonatal disorders in the preterm and term infant requiring surgical intervention include congenital disorders such as intestinal atresias or abdominal wall defects such as gastroschisis and omphalocele. Acquired conditions such as spontaneous intestinal perforation (SIP) and necrotizing enterocolitis (NEC) are also more common in preterm infants. NEC is characterized by variable damage to the intestinal tract ranging from mild injury to injury significant enough to warrant surgery to remove parts of the diseased bowel. Surgical exploration of the abdomen results in bowel rest and recovery that requires parenteral nutrition (PN).

In surgical cases requiring bowel resection or ostomy creation, shorter intestinal transit time and lower surface area is available for digestion. This may lead to malabsorption initially post-surgery. Fortunately, the body can respond to this with intestinal adaptation that increases the surface area and capacity of existing bowel exposed to feeding to improve its function. The dietitian may see changes over time to reflect this period of adaptation, such as improved absorption and growth. If significant portions of the bowel are removed or diverted, unique considerations are required to determine the changes in nutrient delivery affected by the reduced length and segment of bowel lost.

INITIATING FEEDINGS

Parenteral Nutrition

PN is an urgent requirement for early preterm infants as they have limited nutrient stores and are not able to receive full enteral nutrition (EN) immediately after birth. Dextrose-containing intravenous (IV) fluids should be started after birth to avoid alterations in blood glucose. For preterm infants, specifically VLBW infants, the dextrose-containing IV nutrition should contain amino acids to promote an anabolic state, and some institutions have calcium added as well for regulation of bone metabolism. For ease, most units have "starter" solutions on stock. As soon as possible, the infant should be prescribed full PN to allow for optimal nutrient delivery, and macronutrient and micronutrient goals should be attained ideally within several days of birth.

Chapter 9 provides guidelines for initiation, advancement, and goal PN for premature and ill neonates. Immediate administration of protein after birth prevents catabolism, which is common after birth, and improves growth. Minimally the infant should receive at least 1.5 g/kg daily to prevent catabolism, but up to 3-4 g/kg per day may be safe and beneficial. Amino acid solutions that provide conditionally essential amino acids are typically used for preterm and term infants (Chapter 9). Total PN energy goal is 80–110 kcal/kg per day.

Sodium and potassium doses may be limited during the first day of PN until postnatal diuresis has been achieved. Potassium can safely be provided once urine output has been established. Calcium and phosphorus should be added as soon as PN is initiated to assist with bone mineral accretion. Monitoring of electrolytes and glucose should occur often during the first few days of providing PN until fluid status and electrolyte levels are stabilized, and adjustments should be made as indicated (Chapter 9).

A key element for consideration of PN is access (Chapter 7). To optimize nutrient provision, central venous access is preferred unless full EN volume can be attained quickly.

Enteral Nutrition

One of the interventions that is associated with a reduced risk of NEC in preterm infants is the development of a standardized feeding protocol. Aspects of the protocol include initiation and advancement of EN, a fortification plan, and the type of enteral feeding. An additional intervention associated with reduced risk of NEC is use of human milk.

Although preterm infants have an immature gastrointestinal immune system and are at increased risk for NEC, there is little evidence to suggest withholding feedings for an extended period after birth is beneficial. Initiating EN soon after birth may prevent gastrointestinal atrophy, lead to achievement of full volume EN sooner, improve growth, and prevent complications related to long-term PN provision. Initiation of EN is typically a small volume of 10–24 mL/kg per day and referred to as minimal enteral nutrition (MEN), trophic feeding, or gut priming. The most beneficial duration for MEN prior to advancement is not fully known. It is reasonable to continue these small volume feedings for several days. Once tolerance to MEN is established, it is safe to begin advancing EN volumes.

A wide range of EN advancements have been reported, but advancing up to 30 mL/kg per day in VLBW infants is safe without increasing the risk for NEC. For more mature preterm infants, advancing 40 mL/kg per day may be tolerated. Goal EN volumes of 150–160 mL/kg per day with fortified feeds to 24 kcal/oz should provide 120–128 kcal/kg per day, though higher EN volumes may be tolerated in lower risk infants.

Due to oral immaturity, premature infants are initially dependent on short-term enteral access devices for delivery of EN, either nasogastric or orogastric. Routine trans-pyloric delivery is not recommended to avoid bypassing gastric digestion. EN may be delivered as an intermittent bolus over gravity or via a timed pump to slow delivery time. While longer delivery times, including continuous delivery, may improve feeding tolerance, prolonged pump times of an hour or greater decrease fat delivery when utilizing human milk due to fat adherence to plastic surfaces, thus reducing energy intake.

Human milk is the preferred feeding source for all infants due to its nutrition content and abundant bioactive components that improve immunity and growth. Specifically for the preterm population, maternal milk reduces the risk for NEC, late-onset sepsis, and severe retinopathy of prematurity while also improving long-term neurodevelopmental and cardiac outcomes. NICU staff should actively promote milk expression, skin-to-skin contact with the mother, and direct breastfeeding (when medically able) to counter the many barriers that hinder successful lactation in these mothers, such as separation from her child, the stress of having a preterm infant, and her own health.

If maternal milk is not available, use of pasteurized donor milk (PDM) should be considered. PDM is not equivalent to maternal milk due to its decreased nutrition content, particularly in protein, and the partial or complete loss of bioactivity of many of its components due to pasteurization. While lagging growth may be a concern with PDM, adequate growth can be achieved with active monitoring and increased fortification strategies. PDM should be used as a bridge until maternal milk supply is established or until an established chronologic or corrected gestational age, though no consensus exists for duration or the upper gestational age limit of its use. PDM should be purchased from a regulated milk bank or company and should not be obtained over the internet or via informal sharing due to risk of contamination. Individual milk banks may vary in their donor pooling processes, and providers are encouraged to discuss with their milk bank to learn more.

Although human milk is the preferred feeding source for a preterm infant, it does not meet full nutrition recommendations when unfortified. This is due to the greater rate of growth and nutrient needs of the preterm infant compared to the term infant. The optimal time frame for fortification is unclear, but fortification of human milk can be safely achieved at volumes of 40–60 mL/kg per day. Fortification should also occur prior to discontinuation of PN. This will ensure more appropriate provision of energy, protein, and vitamins and minerals. Both human milk-based and bovine-based human milk fortifiers (HMF) are available. HMFs are added to human milk to provide additional

energy, protein, calcium, phosphorus, and zinc. These products may vary in the type and distribution of nutrients between manufacturers. Typically HMFs are added to provide a composition of 24 kcal/oz (based on the assumption that human milk on average contains 20 kcal/oz), but may be higher if the infant has higher nutrient needs or is fluid-restricted. HMFs are available both in powder and liquid forms.

For preterm infants unable to receive human milk, or when mother's supply does not meet the demand of the infant and PDM is not available, preterm formulas are available and are designed to provide higher amounts of macro- and micronutrients to meet the increased needs of preterm infants. Hospital preterm formulas are premixed, ready-to-feed products available in a variety of caloric densities from 20 to 30 kcal/oz. Discharge preterm formulas are available as powders or ready-to-feed liquid formulas that also provide additional energy, protein, and micronutrients. They are typically 22 kcal/oz but can be mixed to higher energy densities, if needed. If a premature infant requires a specialty formula, such as hydrolysate or elemental formula, additional supplementation will be needed to meet nutrient needs. See Chapter 5 for additional information about term infant formulas.

Oral Nutrition

Oral feeding may be attempted once infants start to exhibit oral readiness and hunger cues. This typically occurs after the development of sleep-wake cycles at approximately 32 weeks corrected gestational age, though the safe coordination of sucking, swallowing, and breathing may not be present until 33–34 weeks. Following infant oral cues is important as it creates a positive association with the experience. Oral feeding attempts should be limited to 20–30 minutes to avoid fatigue and increased energy expenditure. Non-nutritive sucking on a previously emptied breast can help support long-term success at breastfeeding as well as promoting positive oromotor training. For some infants, immature feeding patterns and poor coordination may persist until term-corrected age. Due to concerns for aspiration, infants should not be requiring significant respiratory support, though the maximum degree of noninvasive support at which it is safe to feed orally is unclear.

For mothers who have maintained a milk supply, direct breastfeeding should be introduced first, and once infants are able to latch well, bottles may be introduced. Direct breastfeeding while in the NICU does not delay discharge readiness and promotes sustained lactation and a human milk diet at discharge. Most infants will be discharged home only partially direct breastfeeding and some preterm infants will continue to need fortified feedings at home. Initially, breastfeeding should be limited in frequency (e.g., 2–4 times per day) and then increased over time with close monitoring of growth since direct breastfeeding may require more energy than bottle feeding.

NUTRITION MANAGEMENT

Nutrition Assessment

Infant nutrition assessment includes growth monitoring and evaluation of nutrient intake. Preterm and critically ill infants require more frequent and detailed assessment.

Anthropometric Measurements and Growth Charts

The importance of accurate anthropometric measurements cannot be overstated. Although weight should be measured daily, weight gain velocity should not be calculated over periods shorter than 5–7 days as too short of a time period can under- or overestimate growth. Length measurement is most accurate with use of a recumbent length board and two examiners (Chapter 1). Head circumference should be measured with non-stretchable tape over the widest part of the infant's skull (Chapter 1). Head circumference should be repeated 24 hours after birth as skull molding and

TABLE 12.1
Commonly Utilized Intrauterine and Postnatal Growth Charts

	Intrauterine Growth Charts
Aris (2019)	• Developed with 3,285,552 births from 22 to 42 weeks using U.S. natality files • Reflects modern size of U.S. infants, with reliable gestational age from mothers with early prenatal care • May be inappropriate reference outside of the U.S. context
Fenton and Kim (2013)	• Developed with 3,986,456 births from six high-income countries • Age is actual age instead of completed weeks • Harmonizes with WHO growth standard
Olsen et al. (2010)	• Developed with 257,855 preterm births from the USA who survived to discharge • Selection of only survivors in development of curve • May be inappropriate reference outside of the U.S. context
	Postnatal Growth Charts
INTERGROWTH-21st (Villar et al. 2014)	• Developed with 224 singleton preterm births form antenatally enrolled mothers of low-risk birth from 8 international locations • Harmonizes with WHO • Small sample size overall and small sample size of early gestational ages
WHO (de Onis et al. 2006)	• Developed with 8,440 healthy breastfed infants from international locations • Should be used in preterm infants past term-corrected age. Should not be used in preterm infants without prior to term-corrected age • Contains longitudinal measurements through 2 years of age

swelling related to labor and delivery can distort this measurement. Length and head circumference should be assessed weekly during hospitalization.

All infants should have their growth monitored with the routine use of a reference growth chart. There are two types of infant growth charts: intrauterine and postnatal. Intrauterine growth charts reflect fetal growth, since they are developed by collecting anthropometric measurements at birth, and they serve as a reference. Postnatal growth charts reflect how infants grew over time. These are intended to serve as a standard and be prescriptive (Table 12.1).

There are multiple considerations with use of growth charts in a preterm or ill infant. First, postnatal growth charts are usually developed with a relatively small sample size. Second, as incidence decreases with decreasing gestational age, preterm infants of the earliest gestational ages (22–25 weeks) have the smallest sample size on each growth curve and may be relatively underrepresented. Third, although historically the American Academy of Pediatrics has stated that the growth of a preterm infant should match the growth of a reference fetus, this recommendation is not substantiated by data and cannot always be achieved in clinical practice. Experts have discussed other growth velocity goals which will subsequently be discussed. However, monitoring a preterm infant's growth with use of an intrauterine growth chart is practical.

Corrected age should be used for former preterm infants through the first 2–3 years of chronological age. In practice, since the WHO growth charts are available until 2 years of age, correction is applied until this age as correction is not practical on the 2–20-year growth chart. Corrected age is calculated by subtracting the number of weeks born before 40-week gestation from the chronological age (Figure 12.1).

The WHO growth chart should be used for former preterm infants after term-corrected age. Former preterm infants should be plotted on the WHO chart using their current age and corrected age. As the Fenton and WHO growth charts harmonize from 40 to 50 weeks, the transition from monitoring an infant on the Fenton growth chart to the WHO chart can occur at 44–46 weeks corrected age.

Corrected age (mo) = Chronological age (mo) − ([40 wk – GA at birth in wk] ÷ 4)

Example: 31-month-old former 24-week infant:

31 mo – ([40 wk – 24 wk] ÷ 4 wk) = corrected age 27 mo

mo = months
wk = weeks
GA = Gestational age

FIGURE 12.1 Calculating corrected age.

Size for Gestational Age

All infants should have their anthropometric measurements compared to gestational age at birth. Small for gestational age (SGA) denotes infants with birth size below the 10th percentile, appropriate for gestational age (AGA) denotes infants with birth size between the 10th and 90th percentiles, and large for gestational age (LGA) denotes infants with birth size above the 90th percentile. Since 20% of the population will fall into an SGA or LGA category by this statistical cutoff, a designation of SGA or LGA does not equate to illness. Likewise, AGA does not equate to wellness. An infant's birth size can technically be AGA, yet they could have experienced intrauterine growth restriction (IUGR) and be smaller than her genetic potential. Despite the limitations of this designation, size for gestational age is important because it helps risk stratify infants. WHO growth charts should only be used to assign size for gestational age in term infants. Fenton, Olsen, or Aris growth charts are all appropriate choices to assign size for gestational age in preterm infants. The Fenton growth chart should not be used to assign size for gestational age in infants born after 37 weeks.

IUGR and SGA are not synonymous terms but may overlap in many cases. IUGR implies a fetus's growth rate has been less than its potential rate. For example, a fetus could begin growing along the 80th percentile and fall to the 30th percentile at birth. This fetus experienced growth restriction in utero but would not be designated as SGA. Placental insufficiency is the most common cause of IUGR, and many maternal and genetic conditions can lead to IUGR. IUGR is a challenging antenatal diagnosis. Serial fetal ultrasonography is not universally available, and size assessment accuracy is dependent on technology and personnel. Finally, there are numerous fetal growth charts in use by obstetricians. The INTERGROWTH 21st fetal growth standards are the best available as they were developed with healthy pregnancies in a large international cohort, but use of these standards is far from universal. IUGR can be suspected postnatally based on known fetal growth trajectory, a history of conditions that lead to growth restriction, size at birth, and physical exam features. A deficiency of subcutaneous tissue in the cheeks, neck, chin, arms, back, buttocks, legs and trunk, a thin umbilical cord lacking in Wharton's jelly, widened cranial sutures, and dysmorphic features may be associated with IUGR but would not be expected in an infant who is physiologically SGA. Infants who are born with SGA or IUGR start off with reduced nutrient stores and are smaller in size and may have altered proportions. Their demands for growth are unique and they are at higher risk of metabolic consequences later in life.

Growth Velocity of Preterm Infants

There are many different methods used in the literature to report on preterm infant growth velocity. Although expected preterm growth rates are often quoted as 15 g/kg per day weight gain and 1 cm/week length and head circumference gain, growth is not linear or consistent throughout gestation and early infancy. This estimated velocity does not equally apply at all gestational ages, and this can be visually noted on an intrauterine growth chart as a curve that naturally slows in the last trimester due to physical constraints of the uterus.

There are different methods for calculating weight gain velocity. Of these, the average 2-point method is the best choice (Figure 12.2). A rate of 15–20 g/kg per day using the average 2-point method is a reasonable goal for infants for 23–36 weeks, as this agrees with Fenton, Olsen, and INTERGROWTH growth curves with some initial downward deviation. After 36 weeks, this is

Weight gain velocity (g/kg per day) = (W2–W1) / [(W2+W1)/2] /1000 / number of days

Example: Preterm infant weighing 1200 g at first assessment and 1350 g 7 days later

Overall weight gain = 1350-1200 = 150 g

Average body weight during the 7 days = (1350 + 1200)/2= 1275 g = 1.275 kg (i.e., 1275/1000)

Weight gain per kg body weight during the 7 days = 150/1.275 = 117.65 g/kg

Weight gain per kg body weight per day = 117.65/7 = 16.8 g/kg per day

W1 = initial body weight in grams
W2 = final body weight in grams

FIGURE 12.2 Calculating weight gain velocity using the average 2-point method.

no longer an appropriate goal and is accelerated compared to the curve on an intrauterine chart. Typically, for children above 2 kg, a weight gain goal of 20–30 g/day is appropriate. A limitation to note with weight gain is that it may not accurately reflect changes in lean body mass, especially in times of fluid issues such as dehydration or edema.

Weekly monitoring of z-scores avoids the confusion of different velocity calculations. Z-scores also demonstrate the magnitude of variance from the mean and trending z-scores show a pattern of accelerating, constant, or decelerating growth velocity. Studies show that overall improved growth of preterm infants is associated with improved neurodevelopmental outcomes, but the pattern is important and growth measurements at only one point in time are an inadequate predictor of long-term outcomes.

All infants are expected to have initial postnatal weight loss due to fluid loss and postnatal adaptation. Weight loss between 3% and 12% of birth weight is expected in the first week of life. Careful attention to fluid provision, insensible fluid losses, and fluid gains is needed to accommodate this postnatal adaptation. After the initial weight loss, preterm infants should demonstrate consistent growth. International, multicenter cohort studies have shown that healthy preterm infants consistently adapt in the first weeks of life to a new trajectory that is on average 0.8 z-scores below their birth weight z-score. Free web-based calculators exist to aid in determining an individual trajectory (http://www.growthcalculator.org, www.peditools.org). Alternatively, the target z-score or percentile can be determined around 3 weeks of life after weight gain has steadied. Preterm infants should maintain their z-score after this point.

Nutrient Intake

Nutrient intake via PN, EN, and oral routes should be assessed and compared to established standards. Type, route, and volume of nutrition should all be noted.

PN should be at goal for most nutrients within several days of initiating PN as long as there are no compounding issues such as IV access, interventions that would impede advancement of nutrients, hyperglycemia, and comorbidities. It is vital that nutrient intake be monitored closely as the transition from PN to EN occurs as this is a common time period when nutrient intake could be suboptimal. EN intake varies depending on tolerance (emesis, abdominal distention, changes in stooling patterns), ability to advance EN, and interventions that may impede provision of EN (surgeries, procedures, and tests).

Oral feeding skills and intake are assessed to determine when nutrition support therapy can be discontinued. This assessment includes monitoring tolerance (emesis, abdominal distention, changes in stooling patterns), changes with acceptance of the breast and/or bottle, as well as any changes in volume of intake. If oral intake is not adequate to meet the nutrition needs of the preterm infant at the time of discharge, the infant may require an enteral access device for home. It is safe to send infants home with a nasogastric feeding tube if education has occurred for care providers and close follow-up is established. If oral feedings are not an option or EN is expected to be needed for more than 4–12 weeks, a long-term enteral access device can be placed. Close monitoring for oral skills, nutrient

intake, and tolerance post-discharge should be established for all preterm infants. Consideration for type of nutrition, volume of nutrition, and ability for full nutrition provision includes assessing for comorbidities that include the intestinal, neurological, and respiratory systems.

Nutrition-Focused Physical Exam

Performing a nutrition-focused physical exam is important when assessing premature and critically ill infants. Physical assessment signs that could indicate inappropriate intake or clinical concerns are listed in Table 12.2.

Nutrition Diagnosis

Nutrition diagnoses applicable to preterm and ill infants include:

- Inadequate oral intake
- Increased nutrient needs
- Predicted inadequate nutrient intake (calcium, phosphorus, vitamin D)
- Altered gastrointestinal function
- Altered nutrition-related laboratory values
- EN composition inconsistent with needs
- EN administration inconsistent with needs
- PN composition inconsistent with needs
- PN administration inconsistent with needs

Malnutrition indicators have been established for preterm infants to adults. These indicators provide criteria for growth and intake assessment. They are used to diagnose malnutrition which falls into three criteria: mild malnutrition, moderate malnutrition, and severe malnutrition. Use of neonatal malnutrition indicators are to be used for preterm infants (less than 37 weeks of age until corrected term) as well as term infants (37 weeks or greater) until 28 days of life; after that time the pediatric malnutrition indicators can be used. With the neonatal indicators, some are appropriate during the first 2 weeks of life and others are not appropriate until after 2 weeks of life. Malnutrition indicators may not be appropriate for assessment based on various factors such as disease state, clinical condition, and other comorbidity factors such as genetic conditions. See Chapter 10 for indicators for neonatal and pediatric malnutrition.

Nutrition Intervention

Nutrition Prescription

Preterm infants have increased energy, protein, and fluid needs. Table 12.3 outlines nutrient needs of preterm infants. For term infants, standard equations can be used (Chapter 3).

TABLE 12.2
Common Signs of Nutrition Deficiencies in Neonates

Sign	Nutrient
Pallor	Anemia, chronic disease
Skin dryness	Vitamin deficiency, zinc deficiency, essential fatty acid deficiency, dehydration
Skin breakdown, non-healing wound, dermatitis	Zinc deficiency, vitamin C deficiency, protein deficiency, dehydration
Edema	Fluid shifts, protein-energy deficiency
Muscle wasting	Protein-energy deficiency

TABLE 12.3
Nutrition Prescription for Preterm Infants

Nutrient	Recommended Intake via Parenteral Nutrition	Recommended Intake via Enteral/Oral Nutrition
Fluid	100–140 mL/kg	135–200 mL/kg
Energy	80–110 kcal/kg	110–135 kcal/kg
Protein	1.5–4 g/kg	2.5–4.5 g/kg

Common Nutrition Interventions

Parenteral Nutrition in the NICU

After attaining goal nutrition recommendations via PN, the focus shifts to progressing EN and transitioning off PN. However, there are many subpopulations within the NICU that are at high risk for requiring prolonged PN. Prolonged exposure to PN is associated with increased morbidity and mortality, including central line-associated bloodstream infections (Chapter 8) and intestinal failure-associated liver disease (IFALD, see Chapter 17). Lipid-sparing strategies (e.g., restricting to 0.5–1 g/kg per day) aim to reduce theoretical risk of inflammation and hepatotoxicity, but the evidence is limited and heterogeneous. Furthermore, this must be balanced with the awareness of the increased nutrition needs of premature infants, especially VLBW infants, whose development is sensitive to poor growth. As medically appropriate, advancing EN to limit the exposure to PN is prudent.

The type of lipid emulsion should be considered as well (Chapter 9). Soybean oil emulsions, which contain both omega-6 (linoleic acid) and omega-3 (α-linolenic acid) fatty acids, have been used traditionally, but metabolites of linoleic acid may induce inflammation and toxic effects. Fish oil-containing emulsions such as SMOFlipid® (soy, medium-chain triglycerides, olive, and fish oils) and Omegaven® contain predominantly omega-3 fatty acids, which may be more hepatoprotective. Smaller studies have shown reduced cholestasis when fish oil-containing emulsions are used preemptively, but this has not been demonstrated by larger studies. Currently, there is insufficient evidence to support its routine use to prevent or reduce neonatal morbidities. Omegaven is typically reserved for patients with liver compromise.

Enteral and Oral Nutrition in the NICU

After infants have reached fortified full volume EN, growth should be assessed weekly. Human milk contains on average 20 kcal/oz, and standard fortification recipes for preterm infants aim to yield 24 kcal/oz based on this assumption. However, human milk is highly variable in its content due to a multitude of factors, including infant's gestational age, mother's stage of lactation, method and duration of expression, the time of day, and losses during handling and storage. Thus, the actual nutrient delivery is unknown and may be insufficient to achieve optimal growth, even with standard fortification.

Infrared human milk analyzers can allow for more targeted nutrition intake, though the time-intensive labor and cost of these machines may be prohibitive. More commonly, additional energy intake is administered by increasing overall feeding volume and/or increasing energy density. Increased energy density can be achieved by adding HMF, though modular agents of protein and lipids may also be used. Modular protein agents may be preferred if weight gain is adequate but linear growth is poor. Particularly with the use of PDM, additional fortification of protein is often beneficial to balance the intrinsic nutrition deficit. PDM also is limited by loss of activity of innate lipases that support better lipid digestion. Some infants may also require additional nutrition support therapy secondary to higher metabolic expenditure.

As discussed earlier, oral feeding should be approached based on infant cues and feeding readiness. Immature feeding patterns and discoordination are common issues due to brain immaturity and

decreased muscle tone associated with prematurity. Occupational therapists and speech-language pathologists integrated in the NICU can provide additional support in gauging feeding maturity and progress. Often premature infants benefit from paced feeds and slower flow nipples to allow for better control of oral intake. Breastfeeding also grants more infant control with the paced volume and flow of milk ejection. Term-corrected age infants who continue to demonstrate poor feeding patterns associated with concomitant respiratory symptoms may require additional feeding evaluation, such as a video or fluoroscopic swallow study. Term-corrected age infants who exhibit oral aversion or an inability to take sufficient feeding amounts orally may need either a nasogastric or gastrostomy tube to facilitate discharge home.

Enteral and Oral Nutrition Considerations Post-Discharge

Maternal milk is the recommended source of feeding for all infants until at least 6 months of age, including infants born prematurely. At the time of discharge, maternal milk alone may not be adequate to optimize the growth of a former preterm infant; therefore, fortification may still be required. Some HMFs are available for use at home but are limited to short-term use. Alternating unfortified maternal milk and enriched formula feedings is one way to provide additional energy as well as protein and other vitamins and minerals. Adding powdered enriched formula to maternal milk is another method for increasing the energy content of human milk. With mothers who have an abundant supply of milk, preferential collection and use of hindmilk (Chapter 5) that is higher in fat content may further increase energy density.

When maternal milk is not available or the supply is not adequate to fully meet fluid goals, formulas are available. Enriched formulas have been designed to provide more energy, protein, and vitamins and minerals such as calcium and phosphorus than a standard term formula to better meet the needs of a former preterm infant.

There is no clear evidence as to the optimal duration for milk fortification or the use of enriched formulas. Changing to a term formula or discontinuing fortification at 6 months corrected age could be considered in situations where growth is at or above goal; however, use until 12 months corrected age may be suitable as well. If a former preterm infant is not gaining weight appropriately post-discharge, the enriched formulas can be concentrated further to provide additional energy and protein. If growth becomes excessive after discharge, fortification may be discontinued.

The type of formula used is dependent on the infant's disease state, gestational age, and clinical condition. Specialty formulas are available if an intact-protein formula is not tolerated or not indicated, though their nutrition content does not match those of enriched premature formulas. Due to their inappropriate nutrient profiles for infants, toddler milks and toddler formulas should not be offered during the first year of life.

Specific time frames for initiating complementary feedings are not known for former preterm infants, and it may be more appropriate to provide anticipatory guidance for feeding with corrected age in mind. It is also important to recognize developmentally appropriate signs for initiating solids such as sitting upright with minimal support, good head and neck control, minimal to no extrusion response, and a decrease in the gag reflex. This will typically occur between 4 and 7 months corrected age. It is not recommended to begin solids prior to around 4 months corrected age and it may be more appropriate to provide anticipatory guidance for feeding with corrected age in mind.

Supplements

Trace elements and vitamins should be included in PN solutions. For infants receiving full EN, trace minerals such as zinc, copper, selenium, and iodine are provided by formulas or HMFs, and vitamin D can be initiated. Preterm infants are at risk for anemia of prematurity as iron stores are obtained during the last trimester of pregnancy (Chapter 4). Iron supplementation should be given to promote erythropoiesis. Zinc and sodium supplementation may also be provided to premature infants.

Premature infants who receive prolonged periods of PN or diuretic therapy are also at risk of developing metabolic bone disease due to the limited amounts of calcium and phosphorus that can be added without precipitation or due to excess calcium excretion. These infants may need additional calcium, phosphorus, and vitamin D supplementation. Infants who receive maintenance diuretic therapy, such as those with bronchopulmonary dysplasia or congenital heart disease, may need additional chloride supplementation; in this scenario, potassium chloride is preferred over sodium chloride to avoid counteracting the natriuretic effect.

Education

Education of caregivers is vital to promote optimal outcomes for a preterm infant. Education should begin upon admission as it allows caregivers to understand the care of the infant and supports family-centered care. Education topics include:

- Benefits of human milk
- Breastfeeding
- Skin-to-skin care
- Feeding choice(s)
- Transition from PN to EN to oral feeding
- Fortification
- Anthropometrics and overall growth
- Laboratory values
- Indications for supplementation
- Caregiver presence and participation in the infant's care
- Placement of feeding tubes

Education is needed for feeding preparation once the infant is ready for discharge. Return demonstration, or teach-back, is an effective way for caregivers to show their understanding of a specialized feeding preparation.

Nutrition Monitoring and Evaluation

As described above, growth in all three anthropometric measurements should be reviewed weekly while infants are in the NICU and regularly after discharge. While growth velocities are commonly utilized, following z-scores provide a more consistent trend over time and assessment compared to reference growth curves.

Laboratory monitoring of serum electrolytes should occur routinely in infants receiving PN, especially in the initial days as components are advanced and adjusted. Infants receiving maintenance diuretics should also have serum electrolytes followed to ensure adequate chloride supplementation.

For infants at high risk for metabolic bone disease (VLBW or prolonged PN or diuretic exposure), serum screening labs including alkaline phosphatase (ALP), calcium, and phosphorus may be beneficial. However, none of these biomarkers are specific for metabolic bone disease, and it is unclear at what cutoff additional enteral supplementation should be initiated. Alkaline phosphatase levels are increased in infancy due to normal physiologic bone turnover, though levels greater than 500 IU/L may suggest impaired bone accretion while levels greater than 700 IU/L are concerning for bone demineralization. Routine radiographs are of limited utility for screening as signs of early disease are not readily apparent.

Optimizing nutrient intake and growth of preterm and ill neonates is essential to promote the best long-term outcomes. Preterm and ill neonates have increased nutrient needs. Frequent nutrition reassessment, including monitoring of anthropometric measurements, is critical to ensuring adequate nutrient intake.

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13 Care of the Critically Ill Pediatric Patient

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CONTENTS

Optimal nutrition management of the critically ill child is associated with improved clinical outcomes and is multidimensional. It requires an awareness of the dynamic metabolic response to critical illness/acute injury, evaluation of nutrition status, determination of individualized macronutrient and micronutrient needs, and selection of the best timing and route of nutrient delivery for each patient. Critically ill children admitted to the pediatric intensive care unit (PICU) present with variable ages, baseline nutrition status, and diagnoses, coupled with the unpredictable metabolic demands placed by the critical illness. Furthermore, this cohort is characterized by challenges to both enteral nutrition (EN) and parenteral nutrition (PN) during the acute phase of illness. A thoughtful, individualized, and evidence-based approach to prescribing and delivering nutrients in this patient population has the potential to improve clinical and functional outcomes (Figure 13.1). In the following sections, we will review the current evidence-based recommendations, discuss challenges, and explore new concepts of nutrition management of the critically ill child.

METABOLIC RESPONSE TO STRESS

There are several factors that distinguish nutrition strategy during critical illness in children from that during health. Baseline nutrition status, the burden of underlying chronic illness, and the metabolic state during the acute illness are important contributors to nutrition needs in this population. The evolutionary response provides essential substrate to the host by mobilizing endogenous stores during periods of nutrient scarcity. Our understanding of the human response to critical illness from injury, infection, or surgery has guided the approach to metabolic support for these groups of patients. In brief, the metabolic stress response is characterized by protein catabolism to provide free amino acids that are re-prioritized for gluconeogenesis, tissue repair, and the anti-inflammatory response. Prolonged or profound response to certain injuries/illnesses may result in loss of lean body mass over time, with consequential morbidity. The stress response also places an energy burden on the patient, although the degree of this burden is not predictable and may have been overestimated in the past. Energy and protein requirements in the critically ill child have been estimated based on the metabolic state and observational studies. However, these requirements may need to

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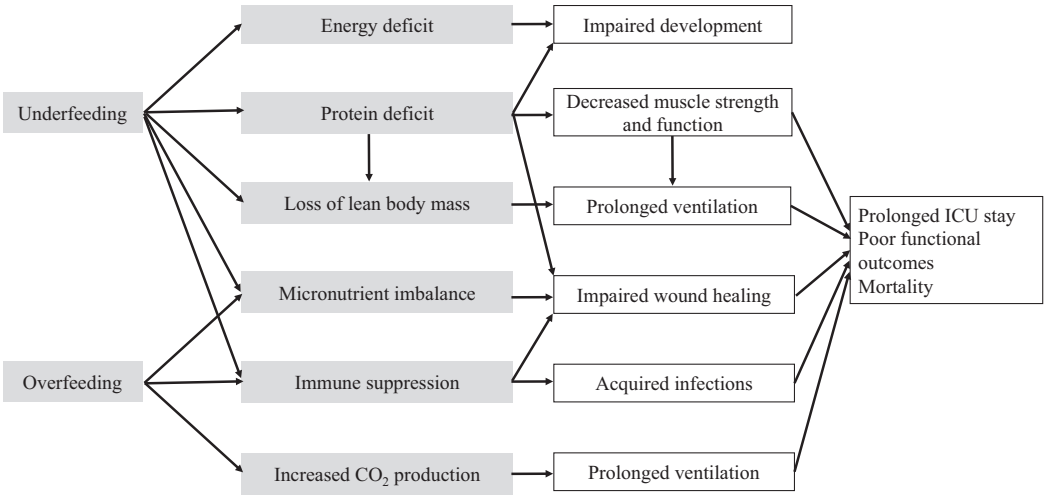

FIGURE 13.1 Nutrition goals and outcome in the PICU.

be individualized based on the baseline nutrition status, the nature of critical illness and its impact on the dynamic metabolic state, and the feasibility of safe delivery of nutrients.

NUTRITION ASSESSMENT

Nutrition screening has been adopted in most centers in order to flag patients with risk factors for malnutrition (Chapter 3). This is followed by a more detailed initial nutrition assessment (within 48 hours of PICU admission) conducted by a trained dietitian. A variety of tools exist for nutrition screening and assessment of hospitalized children. However, there is a paucity of validated tools that can be applied specifically to critically ill children. Despite these shortcomings, institutional processes based on manual and electronic medical record review allow identification of patients who might be already malnourished or at risk of malnutrition during the illness course. The premise of screening and initial assessment is to direct clinical resources for timely intervention in these vulnerable patients who might potentially benefit from nutrition therapies. Critical illness often results in further nutrition deterioration during the illness course, probably due to the failure to offset the burden of metabolic stress. Children admitted to the PICU, including previously healthy children or children with obesity, can still present at increased nutrition risk if nutrition therapy is delayed or delivery is inadequate over prolonged periods throughout their hospitalization. Hence, serial assessments (at least weekly throughout PICU stay) should be considered.

Anthropometric measurements (weight, length/height, head circumference, mid-upper arm circumference) are routinely used as markers of nutrition status in hospitalized children (Chapter 1). The use of z-scores allows normalization of these variables and helps classify patients as either well nourished or with a particular degree of malnutrition. While anthropometric data are a crucial component of the nutrition assessment, these measurements may not be feasible in the critically ill child with instability or may be inaccurate in patients with significant fluid shifts, edema, or presence of medical devices. The lack of calibrated, easy-to-use equipment at the bedside, such as appropriate scales, further limits the ability to get reliable anthropometry in the PICU environment.

Recent studies have highlighted the role of body composition assessment methods in the PICU, especially muscle ultrasound (mUS) that can reliably measure muscle thickness, as a surrogate for lean body mass. Other methods of body composition assessment, such as the bioelectric impedance spectroscopy (BIS), have potential but need to be proven as a reliable tool in the critically ill child.

A detailed diet history and growth history, as well as a comprehensive nutrition-focused physical exam, complements anthropometric data and body composition assessment in the PICU.

Early identification of nutrition risk and presence of malnutrition in hospitalized patients is important in order to tailor targeted nutrition interventions to those patients deemed at greatest risk. Both underweight and overweight status in hospitalized children have been associated with adverse clinical outcomes, such as increased risk of infection, longer periods on mechanical ventilation support, longer lengths of stay (LOS), and increased mortality.

Nutrition Diagnosis

Nutrition diagnoses in the PICU depend on multiple factors, including nutrition status, reason for admission, and current medical and surgical issues affecting nutrition status. A diagnosis of malnutrition is common in PICU and should be identified and addressed early to improve outcomes. Common nutrition diagnoses include:

- Inadequate energy intake
- Predicted inadequate energy intake
- Inadequate oral intake
- Increased nutrient needs
- Malnutrition (undernutrition)
- Increased energy expenditure in this population is uncommon

Nutrition Intervention

Nutrition Prescription

Energy

Accurate determination of energy needs during critical illness remains a significant challenge. Predictive energy equations available for pediatric patients have demonstrated significant variability that can lead to unintended consequences associated with both underfeeding and overfeeding. Indirect calorimetry (IC) remains the gold standard for accurate measurement of energy expenditure and a guide for daily energy prescription. Table 13.1 highlights PICU patients who are suspected to have greater metabolic variability and should be prioritized for IC measurements if available. However, its availability in PICUs remains limited and the required resources and expertise for IC measurements and interpretation is often not available at most centers.

In the absence of IC, the Schofield or Food Agriculture Organization/World Health Organization/United Nations University (FAO/WHO/UNU) predictive equations may be used without the addition of stress factors to estimate energy expenditure (Chapter 3). A simplified equation that utilizes measured VCO_2 available from modern mechanical ventilators in the PICU may be another alternative when IC is not feasible. Whether using IC or a predictive equation to determine energy needs, close nutrition monitoring is essential to ensure the nutrition prescription is meeting the patient's nutrient needs.

Protein

Protein dosing during the acute phase of pediatric critical illness is associated with clinical outcomes. The beneficial effects of optimal protein dosing can be observed independent of energy delivery and severity of illness. It is now recommended that protein delivery be optimized during acute critical illness. Updated pediatric critical care nutrition guidelines recommend providing at least 1.5 g protein/kg per day. Specific patient populations, such as neonates/infants, as well as catabolic conditions, such as burn injuries or respiratory illnesses, require higher protein intake goals to achieve positive nitrogen balance. Patients who received >60% of their protein goal enterally during

TABLE 13.1
Targeted Indirect Calorimetry

Underweight, overweight, or obese
Children with >10% weight change during ICU stay
Failure to consistently meet prescribed energy goals
Failure to wean or need to escalate respiratory support
Neurologic trauma
Oncologic diagnoses
Children with thermal injuries or amputations
Children requiring mechanical ventilator support for >3 days
Children suspected to be severely hypermetabolic

Source: Adapted from Mehta N, Bechard L, Leavitt, K, Duggan C. Cumulative energy imbalance in the pediatric intensive are unit: role of targeted indirect calorimetry. *J Parenter Enteral Nutr*. 2009, 33: 336–344.

the first week have had improved outcomes. However, parenteral protein delivery within the first 24 hours of admission has been associated with poorer outcomes. Hence, the optimal protein dosing and mode of delivery in children in the PICU is unclear.

Micronutrients

Accurate assessment of micronutrient status along with the role of isolated or combined micronutrient supplementation during critical illness remains an area of interest. It is well described that both altered nutrient utilization and demand combined with inadequate nutrient delivery places many patients at risk for micronutrient deficiencies. In the absence of reliable biomarkers of micronutrient deficiency and in the face of insufficient evidence, clinicians should ensure delivery of adequate micronutrients to meet references for age.

Nutrition Delivery

Nutrition delivery in the PICU has been described using three factors: timing, route, and dose. The primary goals of nutrition delivery in a critically ill child should include choosing the most appropriate and safest route of nutrition support therapy and determining the right time to initiate nutrition, in order to limit the loss of lean body mass and offset the burden of the metabolic stress response. Oral nutrition is often not an option following critical illness, prompting the clinician to consider initiation of either EN or PN.

Studies continue to demonstrate significant inadequacies when comparing energy prescriptions to what is actually delivered to the patient at the bedside. Energy intake >60% of estimated energy goals during the first week of PICU admission has demonstrated improved outcomes in mechanically ventilated children. Children receiving >60% energy and protein adequacy by day 7 of PICU admission were observed to have better outcomes compared to children who did not meet that threshold. Thus, it is critical to determine the appropriate feeding route and initiate feeding early in order to improve clinical outcomes.

Enteral Nutrition

EN is the preferred route of nutrient delivery in critically ill children with a functioning gastrointestinal tract. Current guidelines recommend early EN when possible; defined as initiation within 24–48 hours of PICU admission. Early enteral nutrition (EEN) has been associated with improved survival compared to patients who received delayed EN. Even in children with septic shock or

sepsis-associated organ dysfunction, who have no contraindications to EN, EEN via the gastric route is recommended. When EN cannot be advanced to goal feeding volume, minimal EN or trophic feeding may have non-nutritive benefits.

Based on available data, initiation of EN via the gastric route is recommended and found to be safe in the majority of critically ill children. Gastric EN may be delivered either as continuous or intermittent bolus feeding. Intermittent bolus feeding is thought to be the more physiologic method but may be challenging in the PICU or not tolerated during acute critical illness. Intolerance to EN or risk of aspiration of gastric contents in the setting of gastric dysmotility might limit the ability to use EN as the only source of feeding in the critically ill. Feeding beyond the stomach may be of benefit in this subgroup in the PICU. Reassuringly, bedside placement of post-pyloric enteral access devices have been proven to be feasible and safe, and has been utilized in many centers to achieve EN delivery.

Ensuring optimal EN delivery appears to be dependent on the timing of initiation, as well as the presence of both a dedicated registered dietitian and an EN algorithm to provide a standardized approach to advancement. Figure 13.2 shows an example of a PICU EN algorithm guiding a stepwise advancement. Algorithms to guide EN initiation, advancement, and management of EN intolerance have been shown to improve EN delivery in the PICU.

Parenteral Nutrition

Due to the infection risk and higher cost associated with PN, there continues to be an ongoing debate on the optimal strategy to utilize this therapy when EN is contraindicated or not tolerated. A large study found that outcomes were overall worse with early PN initiation (day 1 of PICU admission) than with late PN initiation (after 7 days of PICU admission). Hence, PN practice guidelines do not recommend PN initiation within 24 hours of PICU admission. However, an individualized approach may be necessary to determine the indication and timing of PN as a supplement to inadequate EN after this period. The American Society for Enteral and Parenteral Nutrition (ASPEN) consensus guidelines on the appropriateness of PN in pediatrics recommend initiation within 1–3 days in infants and within 4–5 days in older children and adolescents when it is clear that EN will not be possible or remain significantly insufficient to meet nutrient needs for an extended period. The presence of malnutrition and the degree of critical illness should be assessed prior to PN initiation, to determine the risk of anticipated cumulative nutrient insufficiencies that may occur during PICU admission.

Implementation of EN algorithms in the PICU, as discussed earlier, have been shown to decrease the reliance on PN therapy. Reassuringly, PN use appears to be safe in the modern PICU with emphasis on safety. Implementation of quality improvement initiatives supporting best practice care bundles for insertion and maintenance of central venous catheters have reduced the incidence of central line-associated bloodstream infections (CLABSI) in the hospitalized setting.

Nutrition Monitoring and Evaluation

Routine monitoring is crucial in order to assess adequacy of nutrition delivery and tolerance of nutrition interventions in the critically ill child. As the patient's clinical status changes in the PICU, so should the nutrition plan to tailor to metabolic needs. Monitoring for unintended consequences of nutrient provision or lack thereof is essential to maximize the benefits of nutrition support therapy. The main components of such a monitoring plan include:

- Serial anthropometric measurements
- Blood chemistry for electrolyte and glucose alterations
- Signs and symptoms of intolerance to EN and/or PN
- Assessment for evolving micronutrient deficiencies

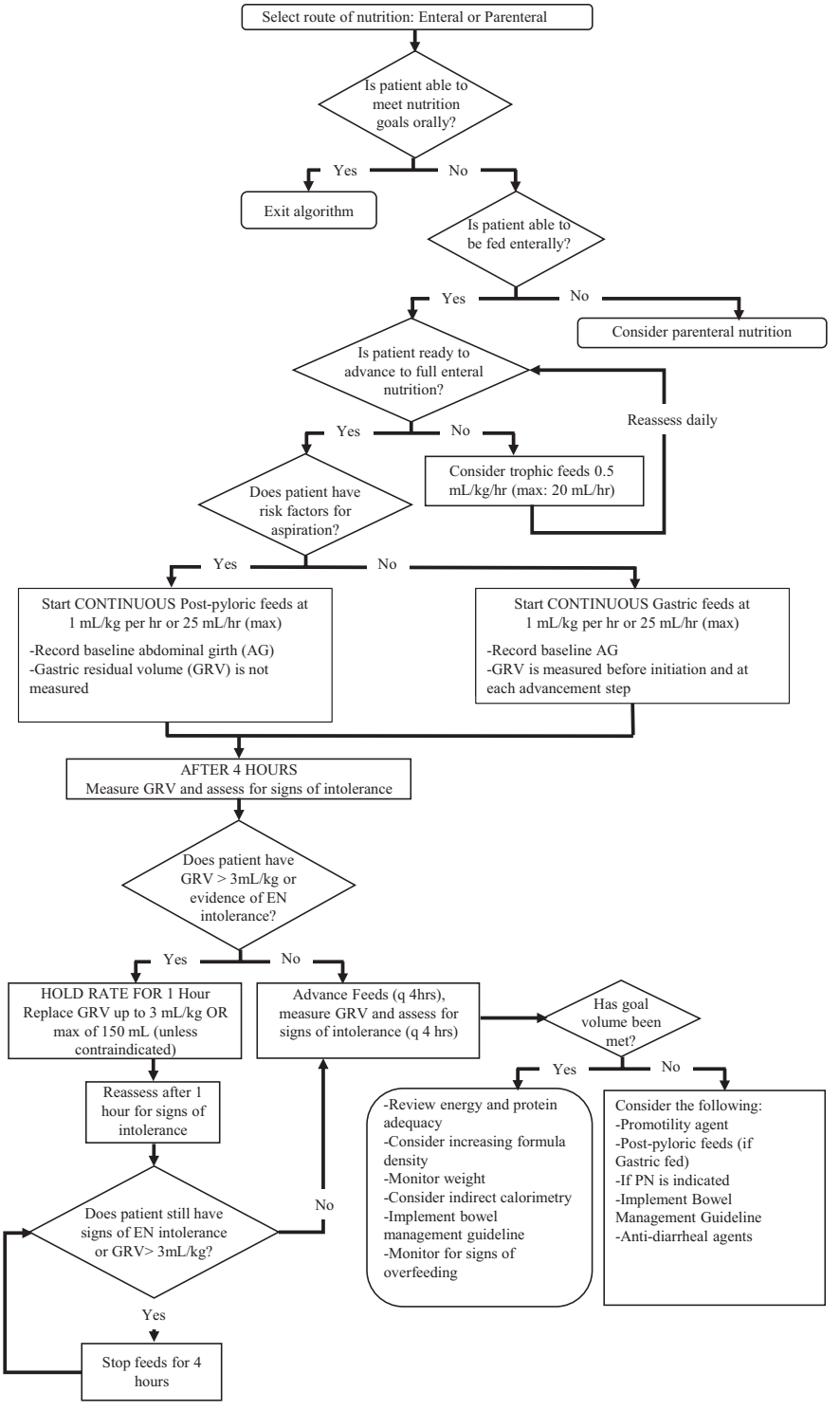

FIGURE 13.2 Initiating and advancing enteral nutrition in the pediatric intensive care unit. (Reprinted with permission from Hamilton S, McAleer D, Ariagno K, Barrett M, Stenquist N, Duggan C, Mehta N. A stepwise enteral nutrition algorithm for critically ill children helps achieve nutrient delivery goals. *Pediatr Crit Care Med*. 2014, 15: 583–589.)

Accurate anthropometric measurements, although challenging in the PICU setting, are considered the gold standard when assessing the adequacy of energy and protein delivery and the nutrition status of the patient. EN intolerance definitions and management guidance are components of stepwise EN algorithms. In recent years, the utility of measuring gastric residual volume (GRV) and its use as a sole marker of EN intolerance has been questioned. Standard blood chemistry protocols have been recommended for routine monitoring of patients on long-term PN (Chapter 9). Age-dependent metabolic demands and a predisposition to environmental influences also need to be considered due to their influence on micronutrient status. Monitoring of both acute-phase and visceral proteins may be helpful to trend in order to appreciate when the acute response following critical illness is lessening and nutrition therapy can be further optimized. Table 13.2 outlines nutrition monitoring considerations during critical illness. Biomarkers that indicate adequacy of nutrient therapies during critical illness are currently lacking.

TABLE 13.2
Nutritional Monitoring and Associated Limitations during Critical Illness

Methodology	Clinical Indication/Use	Critical Illness Considerations
Weight	Standard growth reference	Falsely affected by fluid shifts, edema Difficult to obtain
Length/height	Standard growth reference	Difficult to obtain
Body mass index	Index used to evaluate adiposity, proportionality, nutrition status as it relates to weight and height	Falsely affected by inaccurate weight and height measurements
Tricep skinfold thickness	Estimate fat stores	Can be falsely affected by total body edema Difficult to obtain
Serum albumin	Visceral protein stores Useful for long-term nutrition monitoring/assessments	Falsely low due to immobility, capillary leak syndrome, renal or gastrointestinal losses, or hepatic disease
Serum prealbumin	Visceral protein stores Useful to detect acute changes in nutrition status	Falsely low during periods of inflammation Influenced by liver and renal disease
Hemoglobin	Iron status	Falsely low with phlebotomy, anemia of chronic disease
Transferrin	Reflects protein depletion	Influenced by liver disease and inflammation
Serum retinol binding protein	Vitamin A status Often low with malnutrition	Falsely low during periods of inflammation Influenced by liver and renal disease
CBC with differential white cell count	Laboratory measure of nutrition status	Falsely elevated during periods of inflammation
C-reactive protein (CRP)	Reflects presence of inflammation	When persistently elevated, substrate utilization may be altered and growth may be affected Helpful to follow trends during critical illness
Nitrogen balance	Tool to assess adequacy of protein provision	Accuracy may be affected by altered renal function as well as increased gastrointestinal losses

Source: Adapted from Joosten K, Hulst J. Nutrition Assessment of the Critically Ill Child. In: Goday PS, Mehta NM, eds. *Pediatric Critical Care Nutrition*: The McGraw-Hill Companies, Inc.; New York. 2015: pp. 19–32.

PATIENT-SPECIFIC CONDITIONS

In addition to the general principles outlined earlier, patients may present to the PICU with a variety of conditions and diagnoses with unique nutrition and metabolic considerations that might influence nutrition support therapy decisions. The critically ill child with obesity presents many challenges to the clinician. This patient population remains at the same risk of protein catabolism and loss of lean body mass; however, it may not be as apparent on physical exam given their overall body habitus. Guidelines recommend protein dosing similar to the general PICU population (1.5 g/kg/day) using ideal body weight. Permissive underfeeding is not recommended for children with obesity in the PICU.

Critically ill patients who require extracorporeal membrane oxygenation (ECMO) are at increased nutrition risk. Despite the known inflammatory burden associated with ECMO, both hypermetabolism and hypometabolism have been reported. Protein delivery up to 3 g/kg per day may be necessary to offset the significant protein catabolism associated with ECMO therapy. Retrospective, observational studies have demonstrated the ability to safely initiate low volume EN in patients on extracorporeal membrane oxygenation (ECMO); however, it is not uncommon for barriers to limit advancement to goal and there may be a need for supplemental PN in this group.

The pediatric patient with burn injuries is at increased risk of nutrition deterioration from the profound degree of muscle protein catabolism that continues well after the initial burn injury. Timely and adequate provision of both macronutrients and micronutrients is crucial to attenuate the loss of lean body mass and muscle function. A variety of non-nutrition pharmacologic interventions have been studied in combination with nutrient delivery in this group.

In all of these high-risk critically ill pediatric patient conditions, a bundle of complimentary therapies should be considered to aid in the preservation of lean body mass and improve both short-term and long-term functional outcomes, such as emphasis on early mobility, protein modular supplementation, and role of specific pharmaconutrients.

Nutrition therapy is an important component of critical care, with potential to improve long-term patient-centered outcomes in PICU patients. A prudent nutrition strategy includes the selection of optimal dose, timing, and route of delivery that are individualized to the patient. Early EN, preferably into the stomach, and guided by stepwise algorithm is an accepted practice. Optimal PN indication and timing are being studied and have guided practice aimed at safest and most efficient use of this therapy. In the absence of well-designed large trials to clarify several aspects of nutrition therapy in the PICU, a rigorous and ongoing effort to provide recommendations based on the best available evidence and consensus has helped guide bedside practice. Future studies of nutrition interventions in critically ill children must determine best practices based on proven benefits for long-term, patient-centered outcomes.

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14 Cardiac Disease

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CONTENTS

Congenital heart disease (CHD) is the most common congenital defect in the USA with an incidence of approximately 9 per 1,000 live births. The majority of CHD cases are diagnosed during routine prenatal care or shortly after birth, though mild forms of CHD can be discovered later in life. Approximately 25% of infants born with CHD have critical congenital heart disease (CCHD) and will require a corrective surgery or procedure within the first year of life.

Many patients with CHD, and particularly those with CCHD, have difficulties with nutrition and growth. Malnutrition and growth impairment are common worldwide in infants and children with CHD. The etiology of growth failure in patients with CHD is multifactorial but has been attributed to inadequate energy intake, poor feeding skills, increased metabolic demands, and disturbances in gastrointestinal function contributing to inefficient absorption and utilization. Malnutrition in pediatric patients with CHD results in more frequent and lengthier hospital admissions, ultimately increasing the cost of their care. There has also been a strong association noted between a decrease in weight-for-age z-score following surgical correction of CCHD and late mortality during the first year of life. Chronic malnutrition and impaired growth in patients with CHD have been associated with worse neurodevelopmental outcomes and disabilities in infants and children with single ventricle physiology.

Corrective surgery for CHD has become increasingly possible in neonates and very young children, which often improves the ability to provide adequate nutrition and achieve optimal growth during critical stages of development by eliminating cardiac factors that contribute to malnutrition. However, feeding difficulties and nutrition complications contributing to malnutrition often continue after surgery.

ANATOMY, PHYSIOLOGY, AND RELATIONSHIP TO NUTRITION AND GROWTH

Congenital heart disease is classified as cyanotic or acyanotic, depending on the directionality of shunting of blood in the cardiopulmonary circulation (Table 14.1). Cyanosis heart disease occurs when the deoxygenated blood from the right side of the heart (that is heading to the lungs) mixes with the blood in the left side of the body that then supplies the rest of the body. The type of cardiac

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TABLE 14.1
Common Congenital Heart Disease Diagnoses

Cyanotic	Acyanotic
Ebstein's Anomaly of the Tricuspid Valve	Atrial Septal Defect (ASD)
Hypoplastic Left Heart Syndrome (HLHS)	Atrioventricular Septal (AV Canal) Defect
Pulmonary Atresia with Intact Ventricular Septum (PA/IVS)	Patent Ductus Arteriosus (PDA)
Critical Pulmonary Stenosis (PS)	Truncus Arteriosus
Tetralogy of Fallot (TOF)	Ventricular Septal Defect (VSD)
Total Anomalous Pulmonary Venous Return (TAPVR)	Aortic Stenosis (AS)
Transportation of the Great Arteries (TGA)	Coarctation of the Aorta (CoA)
Tricuspid Atresia	Interrupted Aortic Arch (IAA)

lesion, degree of left-to-right shunting (which can lead to pulmonary over-circulation), and overall cardiac systolic function can impact the patterns of pediatric growth failure.

Cyanotic heart diseases are characterized by right-to-left intracardiac shunts and decreased effective pulmonary blood flow. Acyanotic heart diseases consist of lesions with varying degrees of compromised systemic output with or without a net left-to-right shunt. Patients with large left-to-right shunts, as are seen in lesions such as moderate to large ventricular septal defects (VSDs), patent ductus arteriosus (PDA), truncus arteriosus, and complete atrioventricular canal defects, can develop congestive heart failure and resultant poor growth. Acyanotic lesions with a large degree of left-to-right shunting typically affect weight while sparing height in the early stages before surgical repair.

Growth failure is less common in patients with acyanotic lesions, though growth problems have been described in this population as well. One potential reason for this is that the basal metabolic state of the heart in infants and children has been found to be significantly greater in the presence of cyanosis compared with acyanosis. Infants and children with CCHD, whether cyanotic or acyanotic, commonly have growth problems. This is classically exhibited by patients with hypoplastic left heart syndrome (HLHS) or other forms of single ventricle. This group is known to have poor growth early in life, and this is likely multifactorial in nature.

NUTRITION MANAGEMENT

Nutrition Assessment

Because of risk for malnutrition, this patient population requires nutrition screening and close monitoring from infancy through adulthood. Anthropometric measurements, including weight, length/height, head circumference (<2 years of age), and mid-upper arm circumference (MUAC), should be measured frequently both inpatient and outpatient to closely monitor growth trends. Nutrition-focused physical exam (NFPE) is important with each assessment to help support the nutrition diagnosis.

An imbalance of metabolic supply and demand contributes to poor somatic growth in children with CHD. Often this imbalance is related to insufficient energy and protein intake, poor utilization or absorption of nutrients, increased expenditure, genetic predisposition, or a combination of the above. Hypermetabolism has been well described in CHD and may contribute to malnutrition and growth failure. Insufficient cardiac output or heart failure often leads to an increased metabolic demand given the body's natural cascade of reactions in an effort to restore normal perfusion. A thorough nutrition assessment is required to determine nutrient intake, assess growth trends, and determine if adjustments are needed in the nutrition prescription and intervention.

Nutrition Diagnosis

Common nutrition diagnoses for patients with CHD include:

- Increased energy expenditure
- Inadequate energy intake
- Inadequate oral intake
- Inadequate enteral nutrition infusion
- Growth rate below expected
- Swallowing difficulty
- Malnutrition (undernutrition)

Nutrition Intervention

Nutrition Prescription

Children with CHD have a much higher total daily energy expenditure (TDEE) than healthy infants. This can be up to 36% higher. On the contrary, one study by Irving and colleagues found that resting energy expenditure (REE) at 3 months of age for infants following neonatal cardiac surgery did not differ between postsurgical infants with CHD and healthy infants. However, the infants with CHD were found to have lower growth z-scores and lower percent body fat thus indicating potential stunting and slower rate of growth overall.

Critically ill neonates are at high risk for malnutrition due to metabolic stress, limited reserves, and inadequate supply of nutrients. The primary nutrition goal after birth for neonates diagnosed with CHD is to minimize neonatal weight loss during the preoperative period. It is well described in the literature that preoperative malnutrition is associated with a longer intensive care unit length of stay. Early enteral feeding has been widely recognized as safe and beneficial in preterm and term neonates. Infants with ductal-dependent pulmonary or systemic circulation are believed to be at risk for intestinal hypoperfusion due to cyanosis, potentially increasing their risk for necrotizing enterocolitis (NEC). Feeding of infants with cyanosis has not been shown to date to be associated with an elevated incidence of NEC. American Society for Parenteral and Enteral Nutrition (ASPEN) clinical guidelines recommend initiating minimal EN within 2 days of life for those at risk for NEC along with the preferential use of human milk over formula. The benefits of preoperative feeding in the infant with CHD include oromotor-skill and neuro-development, maternal bonding, improved hemodynamics, and protective health benefits to the gut.

Protein-energy malnutrition in hospitalized children is associated with increased physiological instability and increased resource utilization potentially affecting outcomes. Protocols for initiating and advancing EN during the preoperative and postoperative periods are advantageous. When determining energy needs for the critically ill infant, indirect calorimetry (IC) is the gold standard. Energy needs are heterogeneous and predictive equations are often inaccurate. Obtaining IC is challenging in small infants due to the specific criteria and limited resources available. If IC is unavailable, literature recommends initially aiming for basal energy expenditure using the WHO tables during the first 3–5 days, then multiplying basal energy expenditure by stress or injury factors after postoperative days 5–7. Alternate predictive equations to consider are the Dietary Reference Intakes (DRI) from 2002 and REE tables by Page and colleagues. Table 14.2 summarizes postoperative nutrition guidelines for patients with CHD.

Nutrition support therapy via EN or PN should be initiated as early as 24–48 hours in order to promote wound healing, minimize the loss of lean body mass, and support vital organ function. Barriers to the provision of nutrition include hemodynamic instability, hypotension, hyperglycemia, electrolyte derangements, fluid restrictions, impaired renal function, and mechanical ventilation. PN should be initiated for patients when EN is contraindicated, including times of hemodynamic instability, acute decompensated heart failure, escalating pressor support, or concern for NEC.

TABLE 14.2
Nutrition Guidelines for Neonates Undergoing Surgery for Congenital Heart Disease

	Postoperative Guidelines	Acute Care Guidelines
Energy	Determined by indirect calorimetry[a] 55–65 kcal/kg for first 3–5 days	Advance to 120–150+ kcal/kg[b]
Protein	Preterm: 3–4.5 g/kg Term: 3–4 g/kg Protein needs lower with acute kidney injury (AKI) or higher with continuous renal replacement therapy (CRRT)/Peritoneal dialysis	2.2–3.5 g/kg
Carbohydrate	40%–60% of total calories Initiate GIR 4–8 mg/kg per minute Advance to max GIR 12–14 mg/kg per minute	
Lipid	1.5–3 g/kg[c] 2 g/kg (minimum dose in infants) of SMOFlipid® if warranted	
Fluid	Fluid restriction 50%–85% mIVF mIVF fluid: 100 mL/kg	Advance to 100–150 mL/kg Increased 10%–15% with insensible losses due to fever, tachypnea, tachycardia, diarrhea

Source: Table created using data from Nydegger, A. and J.E. Bines, Energy metabolism in infants with congenital heart disease. *Nutrition*, 2006. **22**(7–8): pp. 697–704. Owens, J.L. and N. Musa, Nutrition support after neonatal cardiac surgery. *Nutr Clin Pract*, 2009. **24**(2): pp. 242–9.

Abbreviations: GIR, glucose infusion rate; mIVF, maintenance intravenous fluids.

[a] If available, results may be affected by ventilation, sedation, medications.

[b] Estimated needs from EN.

[c] Limited with cholestasis or hypertriglyceridemia.

PN and EN should be used simultaneously in the gradual transition to full EN. Once full EN is achieved, nutrition support therapy should be optimized to provide adequate energy and protein to promote weight gain.

Fluid restriction to 50%–80% maintenance in the first 24 hours is common after heart surgery. Fluid that has to be administered includes medication infusions and flushes and may limit the amount of nutritional fluid that can be provided. As the patient reaches more stability and diuresis is initiated, the total fluid allotment should be liberalized. The use of diuretics may deplete total body sodium and potassium; these ions as well as calcium, phosphorus, and magnesium levels and should be monitored and addressed.

Acute kidney injury (AKI) is the most common complication following pediatric heart surgery. The management of AKI can further complicate nutrition support therapy. See Chapter 20 for management of nutrition therapy in AKI.

Common Nutrition Interventions

Parenteral Nutrition

When planning nutrition support therapy for an acutely ill infant or child, the multidisciplinary team should review all fluids objectively. The volume of PN is often driven by the total fluid limit and postoperative day of each patient. Laboratory values including basic metabolic and renal panels, ionized calcium, phosphorus, and magnesium should be monitored daily until stable. Daily weights should be obtained to evaluate fluid status changes and response to nutritional management. Medication infusions should be reviewed with the pharmacist so that they can be concentrated appropriately to maximize fluid allotted for PN.

PN can be initiated postoperatively with a glucose infusion rate (GIR) of 4–6 mg/kg per minute, and may be advanced as tolerated on a daily basis until desired goals are reached. Postoperative infants may tolerate a GIR of up to 12–14 mg/kg per minute. Lipid injectable emulsions (ILEs) are concentrated energy source and also provide essential fatty acids. Hepatic function and triglyceride levels should be monitored to assess tolerance to ILE.

The mineral needs for bone development may be difficult to meet in the short term, due to the use of PN and fluid limitations. Diuretic use may alter calcium status through increased urinary excretion of calcium. Calcium and phosphorus requirements for bone mineralization in the preterm and term infant often cannot be optimized from PN alone. Signs of cholestasis and bone demineralization should be monitored closely for patients requiring long-term PN.

Enteral Nutrition

EN is the preferred mode of feeding when the gut is functional. It is common that infants and children with heart disease may require supplemental EN throughout the phases of care in order to achieve adequate nutrition or to promote weight gain. Factors that prevent these children from achieving adequate oral or EN intake include heart failure, gastroesophageal reflux (GER), swallowing dysfunction, dysphagia, oral aversion, and other endocrine and genetic factors. For these reasons, establishing best nutrition practices may improve nutrient delivery and intakes preventing malnutrition.

EN should be initiated as soon as the patient is hemodynamically stable. Human milk is recommended, although standard infant formula may be an appropriate alternative. Minimal volume feeds initiated at rates of 10–20 mL/kg per day may be appropriate orally or via EN. When a concern for compromised systemic cardiac output is present, patients may be at risk for feeding difficulties or malabsorption and may require hydrolysate or elemental formulas for improved EN tolerance and absorption. When EN is needed, gastric feeds may be trialed, although post-pyloric feeding has been found to be safe when patients require high non-invasive respiratory support, or if there are concerns for gastroparesis or reflux. Since infants and children with CHD often need additional energy and have fluid restrictions, it may be necessary to prescribe energy-dense human milk or formulas concentrated to>20 kcal/oz, ranging frequently from 22 to 30 kcal/oz in order to achieve adequate growth. The energy needs of infants with CHD are difficult to estimate, but many infants will need 120–150 kcal/kg or even greater if additional energy is required for catch-up growth. Toddlers and children may also have increased needs, up to 20%–33% more than their peers. After cardiac repair, the energy needs will usually decrease with more stability but may stay 10–15 kcal/kg above the average for some infants or children, especially if additional energy is to achieve catch-up growth due to presence of malnutrition before surgery. Feeding tolerance should be closely monitored with all feeding changes and continued assessment of growth is important in the care of these patients.

Gastrointestinal disturbances and feeding dysfunction are often present in hospitalized infants and children with cardiac disorders, and may have a significant negative impact on outcomes and burden of illness. Inadequate EN intake, gastrointestinal morbidity, and feeding problems can affect growth and recovery and can influence short- and long-term outcomes. A number of gastrointestinal concerns, including fat and/or protein malabsorption, are common in infants with CHD. In addition to causing early satiety and vomiting, decreased cardiac output may also cause decreased nutrient absorption. Some children with CHD have gastrointestinal malformations, including, but not limited to, duodenal atresia, or malrotation, that will affect their ability to tolerate EN and oral nutrition. Poor gut perfusion is another factor recognized as a complication often present in infants with cardiac insufficiency.

Oral Feedings

One predominant cause of growth failure in infants with CHD includes inadequate energy intake and impaired utilization. Achieving adequate calories through oral feedings is sometimes

difficult. Oral feeding, even if the patient's condition allows, requires a great deal of energy expenditure and may result in symptoms like tachypnea, sweating, discoordination, and fatigue during feeding. Oral feeding regimens may need to be limited, modified, or supplemented with EN to meet the nutritional needs. When thinking about transitioning to EN, it is important to remember the impact of the cardiorespiratory system on the achievement of EN. Infants with a history of cardiopulmonary bypass and prolonged respiratory support showed abnormalities in oromotor feeding skills. For pediatric patients intubated for more than 7 days, the risk of dysphagia increases, as does the inability to feed orally by hospital discharge. Other covariates, including narcotic use, vasopressor support, and cardiopulmonary bypass, may also negatively impact oral feeding ability. Tachypnea may cause an uncoordinated suck, swallow, and breathe pattern necessary for successful oral feeding. When prolonged stridor is present or if any manipulation of the laryngeal nerve occurred during cardiac surgery, concern for vocal cord dysfunction should be considered. It has been reported that laryngopharyngeal dysfunction presents after the Norwood procedure in about 48% of patients, with resultant dysphagia, aspiration, and left recurrent laryngeal nerve injury. Aspiration and dysphagia may be present in patients with vocal cord impairment or paralysis. Protocols around the assessments of swallowing function after cardiac repair are common among centers. In addition, poor endurance leading to fatigue is common and puts the patient at risk for aspiration. For this reason, respiratory rates and heart rates should be closely monitored with oral trials.

Sluggish reflexes, decreased sensory input, hypoxemia, neurological insults, or bowel ischemia may impair the gastrointestinal system. In the event of gut hypoperfusion, waiting for return of bowel function may cause delayed initiation of EN. GER is common in up to 65% of healthy infants but may play a more significant role in infants with CHD. Using a nasogastric tube may result in increased reflux symptoms. Medical management to reduce the symptoms of reflux, delayed gastric emptying, or slow gut motility or post-pyloric feeding is common in this population when feeding intolerance is present.

Neurologic maturation is another key factor that should be considered in the ability of an infant to reach optimal oral intake. Evidence suggests, despite that majority of CHD infants are born at full term, they may be neurologically immature and suffer early neurological insults that may have profound effects on impaired feeding ability. Infants with CHD have a higher risk for neurologic complications including central nervous system bleeds or strokes. Children with CHD are often found to have neurologic disabilities. Depending on the severity of deficits, infants and children with these complications are most often supported by long-term tube feedings.

Mechanical Circulatory Support

A ventricular assist device (VAD) is a medical device that can be implanted or sit external to the patient to partially or completely replace the circulatory function of the heart. VADs are often intended as a bridge to transplantation or as destination therapy and increasing in use for pediatric patients. There are left ventricular assist devices (LVAD), right ventricular assist devices (RVAD), or bi-ventricular assist devices (BiVAD) available depending on the extent of failure. Nutritional assessment guidelines for patients with VADs are lacking. A considerable number of VAD patients have minimal nutritional reserves and ongoing nutritional challenges before VAD placement. Due to limited nutritional guidelines, management is often similar to that of critically ill patients. A detailed nutrition assessment before VAD placement is extremely important with a goal to optimize nutrition. The nutrition goals for patients on all forms of mechanical circulatory support (MCS) are to provide adequate energy and protein to minimize catabolism and promote wound healing within the limits of restricted fluid intake. Providing adequate energy and protein intake is paramount in this patient population. Fluid restriction, difficulties with glucose control, end organ dysfunction, anticoagulation management, gastrointestinal complications, early

satiety, and nutritional deficiencies pose challenges of meeting energy, protein, and micronutrient needs. Total PN and EN are initiated as early as possible with maximized energy density. The use of post-pyloric feeding may be beneficial in decreasing the risk of aspiration and GER along with improved time to reach goal feeding.

Electrolyte derangements are frequent occurrences among patients on MCS due to renal dysfunction, fluid resuscitation, and endocrine problems. Careful attention to electrolyte supplementation, particularly optimization of potassium, calcium, and magnesium, is of prime importance in order to avoid dysrhythmias. In addition to electrolyte abnormalities, specific vitamin deficiencies have been identified in patients with heart failure and those requiring MCS. Vitamin B deficiencies have been described in patients with heart failure. Hence, particular attention to thiamine (B_1), riboflavin (B_2), and pyridoxine (B_6) may be warranted and supplementation may be necessary. Another vitamin of particular interest in heart failure and cardiomyopathy is vitamin D. Emerging evidence suggests that vitamin D has additional roles in the musculoskeletal system and extra-skeletal functions like immune cell proliferation, anti-inflammatory, and malignancies. Available research suggests a high prevalence of vitamin D deficiency in patients with cardiac failure and those who have undergone transplantation. Vitamin D deficiency may play a role in myocardial injury in neonates undergoing cardiopulmonary bypass. More studies are needed on wound healing supplementation due to lacking evidence, but nonetheless, supplementation is reasonable if clinical signs of poor wound healing are present.

Cardiac Transplantation

Despite the improvements in surgical repair options and advances in MCS, many survivors of infant heart surgery for CHD are not cured and remain at risk for developing end-stage heart failure as young adults. Heart transplantation currently remains the only viable treatment option for those in the end-stage of their disease.

Pre-transplantation therapy starts with a comprehensive evaluation by the multidisciplinary team focused on optimizing medical therapy, addressing psychosocial needs, and improving nutritional status. Depending on the extent of circulatory failure, patients may have difficulty tolerating full EN or oral feedings and require a combination of nutrition support therapies. It is not uncommon for patients with advanced heart failure to rely on PN to meet their nutritional needs until transplant. Monitoring bone health and frailty scores are essential components of the ongoing nutritional assessment. Frailty is prevalent in patients with advanced heart failure and is emerging as an independent predictor of mortality both before and after ventricular assist device and transplantation. Vitamin D insufficiency or deficiency is associated with heart failure; therefore these components should be addressed early on. IC is also a goal of the pre-transplant evaluation to help provide one's targeted prescription and may need to be repeated as able.

Peri-transplant therapy involves starting nutrition early within 24–48 hours after surgery. The goals are to mitigate the stress response, achieve adequate nutrient intake and promote wound healing and recovery. Depending on respiratory and hemodynamic state, EN or PN may be required. Initially, patients may be fluid restricted but often this is quickly liberalized as the desire of the new transplanted heart is to be "full" and fluid optimized. Monitoring of chest tube output or postop complications, like chylothorax, is another piece of care after transplant. If chylothorax is present, a modified-fat diet is necessary.

Post-transplantation, the nutritional goals continue with a shift in focus toward a home regimen. Often patients are working on transitioning to more intermittent or oral feedings. Monitoring of energy and protein intake is important to help individualize one's prescription and provide targeted education to the patient and family prior to going home. Monitoring of bone health, which can suffer due to the immunotherapy and steroid use, continues after transplantation. Education on steroids and nutrition; bone health; heart healthy eating; and growth goals are provided to the family and patient.

Special Considerations

One complication or disorder that occurs in patients with CHD is chylothorax. Chylothorax is associated with increased mortality, hospital length of stay, intensive care unit length of stay, time on mechanical ventilation, extracorporeal membrane oxygenation use, and cost. This occurs when there is the presence of lymphatic fluid (chyle) in the pleural space caused by damage to the thoracic duct or lympho-venous connections or secondary to lymphatic abnormalities. It is often a result of iatrogenic complications of cardiothoracic surgery, commonly caused by trauma to the thoracic duct or other surrounding lymphatic tributaries. It has also been described in children with genetic syndromes associated with CHD, including trisomy 21, Noonan's syndrome, Turner's syndrome, and cardio-facio-cutaneous syndrome. Additionally, chylothorax can result from high central venous pressure within the superior vena cava (SVC), thereby affecting the pressure in the lymphatic system and inability of the lymphatic system to adequately drain into the bloodstream. This is seen mainly in operations that cause increased SVC pressure, such as the hemi-Fontan or bidirectional Glenn, Fontan, and Senning procedures, and can also be seen in patients with thrombus occluding the SVC or subclavian vessels.

Chyle is often described as a white, milky-appearing substance composed of chylomicrons and lymph. Lymph fluid from the intestines, as well as the lower extremities and liver, is transported by lymphatic channels that converge into the thoracic duct at the level of the cisterna chyli. The majority of terminal drainage of lymphatic fluid into the venous system is through the thoracic duct and main connection at the junction of the left subclavian and internal jugular veins. The primary purpose of chyle is the absorption and transportation of long-chain triglycerides (LCT) in the intestines. Chyle is formed in the lacteals of the intestines during digestion in response to the presence of intraluminal fat. The chyle binds with LCT to form chylomicrons, which are then absorbed and transported by the intestinal lymphatics to the bloodstream. Chyle is also rich in proteins and is responsible for absorbing fat-soluble vitamins; therefore, high losses are of great nutritional concern. When a person is fasting, the fluid can appear less white, and more yellowish or clear.

Treating chylothorax can be multifactorial, but the primary goal remains conservative therapies directed to reduce intestinal lymphatic flow through dietary modifications and/or medications. The main therapies used in reducing chylous effusions include pleural drainage, initiating a restricted fat diet that contains minimal LCT and enriched with medium-chain triglycerides (MCT). MCT are absorbed directly from the intestinal lumen into the portal system, as are carbohydrates and amino acids, and thus do not stimulate an increase in lymphatic flow. Nutritional management usually starts with trialing a low-LCT and MCT-enriched formula or diet, observing for a reduction in chylous output, and if ineffective, providing gut rest with PN. Formulas containing high amounts of MCT may not meet patients' minimum essential fatty acid (EFA) needs.

EFA deficiency results when there is insufficient dietary intake of linoleic acid (LA) and alpha-linolenic acid (ALA). Deficiency is further exaggerated by increased metabolic demands required for growth and hypermetabolism after stress, injury, surgery, or sepsis. Therefore, it may be necessary in patients that are fed long term with specialty formulas restricting LCT to supplement with EFA in order to provide 1%–4% and 0.2%–1% of the total daily energy intake from dietary LA and ALA, respectively, in order to prevent EFA deficiency.

Clinical symptoms of a long-term EFA deficiency may include growth retardation, impaired cell membrane and skin integrity, eczematous dermatitis, impaired cholesterol metabolism, poor neurocognitive development, poor wound healing, and alopecia. Periodic laboratory monitoring of EFA biochemical profiles should be monitored for patients on a fat-restricted diet for extended lengths of times with suboptimal EFA intakes or if clinical signs present (Chapter 2). Good concentrated sources of EFA that include both LA and ALA are walnut oil and flaxseed oil. It is imperative that dietitians and clinicians promptly identify and treat subclinical EFA deficiency.

Infants with chylothorax can be treated with skimmed human milk, with the fat removed via centrifugation. They may benefit from using skimmed human milk given the immunological properties and improved gastrointestinal tolerance. Also, specific formulas targeted for the treatment of chylothorax and other lymphatic disorders are available and commonly used. Close attention should be made to assure complete nutrition is achieved.

Several published protocols for treating chylothorax have recommended continuing a low-fat, MCT-enriched diet for 4–6 weeks after resolution of chylous drainage, then resuming a regular diet, human milk, or standard formula. Medical management of chylous effusions may include using somatostatin and its analog octreotide. It is known to reduce intestinal secretions and inhibit lymph excretion. Caution must be used when enterally feeding patients receiving somatostatin or octreotide because splanchnic circulation may be diminished; gastrointestinal side effects should be closely monitored.

Fat-soluble vitamins and B-vitamin levels should be screened and monitored for patients with persistently high output chylous effusions as they are at high risk for deficiencies. Large-volume output from chylothorax can cause significant losses of protein, resulting in low albumin levels, and losses of fat, electrolytes, immunoglobulins, and other minerals that may be protein-bound, such as zinc, copper, and selenium. Chylous losses may also lead to hypovolemia, which can lead to hemodynamic instability. Sodium and calcium levels may be decreased, and metabolic acidosis may be seen in patients with high output. Maintaining a restricted fat diet longer than 4 weeks may put individuals at increased risk for deficiencies.

Nutrition Monitoring and Evaluation

Due to varying degrees of critical cardiac anomalies, heart failure, and stages of palliation, it is imperative that nutritional interventions are monitored and re-evaluated frequently during phases of care. A multidisciplinary approach is best when considering all possibilities for malnutrition. Monitoring and evaluating for adequate nutrient intake, tolerance, adherence, anthropometric data, and neurodevelopmental outcomes may improve quality of life and decrease incidence of malnutrition for these complex patients. Caregivers of infants with complex CHD have been shown to have higher stress and anxiety than caregivers of healthy infants and children. For this reason, ongoing assessment of available nutrition and feeding resources can help prevent unwanted stress.

Children with congenital and acquired heart disease are not immune to the growing obesity epidemic, and may suffer the complications of obesity more so than children without heart disease. Patients with heart disease infrequently require strict limitations on activity, but may be perceived as more fragile and thus still avoid participation in activities that may put additional stress on the heart. Patients with heart disease who were advised to restrict their activity and lead a more sedentary lifestyle have been found to be more likely to become either overweight or obese. Furthermore, children with a history of heart failure who had previous difficulties gaining weight during infancy and early childhood and fed high-energy formulas or diets may also continue a high-energy diet even after surgical repair or resolution of heart failure, when high-energy diets are no longer needed. Activity is important in reducing the likelihood of childhood obesity, and it is also an important facet of promoting cardiovascular health. Playing outdoors and high-activity playing have been shown to have positive effects on cardiovascular health in children ages 4–7 years. The activity level of the family influences the activity of the children. A family commitment to a healthy lifestyle, including diet and physical activity, is essential.

In summary, children with CHD often demonstrate some form of growth failure and remain at increased risk for malnutrition (Table 14.3). This growth failure is multifactorial in nature. Aggressive nutritional intervention is often warranted to attenuate complications. Appropriate monitoring and follow-up is ongoing and imperative throughout each phase of care in order to improve

TABLE 14.3
ADIME Summary for Cardiac disease

- Assessment
  - Growth assessment
    - At risk of inadequate growth and malnutrition, monitor anthropometrics closely
  - Nutrition-focused physical exam
  - Nutrient Intake
  - Labs
  - Gastrointestinal Findings
  - Medications/Side Effects
- Diagnosis
- Intervention
  - Nutrition Prescription
    - See Table 14.2
  - Common nutrition interventions
    - Oral
      - At risk of inadequate oral intake
    - Enteral Nutrition
      - May require concentrated formula
      - High-MCT formula or skimmed human milk indicated in patients with chylothorax
    - Parenteral Nutrition
      - Indicated when patient unable to meet nutrient needs with oral and enteral nutrition
    - Education
    - Laboratory Monitoring
      - Essential fatty acid profile in patients with chylothorax
    - Supplements
    - Other specialty referrals
- Monitoring & Evaluation
  - Anthropometrics
  - Labs
  - Tolerance to Oral feeds/enteral nutrition

the nutritional status for each cardiac patient. With concrete understanding of one's cardiac anatomy and through optimal interventions, monitoring, and evaluation, normal growth and neurodevelopment outcomes can be achieved in complex cardiac patients.

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15 Food Allergy

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CONTENTS

A food allergy is an adverse immunologic response to an ingested food protein. Food allergy involves either immunoglobulin E (IgE)-mediated or non-IgE-mediated immune mechanisms, each of which has a different clinical presentation and natural history. Milk, egg, peanut, soy, wheat, tree nut, fish, and shellfish cause approximately 90% of food allergies in children in the USA, and diets restricting these foods can pose nutritional challenges for pediatric patients. Though food allergy prevalence has risen in recent decades, emerging data suggests that introducing allergens early in life may prevent food allergy development in infants and children.

IgE-MEDIATED FOOD ALLERGY

Immunoglobulin E (IgE)-mediated food allergy is an adverse food reaction in which an affected individual is exposed to the implicated food protein and, often within minutes, develops an urticarial rash, angioedema, difficulty breathing, emesis, and/or hypotension. Affected patients often require immediate emergency medical evaluation and treatment with epinephrine and/or antihistamines, depending on the severity of the reaction. The prevalence of childhood food allergy is 7.6%. Milk is the most common allergen in infants <12 months of age; however, milk, peanut, and egg are the most common food allergens in toddlers 1–2 years of age. The prevalence of food allergy among adults is 10.8% and shellfish is the most commonly implicated allergen.

While great strides have been made in recent years towards improving our understanding of the complicated pathophysiology underlying food allergy development, many questions remain unanswered. The dual-allergen exposure hypothesis highlights that exposure to an allergen through disrupted skin leads to the development of food-specific allergic antibody and clinical food allergy, whereas oral exposure to food allergens through the gastrointestinal system leads to the development

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of tolerance to the food. It is clear that atopic dermatitis is a significant risk factor for the development of food allergy. There is a growing body of evidence supporting this hypothesis and highlighting the role of the skin in the development of food allergy. It is important to note, however, that the pathophysiology of this disease is complex and likely multifactorial.

The patient's history is key in making a diagnosis of IgE-mediated food allergy. Common clinical signs and symptoms suggestive of an IgE-mediated food allergy include urticaria, angioedema, a diffuse pruritic rash, wheezing, coughing, increased work of breathing, stridor, changes in the voice suggestive of upper airway angioedema, vomiting, abdominal pain, hypotension, diarrhea, persistent sneezing, persistent rhinorrhea or congestion, and/or change in behavior including lethargy, irritability, or food refusal. The timeline is very important with most signs and symptoms occurring within 60 minutes of oral exposure to the suspected allergen.

If a patient has a history concerning for an IgE-mediated food allergy, referral to an allergist is recommended. Again, while the diagnosis of a food allergy largely is based on a patient's clinical history, testing can be performed to evaluate for the presence of allergic antibody or IgE to the suspected allergen. Skin-prick testing (SPT) is routinely performed in the allergy clinic and evaluates for the presence or absence of allergen-specific IgE by superficial disruption of the skin surface utilizing a device containing a small amount of allergen at the tip. If SPT is unable to be performed, laboratory testing can be obtained examining for allergen-specific IgE in the serum. If the patient's clinical history and testing are inconsistent with an IgE-mediated food allergy, oral food challenge (OFC) testing is indicated. The OFC is a procedure during which a patient is fed increasing quantities of an allergen under medical supervision and closely observed for the development of signs and/or symptoms consistent with an IgE-mediated food allergy. If a reaction occurs, the OFC is stopped, the patient is treated, and a food allergy diagnosis is confirmed.

While the three testing modalities described above are those routinely used in clinical practice, a variety of unaccepted tests for food sensitivity are available to the public. Examples include food allergen patch testing, measurement of food-specific IgG, electrodermal testing, the antigen leukocyte antibody test (ALCAT), and applied kinesiology testing. The use of these tests is discouraged in the evaluation of food allergy as their use has not been validated and may result in unnecessary food avoidance.

The mainstay of food allergy management is strict avoidance of the food allergen. The patient and family should be provided with clear education on allergen avoidance including label reading, cross-contact, and eating outside of the home. A weight-based epinephrine auto-injector should be carried at all times and the patient and family should receive education regarding its appropriate use and scenarios in which its use would be indicated.

In July 2020, the U.S. Food and Drug Administration (FDA) approved the first therapeutic product for peanut allergy in children ≥4 years of age, Palforzia. The product is a peanut allergen powder for oral immunotherapy, a procedure during which a patient with known food allergy is exposed to their trigger food in small, but increasing quantities over time to try to desensitize them to their food allergen. While this is currently the only approved product, many allergists around the world offer oral immunotherapy to their patients utilizing store-bought products. Oral immunotherapy is not curative, but it has been shown to mitigate risk associated with accidental allergen exposure by raising the threshold for the amount of allergen that induces a response.

The natural history of food allergy is different depending on the allergen implicated. The majority of patients with milk and egg allergy in infancy will outgrow their food allergy by school-age or adolescence. Similarly, over 50% of milk and egg allergic patients are able to tolerate the food after extensive heating or baking (i.e., cow's milk or egg in baked goods). Peanut and tree nut tend to be more persistent allergens with only 10%–20% of those affected outgrowing their allergy. Approximately 45%–50% of those with wheat or soy allergy in infancy will eventually develop tolerance.

Previously, delayed introduction of allergenic foods (until after 3 years of age) in individuals with a family history of food allergy was recommended to prevent the development of food allergies. These recommendations have been altered dramatically. In 2015, the results of a randomized

controlled trial of early peanut introduction in infants considered to be high risk for peanut allergy revealed a significant reduction in the prevalence of peanut allergy among subjects randomized to regular consumption of peanut early in life. Recent guidelines now recommend testing infants with severe atopic dermatitis and/or egg allergy for the presence of peanut specific IgE, either by SPT or serum-specific IgE testing, prior to the oral introduction of peanut and that introduction should occur by 4–6 months of age. In patients with mild-to-moderate atopic dermatitis, peanut should be introduced into the diet at around 6 months of age or when developmentally appropriate (Chapter 5). Subsequent studies of early introduction of allergenic foods have also collectively shown a benefit for food allergy prevention with earlier introduction of egg; however, this has not yet been adopted into guidelines. Studies are currently underway to determine the benefit of early introduction of other highly allergenic foods. In general, the recommendation for healthy infants without increased risk of food allergy is to introduce a variety of foods in developmentally appropriate textures, including highly allergenic foods (Table 15.1).

Oral Allergy Syndrome or Pollen Food Allergy Syndrome

Oral allergy syndrome (OAS) or pollen food allergy syndrome (PFAS) is an adverse food reaction characterized by primarily localized oropharyngeal symptoms immediately following consumption

TABLE 15.1
IgE- and Non-IgE-Mediated Food Allergies

	IgE-Mediated		Non-IgE-Mediated		
Diagnoses	Food Allergy	Oral Allergy Syndrome	FPIES	FPIAP	FPE
Symptoms	Rash, angioedema, difficulty breathing, emesis, hypotension	Mouth or throat itching, difficulty swallowing, oropharyngeal angioedema	Vomiting, diarrhea, lethargy, hypotension, methemoglobinemia, acidemia, shock	Blood in stool, loose stools with mucus	Diarrhea, vomiting, malabsorption, poor weight gain, malnutrition
Common Trigger Foods	Milk, soy, wheat, egg, peanuts, tree nuts, fish, shellfish	Raw fruits and vegetables, some patients may also react to cooked fruits and vegetables	Milk, rice, oats, sweet potatoes, banana, legumes, poultry, egg, fish	Milk, soy, egg, corn (in formula or maternal diet for infants fed human milk)	Milk
Age of Resolution	School-age to adolescence, some allergies may persist through adulthood	–	Varies	1 year of age	1–3 years of age
Food Reintroduction	In-office food challenge when recommended by allergist	–	Oral food challenge 12–18 months after most recent reaction	Reintroduction of suspected trigger food around 12 months of age	Reintroduction of suspected trigger food

Legend: FPIES, Food protein-induced enterocolitis syndrome; FPIAP, Food protein-induced allergic proctocolitis; FPE, Food protein-induced enteropathy.

of a food and is mediated by cross-reactivity between food and aeroallergens. Individuals with IgE to aeroallergens (e.g., birch tree, ragweed, oak tree, grass, mugwort) may have IgE that is cross-reactive with particular proteins found in fruits and vegetables. Individuals with this phenotype often develop oral and/or throat itching, difficulty swallowing, nasal and/or ear itching, and/or oropharyngeal angioedema immediately after consumption of the implicated food. In less than 5% of cases, patients develop systemic symptoms or anaphylaxis. Interestingly, a large number of patients with OAS can tolerate the implicated food without symptoms when it has been peeled and/or cooked. OAS is largely managed by avoidance of the fruits and/or vegetables implicated, in either raw and/or cooked form, depending on symptom severity. Patients who experience severe symptoms should carry an an epinephrine auto-injector.

NON-IgE-MEDIATED FOOD ALLERGIES

Non-IgE-mediated food allergies encompass immunologic adverse reactions to ingested foods without the presence of IgE. This group includes food protein-induced enterocolitis syndrome (FPIES), food protein-induced allergic proctocolitis (FPIAP), and food protein-induced enteropathy (FPE). Clinical symptoms, treatment, and natural history vary based on the underlying disease process; however, all non-IgE-mediated food allergies typically affect infants and young children and lack classic IgE-mediated symptoms.

Food Protein-Induced Enterocolitis Syndrome

FPIES is a non-IgE-mediated gastrointestinal food allergy that classically presents in infancy and is characterized by repeated episodes of vomiting starting approximately 1–4 hours after food ingestion. Episodes of vomiting may also be followed by lethargy and diarrhea, with serious cases progressing to hypotension, methemoglobinemia, acidemia, and shock. IgE-mediated signs including skin or respiratory symptoms are not associated with FPIES. The pathogenesis of FPIES has not been completely defined. Chronic FPIES can be seen in very young infants prior to age 4 months and is associated with frequent ingestion of cow's milk or soy-based infant formula.

FPIES has an estimated prevalence of 0.51% in children and 0.22% in adults. While cow's milk is the most common food trigger for FPIES internationally, rice and oats are the most associated solid food triggers. Any food may trigger FPIES symptoms, including foods infrequently associated with IgE-mediated food allergies such as fruits and vegetables. Higher risk trigger foods include sweet potato, banana, legumes, poultry, egg, and fish. While there are overlaps, it should be noted that solid foods causing FPIES tend to be different from those causing IgE-mediated allergies.

Acute FPIES classically presents in children prior to age 1 year. Cow's milk- and soy-induced FPIES often present in early infancy, with solid food FPIES occurring later when these foods are introduced. The cardinal feature of acute FPIES is repeated, and often, severe vomiting. International criteria for diagnosis require the presence of repeated vomiting within 1–4 hours of ingestion of a food without presence of IgE-mediated symptoms and at least three minor criteria. Minor criteria include repeated episodes of vomiting after ingestion of the same food, delayed repetitive vomiting after ingestion of a different food, extreme lethargy, pallor, requirement for emergency department evaluation or intravenous fluid treatment, diarrhea within 24 hours, hypotension, or hypothermia. FPIES-associated symptoms resolve within hours of development, which contrasts with lengthier time of symptom resolution in alternative entities such as infectious gastroenteritis, immune enteropathies, or inborn errors of metabolism.

Chronic FPIES presents solely in young infants who are fed cow's milk- or soy-based infant formulas. Symptoms of chronic irregular vomiting and diarrhea typically present within 1 month of introduction of infant formula with subsequent development of malnutrition. More rarely, serious

symptoms of dehydration and shock can occur. Diagnosis of chronic FPIES can be delayed as symptoms are not correlated with feedings. Complete resolution of symptoms including improvement in growth occurs within days to weeks of strict avoidance of the trigger food. Children who reintroduce the food subsequently present with symptoms consistent with acute FPIES. This is a crucial feature of chronic FPIES and can help distinguish chronic FPIES from other possible etiologies of persistent gastrointestinal symptoms.

No laboratory testing is currently available to definitively diagnose FPIES, and it remains largely a clinical diagnosis. Clinicians should obtain a thorough history during the evaluation of a patient with suspected FPIES as this is the most important diagnostic tool. An OFC is the gold standard for identification of FPIES in cases where the diagnosis is uncertain; however, challenges are not mandatory to diagnose patients with a compelling history. An OFC is also an important tool for evaluation of resolution of FPIES. Skin-prick and food-specific IgE testing are classically negative for patients with FPIES; however, up to 20% of patients can develop positive IgE testing for the trigger food, known as atypical FPIES. These patients may have a more protracted course with longer persistence of FPIES symptoms. Patients with chronic FPIES may develop anemia, hypoalbuminemia, and eosinophilia.

Management of FPIES includes avoidance of trigger foods, treating symptoms after accidental exposure, and following for resolution of FPIES. Strict avoidance of the trigger food is critical. Introduction of complementary foods should not be delayed due to history of FPIES alone, and guidelines for selecting weaning foods are defined in Table 15.2.

TABLE 15.2
Guidelines for Complementary Foods in Infants with FPIES

Food Group	Lower Risk	Medium Risk	High Risk
Vegetables	Broccoli	Carrot	Green peas
	Cauliflower	Green beans	Sweet Potato
	Parsnip	Squash	
	Pumpkin	White Potato	
	Turnip		
Fruits	Avocado	Apple	Banana
	Blueberries	Orange	
	Peach	Pear	
	Plum		
	Strawberries		
	Watermelon		
Protein	Lamb	Beef	Egg
	Tree nuts	Peanuts	Fish
	Seeds		Poultry
Grains	Millet	Barley	Oats
	Quinoa	Corn	Rice
		Wheat	
Dairy & Diary Substitutes			Milk
			Soy

Source: Reprinted with permission from Nowak-Węgrzyn A, Chehade M, Groetch ME, et al. International consensus guidelines for the diagnosis and management of food protein-induced enterocolitis syndrome: Executive summary-Workgroup Report of the Adverse Reactions to Foods Committee, American Academy of Allergy, Asthma & Immunology. *J Allergy Clin Immunol*. 2017; 139: 1111–1126.

Note: Foods should be offered to infants in age-appropriate food textures.

Acute FPIES reactions are a true medical emergency and require prompt and aggressive management with fluid resuscitation and other supportive therapies. Treatment plans for FPIES reactions should be discussed with the patient and family at the time of diagnosis.

Resolution of FPIES is variable and is influenced by a variety of factors including type of food and geographic location. Cow's milk and soy-induced FPIES are postulated to resolve earlier than solid food-induced FPIES. Reintroduction of trigger foods is recommended under physician supervision and should be considered at appropriate intervals to assess for resolution. In the USA, an OFC is commonly offered approximately 12–18 months after the most recent reaction.

Food Protein-Induced Allergic Proctocolitis

FPIAP is an allergic colitis occurring in infants, with presence of inflammation in the distal colon due to immune-mediated responses to ingested foods. Prevalence of FPIAP is poorly defined; however, it is thought to be the most common non-IgE-mediated food allergy.

FPIAP classically presents in otherwise healthy young infants in the first 2 months of life with blood in the stool with variable presence of loose stools containing mucus. A smaller proportion of infants will also present with irritability or food refusal; however, children are otherwise healthy without symptoms of vomiting, severe diarrhea, or weight loss.

Most affected infants are exclusively fed human milk with symptom development after exposure to food proteins from the maternal diet in ingested human milk. Consumption of milk- or soy-based infant formula may also trigger symptoms. Cow's milk is the most common food trigger for infants with FPIAP; however, additional trigger foods include soy, egg, and corn.

FPIAP is a clinical diagnosis; food patch testing, endoscopy, imaging, and IgE-mediated food allergy tests are not recommended as standard diagnostic tools. The diagnosis is supported by resolution of rectal bleeding after removal of the trigger food from the infant's diet.

Removal of the triggering food from the maternal and/or infant diet is required. Most infants fed human milk improve after maternal elimination of all forms of cow's milk. However, strict avoidance of soy or other trigger foods may be required if symptoms persist. Grossly visible rectal bleeding typically resolves within 72–96 hours of dietary elimination, with full resolution of all symptoms within approximately 1–2 weeks.

FPIAP is transient in most cases, and often resolves by 1 year of age. The trigger food can be reintroduced at home at 1 year of age in children without history of IgE-mediated or FPIES-like symptoms. If rectal bleeding returns, the elimination diet must be continued with repeat reintroduction trials every 6 months until successful. A small proportion of infants fed human milk will have spontaneous resolution of symptoms without undergoing an elimination diet.

Food Protein-Induced Enteropathy

FPE is an allergic enteropathy that affects the small intestine leading to symptoms of diarrhea, malabsorption, and malnutrition in infancy. FPE is likely rare, with prevalence unknown. Immune cells including T cells and eosinophils likely play a role in development of mucosal inflammation and damage to the intestinal villa in FPE.

Infants with FPE typically present prior to 9 months of age with chronic, persistent diarrhea with subsequent development of malabsorption and malnutrition. Some patients may also present with intermittent vomiting. FPE most often develops shortly after introduction of cow's milk protein into the infant's diet.

Diagnosis of FPE is supported by small intestinal biopsies significant for inflammation, villous atrophy, and crypt hyperplasia. Resolution of symptoms with avoidance of the triggering food protein and exclusion of other possible causes of malabsorption or malnutrition are additionally recommended; however, there are no clearly defined clinical diagnostic criteria.

Supportive laboratory findings including anemia and hypoalbuminemia are often present. Strict avoidance of cow's milk or another triggering food resolves symptoms of diarrhea, vomiting, malabsorption, and malnutrition. Infants should be placed on an extensively hydrolyzed or elemental infant formula. Data regarding FPE in infants fed human milk is scarce. As with other non-IgE-mediated food allergies, FPE is transient and resolves in most children between ages 1 and 3 years.

Eosinophilic Gastrointestinal Diseases

Eosinophilic gastrointestinal diseases (EGID) include eosinophilic esophagitis (EoE) and eosinophilic gastroenteritis (EGE). Approximately two-thirds of patients with EGID also have atopic disease including food allergies. See Chapter 16 for more information about EoE.

NUTRITION MANAGEMENT OF FOOD ALLERGIES

Because allergen avoidance is the mainstay of food allergy management, a child with food allergy can experience nutritional challenges. Some of these shortfalls are inherent to the diagnosis, as is the case of increased energy and fluid needs necessary for children with malabsorptive gastrointestinal allergy such as FPE. But many nutritional deficiencies observed in children with food allergies result from diet restrictions. Children with multiple IgE-mediated food allergies are at risk of growth delays and nutritional deficiencies, especially when avoiding milk. Children with IgE- and non-IgE-mediated allergies alike may experience diets with limited diversity due to delayed weaning and caregiver anxiety. Although poor nutritional intake and growth failure are the primary nutritional concerns when managing children with food allergies, up to 12% of children with food allergies are obese.

Nutrition Assessment

An initial nutrition assessment should include anthropometric measurements and a nutrition-focused physical exam with specific attention to signs of micronutrient deficiencies common in allergy-restricted diets (Table 15.3). A thorough feeding history and diet recall are helpful in determining nutrient deficiencies and identifying opportunities for improving nutrient intake. Careful attention to food substitutes, such as plant-based milk (PBM) alternatives, is essential in ensuring that the patient is meeting nutrient needs. Nutrition assessment should also appraise caregiver knowledge regarding food allergen avoidance practices such as label reading and cross contact prevention, which are outlined later in this chapter.

Nutrition Diagnosis

Nutrition diagnoses in this population may refer to growth delays, inadequate intake of specific nutrients, or knowledge deficits related to food allergen practices. Common nutrition diagnoses include:

- Inadequate energy intake
- Inadequate protein intake
- Food and nutrition related knowledge deficit
- Inadequate fat intake
- Inadequate vitamin intake (specify)
- Inadequate mineral intake (specify)
- Poor nutrition quality of life

TABLE 15.3
Common Nutrition Deficiencies Associated with Food Allergy

Food Allergen	Nutrients	Alternative Food Sources
Milk	Protein, fat, calcium, vitamins D, B_{12}, A, B_6, riboflavin, phosphorus, pantothenic acid, potassium, magnesium, iodine	Meats, legumes, whole grains, nuts, calcium, and vitamin D-fortified foods/beverages (i.e., plant-based milks: fortified soymilk)
Wheat	Carbohydrate, iron, thiamin, riboflavin, folate, niacin, pyridoxine, biotin, zinc, selenium, magnesium, fiber	Enriched grains (i.e., oat, corn, rice, soy flour), fruits, vegetables, legumes
Egg	Protein, fat, pantothenic acid, biotin, choline, selenium	Meats, legumes, whole grains, fish, seafood
Soy	Protein, fat, iron, zinc, magnesium, thiamin, riboflavin, niacin, pyridoxine, Folate, calcium, phosphorus	Meats, allowed grains/legumes, fortified foods/beverages
Peanut/Tree Nut	Protein, fat, fiber, vitamin e, selenium, zinc, manganese, cooper, magnesium, folate, vitamin B_6, phosphorus	Allowed legumes, whole grains, vegetable oils, fish, seafood
Fish/Shellfish	Protein, omega-3 fatty acids, iron, phosphorus, iodine, zinc, selenium, vitamin B_{12}	Whole grains, milk, nuts, meats, oils, flax seed, soy

Nutrition Intervention

Nutrition Prescription

Children with food allergies have nutrient needs comparable to their peers without food allergies. However, if specific nutrient deficiencies are identified during the nutrition assessment, supplementation of those nutrients is indicated (Chapter 2).

Nutrition Intervention

Once properly diagnosed by the allergist, food allergy management involves avoidance of the offending allergen(s). The dietitian should provide education regarding the forms of the food allergen avoided, how to read food labels, and alternative foods or supplements to replace the foods and nutrients eliminated. Single food allergies such as peanuts or fish may not compromise the nutritional adequacy of the diet; however, the avoidance of milk, eggs, soy, or wheat can significantly impair diet quality.

Nutrition Education

Identifying allergens on food labels may not be visually obvious in processed and packaged foods, thus label reading is an essential skill when following an allergy-restricted diet. The Food Labeling and Consumer Protection Act of 2004 (FALCPA) requires disclosure of the top eight common allergens in the USA (cow's milk, soy, egg, wheat, peanut, tree nuts, fish, crustacean shellfish). Passage of the Food Allergy Safety, Treatment, Education and Research (FASTER) Act requires that sesame also be clearly declared in packaged foods by 2023. FALCPA and FASTER apply to all domestic and imported packaged food products and dietary supplements regulated by the FDA. The allergen must be clearly disclosed using its common name within the ingredient list or in a separate "contains" statement, and cannot be hidden in any vague ingredient terms, such as "natural flavors". Specific tree nut, fish species, or crustacean shellfish must be identified. Mollusks are not considered major allergens and will not be fully disclosed on the food label like crustacean shellfish.

Table 15.4 contains information from the Food Allergy Research and Education organization on how to read a label for the major allergens. Food labeling laws vary by country; therefore, patients should take extra care when traveling abroad.

TABLE 15.4
How to Read Food Labels for Major Allergens

- All FDA-regulated manufactured food products that contain a "major food allergen" (milk, wheat, egg, peanuts, tree nuts, fish, crustacean shellfish, and soy) as an ingredient are required by U.S. law to list that allergen on the product label. For tree nuts, fish and crustacean shellfish, the specific type of nut or fish must be listed.
- Read all product labels carefully before purchasing and consuming any item.
- Be aware of unexpected sources of allergens, such as the ingredients listed below.
- *Note*: This list does not imply that the allergen is always present in these foods; it is intended to serve as a reminder to always read the label and ask questions about ingredients.

How to Read a Label for a Milk-Free Diet

Avoid foods that contain milk or any of these ingredients:

butter, butter fat, butter oil, butter acid, butter ester(s)
buttermilk
casein
casein hydrolysate
caseinates (in all forms)
cheese
cottage cheese
cream
curds
custard
diacetyl
ghee
half-and-half
lactalbumin, lactalbumin phosphate
lactoferrin
lactose
Lactulose
milk (in all forms, including condensed, derivative, dry, evaporated, goat's milk and milk from other animals, low-fat, malted, milkfat, nonfat, powder, protein, skimmed, solids, whole)
milk protein hydrolysate
pudding
Recaldent®
rennet casein
sour cream, sour cream solids
sour milk solids
tagatose
whey (in all forms)
whey protein hydrolysate
yogurt

Avoid foods that contain milk or any of these ingredients:

artificial butter flavor
baked goods
caramel candies
chocolate
lactic acid starter culture and other bacterial cultures
luncheon meat, hot dogs, sausages
margarine
nisin
nondairy products
nougat

How to Read a Label for a Soy-Free Diet

Avoid foods that contain soy or any of these ingredients:

edamame
miso
natto
soy (soy albumin, soy cheese, soy fiber, soy flour, soy grits, soy ice cream, soy milk, soy nuts, soy sprouts, soy yogurt)
soya
soybean (curd, granules)
soy protein (concentrate, hydrolyzed, isolate)
shoyu
soy sauce
tamari
tempeh
textured vegetable protein (TVP)
tofu

Soy is sometimes found in the following:

Asian cuisine
vegetable broth
vegetable gum
vegetable starch

Keep the following in mind:

The FDA exempts highly refined soybean oil from being labeled as an allergen. Studies show most allergic individuals can safely eat soy oil that has been highly refined (not cold pressed, expeller pressed, or extruded soybean oil).
Most individuals allergic to soy can safely eat soy lecithin.
Follow your doctor's advice regarding these ingredients.

How to Read a Label for a Wheat-Free Diet

Avoid foods that contain wheat or any of these ingredients:

bread crumbs
bulgur
cereal extract
club wheat
couscous
cracker meal
durum
einkorn
emmer
farina
farro
flour (all purpose, bread, cake, durum, enriched, graham, high gluten, high protein, instant, pastry, self-rising, soft wheat, steel ground, stone ground, whole wheat)
freekah
hydrolyzed wheat protein
Kamut®
matzoh, matzoh meal (also spelled as matzo, matzah, or matza)
pasta
seitan
semolina
spelt
sprouted wheat
triticale
vital wheat gluten
wheat (bran, durum, germ, gluten, grass, malt, sprouts, starch)
wheat bran hydrolysate
wheat germ oil
wheat grass
wheat protein isolate
whole wheat berries

Wheat is sometimes found in the following:

glucose syrup
oats
soy sauce
starch (gelatinized starch, modified starch, modified food starch, vegetable starch)
surimi

How to Read a Label for an Egg-Free Diet

Avoid foods that contain eggs or any of these ingredients:

albumin *(also spelled albumen)*
egg *(dried, powdered, solids, white, yolk)*
eggnog
globulin
livetin
lysozyme
mayonnaise
meringue *(meringue powder)*
surimi
vitellin
words starting with "ovo" or "ova" (such as ovalbumin)

Egg is sometimes found in the following:

baked goods
breaded items
drink foam (alcoholic, specialty coffee)
egg substitutes
fried rice
ice cream
lecithin
marzipan
marshmallows
meatloaf or meatballs
nougat
pasta

Keep the following in mind:

- Individuals with egg allergy should also avoid eggs from duck, turkey, goose, quail, etc., as these are known to be cross-reactive with chicken egg.
- While the whites of an egg contain the allergenic proteins, patients with an egg allergy must avoid all eggs completely.

How to Read a Label for a Fish-Free Diet

Avoid foods that contain fish or any of these ingredients:

barbecue sauce
bouillabaisse
Caesar salad
caviar
deep fried items
fish flavoring
fish flour
fish fume
fish gelatin (kosher gelatin, marine gelatin)
fish oil
fish sauce imitation fish or shellfish
isinglass lutefisk maw, maws (fish maw)
nuoc mam (Vietnamese name for fish sauce; beware of other ethnic names)
pizza (anchovy topping)
roe
salad dressing
seafood flavoring
shark cartilage
shark fin
surimi
sushi, sashimi
Worcestershire sauce

Keep the following in mind:

If you have fish allergy, avoid seafood restaurants. Even if you order a non-fish item off of the menu, cross-contact of fish protein is possible.

Asian cookery often uses fish sauce as a flavoring base. Exercise caution when eating this type of cuisine.

Fish protein can become airborne in the steam released during cooking and may cause an allergic reaction. Stay away from cooking areas when fish is being prepared.

How to Read a Label for a Shellfish-Free Diet

Avoid foods that contain shellfish or any of these ingredients:

barnacle
crab
crawfish (crawdad, crayfish, ecrevisse)
krill
lobster (langouste, langoustine, Moreton bay bugs, scampi, tomalley)
prawns
shrimp (crevette, scampi)

Mollusks are not considered major allergens under food labeling laws and may not be fully disclosed on a product label.

Your doctor may advise you to avoid mollusks or these ingredients:

abalone
clams (cherrystone, geoduck, littleneck, pismo, quahog)
cockle
cuttlefish
limpet (lapas, opihi)
mussels
octopus
oysters
periwinkle
scallops
sea cucumber
sea urchin
snails (escargot)
squid (calamari)
whelk (Turban shell)

Shellfish are sometimes found in the following:

bouillabaisse
cuttlefish ink
glucosamine
fish stock
seafood flavoring (e.g., crab or clam extract)
surimi

Keep the following in mind:

- Any food served in a seafood restaurant may contain shellfish protein due to cross-contact.
- For some individuals, a reaction may occur from inhaling cooking vapors or from handling fish or shellfish.

How to Read a Label for a Peanut-Free Diet

Avoid foods that contain peanuts or any of these ingredients:

artificial nuts
beer nuts
cold pressed, expeller pressed, or extruded peanut oil
goobers
ground nuts
mixed nuts
monkey nuts
nut pieces
nut meat
peanut butter
peanut flour
peanut protein hydrolysate

Peanut is sometimes found in the following:

African, Asian (especially Chinese, Indian, Indonesian, Thai, and Vietnamese), and Mexican dishes
baked goods (e.g., pastries, cookies)
candy (including chocolate candy)
chili
egg rolls
enchilada sauce
marzipan
mole sauce
nougat

(*Continued*)

Keep the following in mind:

Mandelonas are peanuts soaked in almond flavoring.

The FDA exempts highly refined peanut oil from being labeled as an allergen. Studies show that most allergic individuals can safely eat peanut oil that has been highly refined (not cold pressed, expeller pressed, or extruded peanut oil). Follow your doctor's advice.

A study showed that unlike other legumes, there is a strong possibility of cross-reaction between peanuts and lupine (or lupin). Flour derived from lupine is becoming a common substitute for gluten-containing flours. The law requires that a food product's ingredients must be listed on the label, such as "lupin" or "lupine".

Arachis oil is peanut oil.

Many experts advise patients allergic to peanuts to avoid tree nuts as well.

Sunflower seeds are often produced on equipment shared with peanuts.

Some alternative nut butters, such as soy nut butter or sunflower seed butter, are produced on equipment shared with other tree nuts and, in some cases, peanuts. Contact the manufacturer before eating these products.

How to Read a Label for a Tree Nut-Free Diet

Avoid foods that contain nuts or any of these ingredients:

almonds
artificial nuts
beechnut
Brazil nut
butternut
cashews
chestnut
chinquapin nut
filbert/hazelnut
gianduja (a chocolate-nut mixture)
ginkgo nut
hickory nut
litchi/lichee/lychee nut
macadamia nut
marzipan/almond paste
Nangai nuts
natural nut extract (e.g., almond, walnut)
nut butters (e.g., cashew butter)
nut meal
nut meat
nut paste (e.g., almond paste)
nut pieces
pecans
pesto
pili nut
pine nut (also referred to as Indian, pignoli, pignõlia, pignon, piñon, and pinyon nuts)
pistachio
praline
shea nut
walnuts

Tree nuts are sometimes found in the following:

black walnut hull extract (flavoring)
natural nut extract
nut distillates/ alcoholic extracts
nut oils (e.g., walnut oil, almond oil)
walnut hull extract (flavoring)

Keep the following in mind:

Mortadella may contain pistachios.

There is no evidence that coconut oil and shea nut oil/butter are allergenic.

Many experts advise patients allergic to tree nuts to avoid peanuts as well.

Talk to your doctor if you find other nuts not listed here.

Coconut, the seed of a drupaceous fruit, has typically not been restricted in the diets of people with tree nut allergy. However, in October 2006, the FDA began identifying coconut as a tree nut. Medical literature documents a small number of allergic reactions to coconut; most occurred in people who were not allergic to other tree nuts. Ask your doctor if you need to avoid coconut.

Source: FARE, ©2020, foodallergy.org. Used with permission.

Some food packages bear advisory statements such as "processed in the same facility" or "manufactured on shared equipment" with a particular allergen, complicating the caregiver's ability to determine its allergen content. These statements are not mandatory; they are voluntarily placed on packages by food manufacturers and, in many cases, the verbiage does not imply degree of risk. As a precaution, patients may choose to avoid foods bearing allergen advisory statements. However, depending on the patient and practitioner, if a suitable alternative is not available, then such foods may be permissible to allow variety in the diet.

Preventing cross-contact with allergens is an important part of food allergy management. Cross-contact occurs when an allergen-containing food comes in contact with a "safe" food. This can happen in the home when other family members consume the allergenic foods. Common sources of cross-contact in the home include shared condiments (e.g., as when double-dipping a knife transfers wheat crumbs into a jelly jar) as well as utensils that are hard to clean, such as colanders, slotted spatulas, and toaster appliances. Cross-contact can occur in restaurants if staff members are not properly trained or are inattentive to consumer requests. Cooking utensils, serving utensils, and containers may be shared on buffets, salad bars, and in cafeteria lines and ice cream stores. Grills, marinades, and cutting boards can all potentially transfer allergens. At supermarkets, the deli slicers, bulk bins, and salad bars pose risk of cross-contact.

Food Substitutes for Patients with Milk Allergy

Cow's milk is abundant in our food system and includes fluid milk, cheese, yogurt, ice cream, butter, milk-based infant formula, and all other food products containing traces of milk, such as baked goods and candy. Less obvious sources of milk include high-protein foods that use whey protein as an additive and "nondairy" foods that may contain the milk protein, casein. Goat milk should not be used as an alternative to cow's milk because of the potential cross-reactivity with the beta-lactoglobulins in cow's milk.

For infants with milk allergy who are fed human milk, maternal diet restrictions of cow's milk is only warranted at times. Maternal diet restriction of milk is often not required for infants with IgE-mediated allergies. However, infants with non-IgE-mediated food allergies such as FPE and FPIAP who are fed human milk do require maternal diet restriction. Infants with a milk allergy who are formula fed will continue have an allergic reaction to partially hydrolyzed milk-based formulas and should be prescribed a substitute formula, such as a hydrolysate formula or an elemental formula, until age 2 years. The majority of infants with milk allergy will tolerate hydrolysate formulas; however, 10% of infants or toddlers will not, and will therefore require an elemental formula. Both extensively hydrolyzed and elemental infant formulas supply essential vitamins and minerals that would otherwise be provided by milk in the diet such as calcium, phosphorus, vitamin D, vitamin B_{12}, riboflavin, and pantothenic acid.

For the toddler, cow's milk provides protein and fat, essential nutrients for growth and brain development. Elimination of cow's milk due to food allergy in early childhood can lead to nutrient deficiencies. Therefore, those with milk allergy should be provided an appropriate replacement with a nutrition profile consistent with milk. The United States Dairy Association (USDA) advises that children 1–3 years of age have 2–3 servings of dairy products per day for optimal nutrition, providing approximately 25%–30% of total energy needs for this age range. For toddlers with milk allergy, an elemental pediatric formula is a preferable replacement. A plant-based milk (PBM) containing protein (such as soy or pea-based PBM) may be a suitable replacement depending on the child's intake of nutrients like protein, calcium, and vitamin D at baseline, but generally, PBM should not be used as a primary beverage in children under 2 years of age (Table 15.5). Families should work with health care providers when choosing a PBM alternative, determining which are appropriate given the child's nutritional status, growth, and development. It is important to consider energy, protein, vitamin, and mineral content, as well as the bioavailability of fortified nutrients when providing recommendations to families as these products can have varying nutritional profiles. PBM such as almond, rice, coconut, hemp, flax

TABLE 15.5
Plant-Based Milk Comparison

Per 1 cup (240 mL)	Cow's Milk	Almond	Cashew	Coconut	Flax Seed	Hemp	Oat	Pea	Rice	Soy
Calories (kcal)	150	30–100	25–80	45–90	55	70–170	130	115	110	90
Protein (g)	8	1–5	0–1	0–1	0	2–4	4	8	1	6
Fat (g)	8	3	2–3.5	5	2.5	5–6	2.5	5	2.5	3.5
Carbohydrates (g)	13	9–22	1–20	8–13	9	1–35	24	11	20	15
Sugar (g)	12	7–20	0–18	0–9	9	0–23	19	10	13	9
Calcium (mg)	300	300	100–450	100–450	300	400	350	450	300	400
Vitamin D (IU)	120	110	125	100	100	150	120	150	120	120

Source: Reprinted with permission from Merritt RJ, Fleet SE, Fifi A, et al. North American Society for pediatric gastroenterology, hepatology, and nutrition position paper: Plant-based milks. *J Pediatr Gastroenterol Nutr*. 2020; 71: 276–281.

Note: Average or ranges are reported.

seed, and cashew are not appropriate replacements for young children due to inadequate protein, iron, and iodine. However, these products can be useful as milk replacements in baking and other cooking applications. Medical Nutrition Therapy (MNT) for children with milk allergy requires individual monitoring and recommendations as each child may present with unique nutrition concerns and challenges.

Food Substitutes for Patients with Egg Allergy

Eggs are an inexpensive complete protein and serve as a binder in many baked goods. Eggs may be present in breads, pastas, baking mixes, breaded meats, salad dressings, and other commercially prepared foods; therefore, elimination of these foods may compromise dietary variety and quality. Home recipes can be easily modified using egg replacements (Table 15.6).

Food Substitutes for Patients with Soy Allergy

Soybean avoidance involves restriction of soy-based products like tofu, edamame, tempeh, some vegetarian meat analogs, and soy sauce. Soy protein and soy flour may be present in some packaged foods. But, heat-pressed soybean oil and soy lecithin, the form of soy regularly present in packaged foods, are considered safe for individuals with soybean allergy. These ingredients are highly refined with the protein removed so that only the fat fraction remains, rendering it safe to consume (Table 15.4).

TABLE 15.6
Egg Replacements for Baked Recipes

Each substitution is equal to one egg and tend to work best in recipes calling for 3 eggs or less:

- 1 tsp. baking powder + 1 Tbsp. water + 1 Tbsp. Vinegar
- ¼ cup applesauce or ¼ cup mashed banana
- 1 and ½ Tbsp. water + 1 and ½ Tbsp. oil + 1 tsp. baking powder
- 1 packet gelatin + 2 Tbsp. warm water (do not mix until ready to use)
- 1 Tbsp. ground flax or chia seed + 3 Tbsp. warm water
- Commercial Egg-replacer: typically, potato- or tapioca-starch based

Food Substitutes for Patients with Wheat Allergy

Wheat elimination includes avoidance of all wheat-containing bread, pasta, crackers, breakfast cereals, and baked goods. This includes all-purpose flour and any food that is breaded, baked, or fried with wheat-based flour. Wheat flours are fortified with niacin, riboflavin, thiamin, and iron. If a child's diet is composed of very few whole grain products, they may be deficient in these and other nutrients. Products made with the flours of amaranth, arrowroot, barley, buckwheat, corn, oats, potato, quinoa, rice, rye, soybean, and tapioca are suitable wheat alternatives, as are enriched and fortified corn, rice, and oat cereals.

Food Substitutes for Patients with Peanut Allergy

Peanuts can be present in confectionery foods, like candy, chocolates, pastries, and cookies, as well as savory foods like salads, sauces, and ethnic foods, particularly those of Africa, China, and Thailand. Peanut oil is considered safe for most individuals with peanut allergy if it has been heat-pressed, but crude peanut oil that has been cold pressed, extruded, or expeller pressed should be avoided.

Food Substitutes for Patients with Tree Nut Allergy

Almond, Brazil nut, cashew, chestnut, filbert/hazelnut, macadamia, pecan, pine nut, pistachio, and walnut are considered tree nuts (see Table 15.4 for complete list). Tree nuts are used in cereals, crackers, ice cream, marinades, and sauces, and more recently, gluten-free foods (almond flour) and vegan foods (cashew cheese), making avoidance more difficult. Nut pastes and nut butters are often made on shared equipment. Pure tree nut extracts, such as almond and walnut, may contain allergens; however, natural almond extract is often derived from peach pits and is not allergenic. Coconut is not a tree nut and is safe for individuals allergic to tree nuts.

Coordination of Care

Food allergy management involves allergen avoidance and readiness to treat adverse reactions. Depending on the age and developmental stage of the food-allergic individual, these responsibilities may lie in the hands of a caregiver, daycare or school staff, or the individual herself. Resources and more information for daily living with food allergies can be found from patient advocacy groups listed in Table 15.7.

When it comes to infants, the caregivers control all aspects of feeding – from the choice to feed human milk or formula selection, to timing and type of complementary foods introduced. Because a food allergy diagnosis during infancy can disrupt infant weaning resulting in delayed complementary feeding, referral to a dietitian at this stage is paramount. As the child matures, the opportunity for accidental exposures to allergens increases as she enters new environments with less parental supervision. In this regard, infant management is more straightforward; they are often confined to the home and dependent on caregivers to provide food. But as older infants and toddlers move

TABLE 15.7
Resources

American Academy of Allergy, Asthma, and Immunology
http://www.aaaai.org
Food Allergy Research & Education
http://www.foodallergy.org
Food Allergy and Anaphylaxis Connection Team (FAACT)
https://www.foodallergyawareness.org
Kids with Food Allergies
http://www.kidswithfoodallergies.org

to daycare and preschool settings, age-specific behaviors like significant hand-to-mouth play and thumb-sucking increase the risk of oral exposures. Reactions occurring outside the home are more frequent in young children. Since many daycare centers are peanut- and tree nut-free, the most reactions occurring in these settings are to cow's milk.

To date, no consensus exists regarding strategies to effectively minimize allergen exposures in the school setting. School-wide allergen bans are often proposed as an operative solution, but recent observational studies suggest that this may provide a false sense of security, leading to an increase in accidental exposures and may be impractical because of the assortment of foods implicated in food-allergic reactions. In reality, truly effective measures are nuanced and will depend on the age and maturity of the student, type and severity of the allergy, and school staff competency and resources.

Nutrition Monitoring and Evaluation

Patients with food allergies are at risk of poor nutrient intake and poor growth. Extensive nutrition education is required in order to prevent accidental exposure and allergic reaction. Nutrition reassessment can determine if a patient is meeting their nutrient needs with the food substitutes utilized. Reassessment of nutrient intake and growth are essential to ensure the patient is meeting their nutrient needs. Nutrition monitoring also includes reassessment of patient and caregiver knowledge to ensure that they have the tools and education needed to prevent accidental exposure to allergens (Table 15.8).

TABLE 15.8
ADIME Summary for Food Allergies

- Assessment
  - Growth assessment
  - Nutrition-focused physical exam
    - Look for signs of macronutrient and micronutrient deficiencies
  - Nutrient Intake
    - Assess food substitutes utilized to ensure nutrient needs are met
  - Labs
    - Skin-prick testing
    - Allergen-specific IgE testing
  - Gastrointestinal Findings
    - Assess for signs of allergen exposure
  - Medications/Side Effects
- Diagnosis
- Intervention
  - Nutrition Prescription
  - Common nutrition interventions
    - Oral
      - Recommendations to meet nutrient needs in setting of specific allergens (Table 15.3)
      - Recommendations for food substitutes
      - Formula may be needed depending on allergens
    - Education
      - Label reading
      - Avoiding cross contact
    - Coordination of care
      - School, daycare, and other caregivers
- Monitoring & Evaluation
  - Reassess understanding of reading food labels
  - Reassess nutrient intake and recommend alternate food substitutes as indicated

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16 Gastrointestinal Disease

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CONTENTS

Adequate nutrition is essential to promote the growth and development of children. Poor weight gain and linear growth may be an indication of gastrointestinal (GI) disease. In addition, many GI diseases affect the child's ability to ingest, digest, and absorb nutrients which may lead to malnutrition and poor growth. Nutrition intervention may be needed to support growth for patients with GI diseases or as treatment of their GI disease. This chapter will discuss common GI diseases in children with a focus on the contribution of diet and nutrition to their pathogenesis, presentation, management, and outcome.

COMMON GASTROINTESTINAL (GI) DISEASES IN CHILDREN

Gastroesophageal Reflux Disease

Gastroesophageal reflux (GER), a normal physiological occurrence at all ages, is defined as the passage of gastric contents into the esophagus. This is only pathological when it causes troublesome symptoms or complications (Table 16.1). Then it can be described as a gastroesophageal disease (GERD). However, differentiating normal physiological reflux from GERD can be problematic, especially in infancy when reflux events are developmentally more prevalent. The

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TABLE 16.1
Symptoms or Signs Distinguishing Gastroesophageal Reflux from Gastroesophageal Reflux Disease (GERD)

Vomiting/retching/hematemesis
Feeding refusal/failure to thrive
Irritability/discomfort/heartburn/esophagitis
Apnea/aspiration/chronic cough or wheeze
Dystonic neck posturing (Sandifer's syndrome, under 2 years of age)
Dental erosions

Source: Adapted from Rosen R, Vandenplas Y, Singendonk M, et al. Pediatric Gastroesophageal Reflux Clinical Practice Guidelines: Joint Recommendations of the North American Society for Pediatric Gastroenterology, Hepatology, and Nutrition and the European Society for Pediatric Gastroenterology, Hepatology, and Nutrition. *J Pediatr Gastroenterol Nutr*. 2018;66:516–554.

association of GER with other symptoms or diseases does not prove causation. Furthermore, there is significant symptom overlap. Consider GER and swallowing difficulty, both of which might be present at the same time and implicated in feeding difficulties. In infants this symptom overlap is especially important to consider (see Table 16.2). The prevalence of GER and GERD vary widely according to the populations studied (age and geography) and the definitions used. It is possible that at least a quarter of infants have symptoms of GER on a daily basis and that a quarter of older children may do so on a weekly or monthly basis. The predominant underlying pathophysiology of GER is transient lower esophageal relaxations. These are meal-induced events, whereby distention of the stomach, but not swallowing, promotes relaxation of the lower esophageal sphincter.

Medical management of GERD includes pharmacological acid suppression. Proton pump inhibitor (PPI) medications are perhaps the most effective anti-acid secretory treatment. They are the widely used. While generally considered safe, widespread use has unmasked potential negative associations, such as impact on bone development, more frequent community acquired pneumonia and *Clostridium difficile* infections. The overlap between GERD and swallowing problems is again noteworthy, as children with aspiration may require more hospitalizations when treated with PPI.

Eosinophilic Esophagitis

Eosinophilic esophagitis (EoE) is a rapidly emerging allergic disease driven by dysfunctional immune response to food antigens. It is characterized by recurrent or chronic symptoms of esophageal dysfunction and dense eosinophil-predominant inflammation isolated to the esophagus, triggered by food antigens and/or aeroallergens in genetically susceptible individuals.

TABLE 16.2
Clinical Symptoms of Gastroesophageal Reflux Disease and also of Dysphagia

Gagging, choking
Coughing
Crying or distress during feeding
Food refusal or turning away from food
Failure to thrive
Vomiting

EoE has increasing prevalence, with recent estimates at 1 of 2,000 individuals and is seen more commonly in males. Approximately two-thirds of patients diagnosed with EoE have other allergic disorders, including IgE-mediated food allergies, asthma, eczema, chronic rhinitis, and environmental allergens. The most common symptoms of EoE in infants and young children are emesis, food refusal, malnutrition, and non-specific feeding disorders. Older children often report abdominal pain and GERD-like symptoms. Adolescents and adults report dysphagia and esophageal food impactions. EoE is diagnosed by endoscopy, with esophageal biopsies demonstrating at least 15 eosinophils/high powered field. Untreated EoE over a prolonged period can potentially result in esophageal scarring and strictures.

Pharmacological therapy, such as inhaled steroids in swallowed form, is effective in reducing esophageal inflammation. Diet therapies are also commonly used to treat EoE in children. Dietary antigens are strongly implicated in causing the allergic response in EoE. Nutrition therapy for treatment of EoE involving diet elimination addresses the root cause of inflammation, treats EoE by removing the underlying food trigger(s) of inflammation, and is preferred by families not wanting pharmacological therapy. Multiple elimination diets are used to treat EoE:

- Elemental diet is a liquid diet provided by an elemental formula prescribed to meet 100% of nutrition needs; the efficacy of this diet in achieving histological remission is ~90%.
- Allergy-directed elimination diet involves removing foods based on allergy testing. Efficacy of this diet therapy is <50% reflecting the poor specificity of such testing to predict EoE food allergens.
- Empiric elimination diets involve removing the most common food allergens (cow's milk, soy, egg, wheat, peanut/tree nut, fish/shellfish). Efficacy has been reported to be 72% when removing all six foods (wherein nuts include tree nuts and peanuts; fish includes fin fish and shellfish, giving rise to eight separate food groups).

More recently, decreasing the number of eliminated foods and step-up empiric diet elimination are being trialed to decrease nutrient restriction, improve quality of life and adherence. The rates of success vary from 54% for elimination of cow's milk alone to 64% for four foods.

Constipation

Constipation is one of the most common GI complaints of childhood seen across all populations and care settings, with pooled prevalence around 10%. Constipation usually presents with infrequent or hard stools but children can also present with retentive posturing or excessive volitional stool retention.

Key points in the management of functional constipation include disimpaction, regular maintenance laxative treatment, adequate follow-up, and adequate treatment duration. Given expected improvement over 6–12 months for the majority of children, early specialist medical or surgical consultation should be considered when standard therapy is failing. The evidence-based recommendations support the notion that dietary or lifestyle interventions alone will not successfully treat constipation.

The role of diet in the development of functional constipation has not been widely studied. In infants, use of human milk is associated with decreased risk of constipation and this diagnosis should never prompt a change to formula. Globally, constipation prevalence is highest in countries with "Western" diets. Furthermore, Western dietary patterns can be associated with higher prevalence of constipation in the first 4 years of life. Importantly, this is independent of excess energy intake, or overweight or obesity. Western diets are dominated by increased fat and simple sugars, and decreased complex starch and fiber.

Low dietary fiber intake is most consistently associated with risk of developing constipation. Insoluble fiber can potentially promote increased bowel transit time (see Table 16.3). However,

TABLE 16.3
Dietary Fiber and Potential Gastrointestinal Benefits

Type of Fiber	Examples	Sources
Soluble	Inulin oliogofructose	Onions, beets, chicory root – added to processed foods to boost fiber
Beneficial for diarrhea and constipation	Mucilage, betaglucans	Oats, oat bran, beans, peas, barley, flaxseed, berries, soybeans, bananas, oranges, apples, carrots
Dissolves in water to form a gel-like material	Pectins and gums	Fruits, berries, seeds, citrus peel
	Polydextrose polyols	Added to processed foods as bulking agent, sugar substitute. Made from dextrose, sorbitol, citric acid
	Psyllium	Extracted from rushed seeds or husks of Plantago ovata plant used in supplements, fiber drinks and added to foods
	Resistant starch	Unripened bananas, oatmeal, legumes
	Wheat dextrin	Extracted from wheat starch
Insoluble	Cellulose, some hemicellouse	Nuts, whole wheat, whole grains, bran, seeds, edible brown rice, skins of produce
Promotes the movement of material through digestive system	Lignin	Flax, rye, some vegetables
Increases stool bulk	Some Pectins and gums	
Can be of benefit to those who struggle with constipation or irregular stools		

increasing dietary fiber does not appear to treat constipation. Theoretically bulking stools in constipated children could contribute to more retention and discomfort, if no other treatment is provided. Conversely, as laxatives act to promote more liquid stool, adding fiber might help normalize stool consistency during such treatment. If diet did prevent constipation, it is important to recognize efficacy is hampered by ongoing difficulties in establishing healthy intakes of fruits, vegetables, and whole grains in young children. Furthermore, when applying dietary interventions for constipation prevention and treatment, they are most effective with proper education or counseling from a dietitian, which is not always practical. Hence, there is some justification for using fiber supplements to normalize dietary fiber intake.

At this time there is no evidence to support the use of probiotics to prevent or treat functional constipation. Similarly, the assertion that food allergy, in particular cow's milk allergy, presents as functional constipation is not widely supported by evidence.

Chronic and Recurrent Diarrhea Secondary to Carbohydrate Malabsorption

Carbohydrates provide significant energy in children's diets in various forms of foods including grains, fruits, vegetables, and dairy products and yet may pose significant challenges in their digestion and absorption. When malabsorbed, carbohydrates increase the osmotic load of GI fluid, drawing water into the small intestine and stimulating peristalsis. This combined with bacterial fermentation produces pain, bloating, and diarrhea. Malabsorption of specific carbohydrates is discussed in this section.

Lactose Intolerance

Lactose is a disaccharide composed of galactose and glucose, and is the main carbohydrate in milk. Lactose intolerance refers to the inability to digest lactose due to inadequate activity of the lactase

enzyme, the most common form of disaccharide deficiency. Primary lactase deficiency is a common condition in which lactase activity falls after weaning and can happen at any point in childhood, adolescence, or adulthood, although it is rare under age 6 years of age. Primary lactose intolerance is highly prevalent in African-American, Native-American, and Asian populations and less common in Northern-European, certain African, and Indian populations. Secondary lactase deficiency is usually due to mucosal injury associated with disease, such as celiac disease or Crohn's disease.

Symptoms of lactose intolerance include abdominal pain, bloating, diarrhea, abdominal distension, and flatulence. The severity of symptoms and the amount of lactose that will cause symptoms varies between individuals and depends on the degree of lactase deficiency, how much lactose is consumed, the mixture of lactose with other foods, and other factors. Diagnosis can be made with clinical history and observation, including clinical improvement with a trial of an empiric lactose-free diet for 2 weeks. Diagnostic testing includes stool testing, lactose breath hydrogen testing, or through duodenal biopsy and specific enzyme analysis.

Treatment is to remove or reduce dietary lactose, a common ingredient in many foods including milk and milk products (Table 16.4). Many children can tolerate small amounts of lactose,

TABLE 16.4
Low-Lactose Diet

Food	Allowed	Not Allowed
Milk and dairy foods	Lactose-free milk Nondairy creamers Nondairy whipped topping Plant-based milks, yogurts, cheese (soy, pea, almond) • Foods containing < 1 g lactose per serving: • 1–2 oz aged cheese (Swiss, Cheddar, parmesan) • 2 tbsp cream cheese • ½ cup ricotta cheese	All milk- and dairy-containing foods except those allowed
Meat, poultry, fish, eggs, dried beans and nuts	All, unless prepared with lactose containing ingredients	Foods that contain lactose ingredients (butter, milk, cream, milk solids, etc.) Found in sauces, breading, and processed foods
Grains	All, unless prepared with lactose containing ingredients	Foods containing sauces, processed foods, noodle/sauce packets, stuffed pastas
Vegetables	All unless prepared with lactose containing ingredients	Sauces, seasoning packets, butter
Fruits	All, unless prepared with lactose containing ingredients	Foods containing lactose
Fats, oils	Vegetable-based margarine Oils from nuts or seeds	Butter, margarine, cream. Any containing lactose
Desserts	Fruit ices, sorbets, gelatin Plant-based ice cream (soy, almond, rice, coconut)	Ice cream, any containing lactose
Miscellaneous	Spices and herbs without lactose ingredients	Spice blends with milk, other lactose ingredients
Other		Tips: • Check food label for lactose ingredients • Avoid products that state may contain milk

TABLE 16.5
Foods to Be Avoided on Fructose-Elimination Diet

Milk: milk flavored with fructose or high-fructose corn syrup (HFCS), yogurt with chicory root/inulin, yogurt/cottage cheese with fruit
Protein foods: meat, poultry, fish, or other protein foods prepared with breading or sauces with HFCS/honey such as sweet sour sauce, barbecue sauce, tomato sauces
Grains: wheat-based foods (bread, crackers, pasta) containing fructo-oligosaccharides should be limited
Vegetables: broccoli, brussels sprouts, cucumbers, green beans, okra, peas, zucchini, sweet red peppers, fresh or canned tomatoes and tomato products
Fruits: apple, cherry, grape, pear, lychee, persimmon, watermelon; dried fruits (apple/apricot/currant/date/fig/prune/raisin); fruit juice
Fats and oils: commercial salad dressings, low -fat dressings with fructose, fruit juice concentrate or HFCS
Beverages: beverages made with added sweeteners, including soft drinks, sports drinks, bottled teas/coffees with fructose, HFCS, or sorbitol

Legend: HFCS, high-fructose corn syrup.

particularly yogurt, hard cheese, or ice cream without discomfort. Treatment with lactase enzymes is also possible, taken immediately prior to eating foods containing lactose.

Fructose Intolerance

Fructose, a monosaccharide found in fruits, vegetables and sweeteners, such as high-fructose corn syrup (HFCS), has steadily increased in the diets of children, representing up to 10% of their daily energy intake. The occurrence of fructose malabsorption is common with excessive intake, because fructose is not actively transported. Symptoms of fructose malabsorption may result in bloating, diarrhea, excessive flatulence, and abdominal pain.

Diagnosis can be made via fructose breath test. A detailed diet history can identify the amount of fructose in diet. Treatment is removal of foods high in fructose or with a high fructose to glucose ratio (see Table 16.5).

Congenital Sucrase-Isomaltase Deficiency

Congenital sucrase-isomaltase deficiency (CSID) is a genetic disorder that affects a patient's ability to digest sucrose (table sugar), which is found in fruits, and maltose, which is found in grains. Absence of the enzyme on the intestinal surface prevents digestion and absorption of sucrose, which in turn results in osmotic diarrhea. The prevalence is highly variable from 0.2% of the general European population up to 3%–10% of specific populations, like populations native to Greenland, Alaska, and Canada.

The classic presentation of CSID begins in infancy when sucrose and starch are first introduced in the diet through juices, solid foods, formula, or medications sweetened by sucrose. If an infant is exclusively breastfeeding, she should not have symptoms of CSID until weaning. Symptoms of chronic watery diarrhea and malnutrition are common in infants and toddlers with CSID, as well as abdominal pain, abdominal distension, gassiness, and diaper rash. Milder forms without malnutrition are reported, but diarrhea is predominant at all ages. CSID can mimic irritable bowel syndrome in older children and adolescents. CSID is diagnosed by measuring intestinal disaccharidase activity (lactase, sucrase, isomaltase, and maltase can all be so measured) in small bowel biopsy. Genetic testing is also available. Sucrose breath testing may be recommended to test sucrose tolerance.

Sacrosidase, a prescription oral enzyme replacement for sucrose, is available and approved for children 5 months of age and older. It must be taken before, during, and after meals and snacks to aid in sucrose tolerance. Such therapy is often impractical for young children and overall adherence

may be poor. Hence, management is primarily elimination of sucrose, maltose, and starch from the diet (Table 16.6).

Initially, foods, beverages, and medications that contain sucrose and starch are removed from the diet. For infants consuming infant formula, a standard infant formula with lactose should be tolerated; if not, a metabolic formula without carbohydrates, that contains protein, fat, vitamins,

TABLE 16.6
Sucrose-Isomaltose Elimination Diet

Food	Foods Allowed	Foods Not Allowed
Grains	None	All are avoided initially They are added back one at a time to determine individual tolerance
Milk/dairy products	Cow's milk, evaporated milk, cream (heavy, whipping, half-n-half), sour cream, buttermilk	Flavored milks containing sucrose (i.e., strawberry, chocolate, malted milk) Sweetened condensed milk
	Plain yogurt or sucrose free yogurt	Yogurt with sucrose or fruits high in sucrose
	Natural cheese	Ice cream, milk shakes
	Unsweetened plant-based milks	Processed cheese
Proteins	Fresh meats: beef, chicken, turkey, pork, seafood	Processed meats, breaded proteins that contains sucrose or starch
	Cured meats (fresh bacon, sausage)	Meats cured with sucrose, such as bacon, sausage, deli meat, pate and liverwurst
	Deli meats without sucrose	Silken Tofu
	Eggs	Tree nuts: (almonds, cashews, chestnuts, filberts, hazelnuts, macadamia nuts, peanuts, pecans, pine nuts, pistachios)
	Tofu (not silken)	Nut butters with added sucrose
	Certain nuts/nut butters (Brazil nuts, walnuts, and chia, flax, hemp, poppy, pumpkin, sesame, squash and sunflower seeds; no sugar added almond, peanut, or sesame butter)	
Vegetables	Alfalfa sprouts, artichoke, asparagus, bamboo shoots, bok choy, broccoli, Brussel sprouts, cabbage, cauliflower, celery, cucumber, eggplant, green beans, greens (collard, kale, mustard, turnip, and chard), lettuce (arugula, endive, iceberg, romaine), mung bean sprouts mushrooms, peppers (red, green yellow), radishes, rutabaga, spaghetti squash, spinach, tomatoes, turnips, yellow squash, zucchini	Beets, carrots, cassava (yucca), chickpeas (garbanzo beans), coleslaw, corn, edamame, green peas, jicama, kidney beans, lima beans, okra, onion, parsnips, potatoes, snow peas, split peas, sweet pickles, sweet potatoes, and yams
Fruits	Avocado, blackberries, blueberries, boysenberries, cherries, cranberries, currants, figs, grapes, kiwi, lemons, limes, loganberries, olives, papaya, pears, pomegranates, prunes, raspberries, rhubarb, strawberries	Apples, apricots, bananas, cantaloupe, dates, grapefruit, guava, honeydew melon, mango, nectarine, oranges, passion fruit, peaches, persimmon, pineapple, plums, tangelos, tangerines, and watermelon
Fats	All vegetable oils, butter, margarine, mayonnaise (with no sucrose added)	Salad dressings, mayonnaise that contain sucrose or starch
Sweeteners	Dextrose, fructose, and high-fructose corn syrup	Sucrose, brown sugar, granulated sugar, powdered sugar, raw sugar, beet sugar, cane sugar/syrup/juice, coconut sugar, date sugar, maple syrup/sugar, molasses and syrup Ingredients: brown rice syrup, caramel, corn syrup, corn syrup solids, dextrin, glucose polymers, maltodextrin, and modified tapioca starch

(*Continued*)

TABLE 16.6 (*Continued*)
Sucrose-Isomaltose Elimination Diet

Food	Foods Allowed	Foods Not Allowed
Desserts	Sugar-free gelatin, sugar-free popsicles, sugar-free hard candy with acceptable sweeteners Sugar-free whipped topping Dextrose for baking	Ice cream, popsicles, pudding, sherbet, sorbet, brownies, cakes, cookies, muffins, pastries, pies, whipped toppings, carob, caramel, chocolate, and chocolate syrup/sauce that contain sucrose or starch
Beverages	Milk or milk substitutes (above) Cocoa powder and dextrose or fructose to make chocolate milk/hot chocolate ½ cup 100% fruit juice from allowed fruits Sugar-free sports drinks, soda, drink mixes with dextrose or fructose Regular soda sweetened with high-fructose corn syrup	All beverages sweetened with sucrose Juices made from fruit in the "not allowed" column Fruit drinks, energy drinks, sports drinks, and drink mixes contain sucrose Specialty and flavored coffees or teas that contain sugar All specialty formulas made with sucrose or starch (sucrose, corn syrup, maltodextrin, tapioca starch, or glucose polymers)
Formulas	Human milk, standard lactose-based infant formula Carbohydrate free formula with dextrose or fructose	
Miscellaneous	Salt, pepper, fresh or pure herbs and spices, soy sauce, mustard, dill pickles, vinegar Natural jam, jelly, and preserves made from allowed fruits; no sucrose added	Jam, jelly, preserves Condiments containing sucrose or starch (ketchup, barbeque sauce, chutneys, salad dressings, seasonings, sauces)

and minerals, is commercially available with addition of fructose or dextrose and water to make the formula nutritionally complete. Feeding solids should begin when the individual infant is developmentally ready, and start with low-sucrose, low-starch pureed vegetables, fruits, and then meats; cereals are not allowed. Infants who are breastfed should receive supplemental iron in addition to supplemental vitamin D. Once the child has stabilized and symptoms have resolved, reintroduction of sucrose containing foods with ≤2% sucrose can be introduced one at a time (Table 16.7), generally one new food per week, monitoring for tolerance. After sucrose tolerance is determined, starch can be introduced into the diet; tolerance to starch varies per individual.

Celiac Disease and Non-Celiac Gluten Sensitivity

Celiac disease is the most common autoimmune GI disorder. Worldwide prevalence is around 1%, with a slight female predominance. Prevalence appears to continue to increase in Western countries, while it is likely underreported elsewhere globally. The autoimmune reaction occurs in individuals who are genetically predisposed and only in response to gluten ingestion, a protein found in wheat, barley, rye, or in cross-contact during processing of non-gluten-containing grains, such as oats. The end result is both autoimmunity, with increase in circulating autoantibodies (e.g., anti-tissue transglutaminase, aTTG), and a proximal small intestinal enteropathy, varying from epithelial lymphocytic infiltration to total villus atrophy. Perhaps the most remarkable thing about celiac disease is the greater prevalence of asymptomatic disease, only detected through screening, as well as the myriad of clinical symptoms when present (see Table 16.8).

Typically, children who are suspected of having celiac disease undergo blood testing for aTTG. If it is positive, the child should undergo an upper endoscopy and small intestinal biopsy while on a diet containing gluten. Accurate diagnostic serology and histopathology depend on contemporary consumption of gluten. Furthermore, if a gluten-free diet (GFD) is commenced, the duration and

TABLE 16.7
Low-Sucrose, Low-Starch Solids (<1 g/ 100 g)

Protein	Meat, Poultry, Egg, Fish
Dairy	Human milk, infant formula (free of glucose polymers and sucrose) Cow's milk, unsweetened yogurt, cream
Vegetables	Most except potato, sweet potato, plantain, yam, parsnip, carrots, peas, onion, Sweet corn, beetroot, okra, beans, and lentils
Fruits	Avocado, blackberries, blackcurrants, cherries, dates, grapes, lemons Lychees, melons (Cantaloupe, honeydew), pears, raisins, raspberries, redcurrants Rhubarb, strawberries
Fats	Butter, margarine, lard, vegetable oils
Miscellaneous	Salt, pepper, vinegar, herbs, gelatin, sugar-free jelly, sugar-free drinks, fructose, glucose

Source: Adapted from Academy of Nutrition and Dietetics. Pediatric Nutrition Care Manual. http://www.nutritioncaremanual.org.

TABLE 16.8
Symptoms and Signs of Celiac Disease

Gastrointestinal	Extraintestinal	Asymptomatic
Abdominal pain	Fatigue	Family history (1st degree)
Diarrhea	Malaise	Type 1 diabetes
Nausea/vomiting	Irritability	Autoimmune thyroid disease
Anorexia	Difficulty concentrating/foggy brain	Autoimmune liver disease
Abdominal distention/gas/bloating	Joint pains	Juvenile rheumatoid arthritis
Rectal prolapse	Peripheral neuropathy	Trisomy 21
Constipation	Gluten ataxia	Williams syndrome
Aphthous ulcers	Headaches	Turner's syndrome
Elevated liver enzymes	Epilepsy, possibly with cerebral calcifications	IgA deficiency
Lactose intolerance	Dermatitis herpetiformis	
	Hyposplenism	

Source: Adapted from Husby S, Koletzko S, Korponay-Szabó I, et al. European Society Paediatric Gastroenterology, Hepatology and Nutrition Guidelines for Diagnosing Coeliac Disease. *J Pediatr Gastroenterol Nutr*. 2020;70:141–156.

amount of gluten intake required to trigger the autoimmune response and develop enteropathy is not known. The gluten challenge most often recommended is 4–6 weeks of 5–10 g of gluten/day. More recently, protocols have been developed whereas a small subset of patients can be diagnosed with celiac disease based solely on blood testing.

The impetus for accurate diagnosis and lifelong dietary management of celiac disease is reduction in the risks of associated complications, shown in Table 16.9. Currently, the only recognized treatment for celiac disease is the GFD (Table 16.10).

Non-celiac gluten sensitivity (NCGS) has distinctive clinical features when compared to celiac disease and wheat allergy. However, many symptoms of NCGS are indistinguishable from celiac disease. Fundamentally and importantly, a diagnosis of NCGS cannot be made in any individual who has positive, reliable serology for celiac disease (aTTG), even if they have not yet developed enteropathy. The diagnosis should only be made on the basis of reproducible symptoms triggered by

TABLE 16.9
Complications of Celiac Disease

Complications of Malabsorption	Other Complications
Weight loss/malnutrition/short stature	Enteropathy-associated T-cell lymphoma
Delayed puberty	Microscopic colitis
Iron deficiency	Pneumococcal pneumonia
Osteopenia/osteoporosis	
Osteomalacia/rickets	
Dental enamel hypoplasia	
Infertility and low infant birth weight	

Source: Adapted from Husby S, Koletzko S, Korponay-Szabó I, et al. European Society Paediatric Gastroenterology, Hepatology and Nutrition Guidelines for Diagnosing Coeliac Disease. *J Pediatr Gastroenterol Nutr*. 2020;70:141–156.

TABLE 16.10
Gluten-Free Diet

Food	Foods Allowed	Foods Not Allowed
Grains	Amaranth	Barley: all forms, including malt, malt extract, malt flavoring, malt syrup and malt vinegar
	Nut flours/meal	
	Arrowroot	Rye: all forms
	Oats (GF labeled)[a]	Wheat: all forms including: all-purpose flour, bulgur, couscous, cracked wheat, durum wheat, einkorn, emmer, farina, faro, flour, graham flour, kamut, matzo, semolina, spelt, tabbouleh, triticale, wheat bran, wheat flour, wheat starch
	Potato (starch/flour)	
	Quinoa	
	Buckwheat	
	Ragi	
	Job's tears	Oats: not labeled gluten free (GF)
	Sago	Low gluten flours
	Mesquite flour	
	Sorghum	
	Millet	
	Tapioca	
	Montina	
	Teff	
	Legume flours (chickpea/garbanzo, soy, peas, lentils, lupin)	
	Corn, Corn meal, grits, hominy, corn bran	
	Rice (all-wild, brown, white, sweet rice)	
	Seed flours (i.e., chai, flax, sesame, sunflower)	
Cereals	Rice, corn, millet, quinoa, GF oats, buckwheat, amaranth, flax	Barley, malt flavoring, bran, kasha, rye, wheat germ, spelt, oats not labeled GF
Breads	Breads, bagels, croutons, pancakes, waffles, biscuits, rolls, tortillas, made with GF grains	Breads, bagels, croutons, pancakes, waffles, biscuits, rolls, tortillas made with gluten-containing grains (wheat, rye, barley), oats not labeled GF, crackers, snack foods with Gluten-containing ingredients
Snacks	Pretzels, crackers made with GF grains, chips (i.e., potato, corn, rice)	

(*Continued*)

TABLE 16.10 (*Continued*)
Gluten-Free Diet

Food	Foods Allowed	Foods Not Allowed
Pasta, potatoes, other starches	Pasta made from rice, corn, bean, quinoa, legume/lentil and other GF grains Potatoes, all kinds, Sweet potatoes/yams	Barley, pasta made from wheat, processed noodle/rice/potatoes mixes, couscous, orzo, tabbouleh
Dairy	All types unless listed under not allowed	Ice cream or yogurt with gluten-containing ingredients
Protein	Fresh eggs, fish, meat, and poultry Natural, Aged cheese	Protein foods breaded with gluten-containing ingredients or prepared with gluten-containing ingredients
	Dried legumes, lentils Unprocessed nuts, seeds, nut butters	Processed proteins (i.e., lunch meats, sausages, hot dogs) that contain gluten-containing ingredients Plant-based or vegetarian protein foods that containing gluten-containing ingredients Processed cheese, powder cheese, shredded cheese with gluten ingredients Nut butters with gluten-containing ingredients
Fruits	All fresh, frozen, and canned	Fruits served in sauce-containing gluten
Vegetables	All plain fresh, frozen, and canned	Vegetables breaded with gluten-containing grain or prepared with gluten-containing sauce
Sweets, Desserts	Chocolate, pure cocoa powder, coconut, jelly, honey, sugar, molasses, meringues, hard candies, with GF ingredients Gelatin, puddings, custard with GF ingredients Muffins, cakes, cookies, pies made with GF ingredients (boxed mixes labeled GF)	Candies made with gluten-containing ingredients, licorice Pudding containing gluten-containing thickener/ingredients Commercially prepared baking mixes unless labeled GF
Fats, oils	Butter, oils (i.e., olive, canola, avocado)	Butter sauces thickened with gluten (wheat) Oils used in preparation of gluten-containing foods (i.e., shared fryers)
Spices, flavoring, sauces	Pure fresh herbs and spices, salt Sauces, condiments with GF ingredients	Spice blends, sauce packets containing gluten, Sauces, marinades, seasoning packets or condiments with gluten-containing ingredients; soy sauce, Malt vinegar, Broths
Other ingredients	Starch (implies cornstarch) Maltodextrin (cornstarch, potato starch, or rice starch)	Foods with ingredients such as flour, cracker, filler Communion wafers Malted beverages, ground coffee with added grains

[a] GF oats or uncontaminated oats are safe for most people with celiac disease, but may choose to delay until symptoms have resolved or 6 months on the gluten-free diet.

gluten. Experts propose a diagnostic double-blind challenge of gluten (8 g/day)/placebo over 1 week each, with a 1-week washout between the crossover. A specific symptom questionnaire should be used and a 30% reduction in symptom reporting when gluten free would be diagnostic. Once again its essential that a GFD not be advised before celiac disease is reasonably excluded with appropriate serological testing.

Irritable Bowel Syndrome

Irritable bowel syndrome (IBS) is one of the most common functional GI disorders at all ages, with a global prevalence of 10%. The most common age of onset for IBS is either early, between 4 and 6 years, or later in early adolescence where a female predominance is noted. Abdominal pain is a very common symptom for children presenting to family medicine, pediatricians, and gastroenterologists. Abdominal pain is also a major source of anxiety for caregivers. The associated burdens of IBS are noteworthy, including a very significant impact on school performance and attendance, peer relationships, and family and social participation. In addition, depression and anxiety are not uncommon comorbidities. The only investigation warranted for IBS, in the absence of red flags, is screening for celiac disease.

Very comprehensive guidelines for the treatment of IBS in adults were recently published. Overall a very similar approach is usually undertaken for children, even though the pediatric data are sparse. Given the role of the gut-brain axis, it is very important that non-pharmacological strategies beyond the gut are considered and these have proven effective, including gut-directed hypnotherapy and cognitive behavioral therapy. In the pediatric context, family therapy or behavioral strategies predicated on distraction from pain are also highly relevant. The remainder of this section will focus on dietary interventions.

In individuals with IBS, ingestion of food is the most common trigger for symptoms, hence they report dietary intolerances much more often than the general population. However, recognition of key individual food triggers is often elusive and so as a result ever broadening dietary exclusions may occur, with adverse nutrition consequences, particularly for growing children. Intestinal distention has been felt to be a key mechanism for producing abdominal pain. This has led to the conception and popularity of the low fermentable oligo-, di-, and mono-saccharides and polyols (FODMAPs) diet for IBS. FODMAPs cause luminal distention both by their osmotic effect, increasing liquid distention as they are poorly absorbed, and by gas distention, secondary to rapid bacterial fermentation. Individuals with IBS may be susceptible to one or more foods from each FODMAP group and to variable amounts of each that trigger their symptoms. In fact, very large amounts of FODMAPs are likely to trigger GI symptoms in almost any individual, by overwhelming the usual absorptive capacity (see Table 16.11). There are no specific tests for individual susceptibility to FODMAP malabsorption or to individualized microbial fermentation inducing pain.

Overall, the research suggests that the low-FODMAP diet is consistently the best diet for patients with IBS. It should be the preferred short-term recommendation as a dietary treatment trial for adults with IBS. In children, one study has shown benefit, and hence, this diet should be considered in children with IBS as well. However, children should be screened for symptoms of eating disorder prior to having them commence on the low-FODMAP diet. This diet, which can be quite limiting, is not recommended in the face of restrictive eating or malnutrition.

Inflammatory Bowel Disease

The inflammatory bowel diseases, Crohn's disease (CD), and ulcerative colitis (UC) are chronic disorders that present with both intestinal and extraintestinal manifestations and have significant implications for childhood growth and nutrition (Table 16.12). Approximately a third of patients are diagnosed during childhood. CD is slightly more prevalent than UC and there is a male predominance. There has been increasing prevalence of IBD across the globe, more recently in emerging

TABLE 16.11
Low-FODMAP Diet

Food	High-FODMAP Foods	Low-FODMAP Foods
Grains	Barley	Arrowroot
	Bulgur	Buckwheat
	Chickpea flour	Corn (meal/starch)
	Couscous	Millet
	Durum	GF oat
	Kamut	Polenta
	Lentil flour	Potato
	Pea flour	Quinoa
	Rye	Rice
	Semolina	Sago
	Soy flour	Sorghum
	Triticale	Tapioca
	Wheat (bran, flour, germ)	Teff
Milk/Dairy	Milk (all)	Cottage Cheese
	Soft cheese	Hard Cheese (Cheddar, parmesan, Swiss)
	Soy milk (made from soybeans)	Lactose-free milk, lactose-free yogurt
	Sour cream	Lactose-free ice cream (allowed sweetener)
	Ice cream	Rice milk
	Yogurt	Sorbet (low-FODMAP fruits/sucrose)
		Soy milk
Proteins	Cashew, pistachio	Beef
	Dried peas, beans, lentils	Egg
	Processed meats (i.e., Sausage with onion, garlic, vegetable flavoring)	Poultry
		Pork
	Soybean	Peanut, peanut butter (creamy)
		Seeds (chia, pumpkin)
		Specific tree nuts (almond, hazelnut, pine nut, walnut, pecan)
		Tofu (firm)
		Tempeh
Fruits	Apple	Blueberry
	Apricot	Banana
	Asian pear	Banana chips
	Avocado	Cantaloupe
	Blackberry	Coconut
	Boysenberry	Dried cranberry
	Cherry	Grapes
	Dried fruits	Honeydew
	Fig	Kiwi
	Mango	Lemon
	Nectarine	Lime
	Peach	Mandarin orange
	Pear	Orange
	Persimmon	Passion fruit
	Plum	Papaya
	Prune	Pineapple
	Tamarillo	Raspberry
	Watermelon	Start fruit
		Strawberry
		Tangello
		Tangerine
		Plantain

(*Continued*)

TABLE 16.11 (*Continued*)
Low-FODMAP Diet

Food	High-FODMAP Foods	Low-FODMAP Foods
Vegetables	Artichoke	Alfalfa sprout
	Asparagus	Bamboo shoot
	Cauliflower	Bell pepper
	Celery	Bok choy
	Garlic	Broccoli
	Leek	Brussel sprout
	Mushroom	Cabbage
	Onion	Carrot
	Scallion	Corn
	Shallot	Cucumber
	Snow pea	Eggplant
	Sugar snap pea	Green bean
		Lettuce
		Olives
		Parsnip
		Potato
		Pumpkin
		Rutabaga
		Seaweed
		Sweet potato
		Swiss chard
		Spinach
		Squash
		Sweet potato
		Tomato
		Turnip
		Watercress
		Yam
		Zucchini
Fats/oils	Salad dressings with onion/garlic	Vegetable oil, butter, ghee, lard, margarine
		Garlic-infused oils
Sweeteners	Agave nectar	Artificial sweeteners (aspartame, saccharine, stevia)
	Artificial sweeteners or sugar alcohols (sorbitol, mannitol, xylitol, isomaltose maltitol)	Brown sugar
		Confectioner's sugar
	Coconut Polydextrose	Glucose
	Corn syrup solids	Maple syrup
	Fructose	Molasses
	Fruit juice concentrate	Raw sugar
	High-Fructose Corn syrup (HFCS)	Sucrose (table sugar, cane sugar)
	Honey	

(*Continued*)

TABLE 16.11 (*Continued*)
Low-FODMAP Diet

Food	High-FODMAP Foods	Low-FODMAP Foods
Other	Beverages:	Beverages:
	Apple, pear, mango juice, other low-FODMAP fruit juices (>1/2 cup)	Water, mineral water, soda water, sugar-sweetened beverages (sucrose)
	Beverages with HFCS (high-fructose corn syrup)	Orange juice (limit to ½ cup)
	Teas (oolong, chamomile, fennel, chai)	Cranberry juice (limit to ½ cup)
	Kombucha	Tea (black, green, peppermint, white)
	Garlic powder/salt	Fresh herbs/spices
	Onion powder/salt	Baking powder, baking soda, cocoa, coconut, gelatin, salt, vinegar, fresh and dried herbs (not garlic/onion)
	Spice blends with garlic/onion	
	Spreads/condiments:	Spreads/condiments:
	Chutneys	Jam (with no HCFS)
	Hummus	Ketchup (no HFCS)
	Ketchup (with HCFS)	Marmalade (low-FODMAP ingredients, no HCFS)
	Jelly (with HCFS/fruit)	Mayonnaise
	Pickles/relish (with garlic)	Mustard
		Sugar-free gum, mints, cough drops, and candies

TABLE 16.12
Signs and Symptoms of Inflammatory Bowel Diseases

	Crohn's Disease	Ulcerative Colitis
Intestinal symptoms	Abdominal pain	Abdominal pain
	Diarrhea with or without blood	Bloody diarrhea
	Nausea, vomiting	Nausea, vomiting
Location of intestinal disease	Mouth to anus	Mainly colonic
		Mild ileitis, duodenitis, or gastritis can occur
Extraintestinal associations	Fever, lethargy, malaise, anorexia	
	Erythema nodosum, pyoderma gangrenosum, clubbing	
	Arthralgia, arthritis, sacroiliitis, ankylosing spondylitis	
	Uveitis, episcleritis, keratitis	
Other complications or associations	Malnutrition, short stature, pubertal delay[a]	
	Iron deficiency anemia	
	Osteopenia or osteoporosis	
	Nephrocalcinosis	
	Primary sclerosing cholangitis[b], autoimmune hepatitis and overlap	
	Venous thromboembolism	
	Depression, anxiety	
	Colon cancer[b]	
	Infections or cancers secondary to therapeutic immune suppression	

[a] More prominent in Crohn's disease.
[b] More prominent in ulcerative colitis.

nations becoming westernized and in the pediatric age range. In established industrialized countries, current prevalence estimates are at around 0.5% and forecast to increase.

The pathogenesis of IBD is considered multifactorial with genetic and environmental contributions. As the known genetic factors have only modest overall contribution, it appears that host immune and environmental factors are of greater importance, in particular, aberration in the relationship between the host immune response and the intestinal microbiome. Accordingly, diet must have a critically important role in the pathogenesis of IBD. This is further supported by the rising prevalence being associated with established or acquired westernized dietary patterns. Factors in that diet pattern that have been specifically associated with risk of IBD include higher intakes of red meat, animal fats and simple sugars, lower intakes of vegetables and fiber, and food additives, including emulsifiers.

This chapter will not discuss the various medical and surgical approaches to diagnosis, disease monitoring and management of IBD, beyond the dietary treatments below. There are many excellent society guidelines for either CD, UC, or both that are constantly being updated as new treatments are developed and trials undertaken. In general, treatment for IBD involves two phases: induction of remission and maintenance of remission. Regular use of disease activity scores, both clinical and endoscopic, is an essential part of monitoring. Overall, a key factor essential for success is expert and multidisciplinary care. Given the role of nutrition support and monitoring in outcomes and the role of diet as a potential treatment, the multidisciplinary team must include a dietitian.

Malnutrition and growth impairment are both common presentations and major complications of IBD. Nearly 25% of newly diagnosed children with CD and 10% of newly diagnosed children with UC have a BMI <5th percentile. Impaired linear growth and pubertal delay are more common in CD than UC, with a male predominance. Menstrual disturbances and delayed menarche are common. Both weight loss and decreased weight velocity are common at presentation, more so in CD. Growth faltering is a common first presentation of IBD that can only be detected by early monitoring and vigilance. Disease activity and nutrition status are interrelated and effective treatment will improve and potentially normalize long-term growth outcomes. Hence, growth monitoring is an essential part of treatment planning and evaluation.

Due to malabsorption, these patients are at risk for micronutrient deficiencies (especially of iron, vitamin D, and zinc) that should also be regularly monitored and treated. A combination of chronic inflammation, vitamin D deficiency, and growth failure can all negatively impact bone mass and steroids are an additional risk factor for osteoporosis. Monitoring and intervening with nutrition supplementation can optimize peak bone mass only during childhood and should not be neglected. Finally, attention to nutrition pre- and post-surgical interventions is known to reduce complications.

IBD is a lifelong, chronic, remitting, and relapsing condition. Overall, childhood-onset IBD presents more extensive disease and has a more aggressive course than adult-onset IBD. Traditionally, more than half of all children with CD can expect to have at least one hospitalization, half can expect to have at least one surgical intervention, and 10% may end up with a permanent stoma.

Diet Therapies for IBD

In general, there is limited role for diet to treat the inflammation of UC, although bowel rest will visibly reduce bloody diarrhea in hospitalized patients with severe colitis. For CD, exclusive enteral nutrition (EEN) has been studied and is endorsed as the first-line treatment for induction of remission for pediatric CD. Other diet treatments for CD are being studied with varying results.

Exclusive Enteral Nutrition

Traditionally, corticosteroids were used to induce remission but EEN is at least equivalent to corticosteroids (~80% remission rate). EEN is superior to corticosteroids when mucosal healing (the

ultimate therapy goal) is considered as a primary outcome and given the adverse effects of steroids on growth and bone health.

Usually, EEN is delivered for 6–12 weeks by oral route or nasogastric tube. Exclusive use means only water and chewing gum/hard candy are allowed outside of the formula chosen. Recent studies have shown that EEN has efficacy for induction of remission and improving perceptions of quality of life; but partial enteral nutrition where some percentage of regular diet is allowed does not appear nearly as beneficial. The optimal way to reintroduce foods after the initial 6–12 weeks of EEN is currently controversial. However, it is clear that food reintroduction is associated with increased intestinal inflammation and so transition to an effective drug maintenance therapy is essential.

The mechanism by which EEN achieves remission and mucosal healing is not known. Efficacy is not dependent on the amount or type of protein or fats, which vary widely in formulas used. Monotony, taste fatigue and the potential need for short-term EN (with discomfort and social stigma) are among the downsides for patients in uptake and adherence to EEN. Other barriers to the use of EEN in children with CD include the costs of therapy, need for access to a dietitian, and lack of physician experience or commitment with this approach. Even patients and families who have had positive experiences with EEN and willing to repeat the therapy would prefer an alternative that uses whole foods.

Other Diet Treatments for CD

The role of diet in pathogenesis and treatment is a high priority area for research in pediatric IBD for patients and their families. The interest in diet as therapy for this population has led to the emergence of a number of standardized treatment diets: the specific carbohydrate diet (SCD), Crohn's disease exclusion diet (CDED), and a diet based on whole foods that mimic the nutrient profile of EEN (CD-TREAT) (Table 16.13). Some common themes to all these diets include: reduction in pro-inflammatory nutrient factors thought relevant to the pathogenesis of IBD (e.g., avoiding animal fats and food additives) and providing food likely to be better tolerated in symptomatic patients (e.g., low in complex fiber or highly fermentable carbohydrates, overlapping FODMAPs). Another commonality that should not be overlooked is that most of these diets have been tested in mild or at most moderate CD and few have examined mucosal healing. No data exist for their efficacy in severe CD. As with all exclusion diets there are risks of nutrient deficiencies (see Table 16.14). A dietitian is essential to provide education and support, to ensure nutrient adequacy of the diets, and to promote adherence.

In IBD there are general diet recommendations that have been endorsed by experts, despite limited evidence. Similar to the treatment diets above they include increasing fruits and vegetables and avoiding red meat, saturated fats, added sweeteners, and processed foods. Specifically in CD, avoidance of insoluble fiber for fibrostenosing disease (where there may be narrow areas in the intestine) is advised. Regardless of medical advice, children with IBD will modify the foods they eat such that they are at risk of nutrient deficiencies, unless they are given micronutrient or nutrition supplementation or are on EEN. Again this should emphasize the importance of a dietitian and careful nutrition assessment in the care of all pediatric IBD patients.

Gastroparesis

Gastroparesis is a motility disorder of the stomach characterized by delayed gastric emptying of nutrients into the duodenum. In children, it most often is idiopathic or postviral. It can be a late complication of diabetes mellitus. Patients with gastroparesis self-limit food intake due to early satiety, fullness, nausea, and vomiting. Diet modification is the cornerstone of therapy. Patients should eat a low-fiber and low-fat diet. They should eat small, frequent meals by dividing feedings into five or six smaller meals per day. Since emptying of liquids is better than that of solids, nutrients in liquid form can be trialed. Older children should be encouraged to thoroughly chew foods and as the day progresses with increasing stomach fullness, may need liquid nutrition. In addition, the child should

TABLE 16.13
Popular Crohn's Disease Treatment Diets

	Foods		Evidence	
Diet	**Allowed**	**Not Allowed**	**Study Designs**	**Study Outcomes**
SCD	Certain fruit and vegetables Animal meats Fish Eggs, poultry Select cheeses Natural fruit juice	All grains Most dairy Sugar (except honey) Processed foods Certain legumes & soy Starches Canola oil	Retrospective or prospective uncontrolled studies in children with mild to moderate CD (and UC)	Improvement in clinical symptoms and disease activity; decrease C-reactive protein; when studied most do not show mucosal healing
CDED	Certain fruit and vegetables Eggs, chicken Fish Lean beef	Gluten Animal/dairy fat Red meat Processed foods Soy Chocolate Coffee Alcohol	Prospective uncontrolled studies in mild to moderate pediatric (and adult) CDED +/– PEN Randomized controlled trial in mild to moderate pediatric CDED + PEN compared to EEN	Improvement in clinical symptoms and disease activity; decrease C-reactive protein and fecal calprotectin; better tolerated than EEN, equivalent remission; mucosal healing not studied
CD-Treat	Foods from a list combined to mimic EEN (same profile of macronutrients, vitamins, minerals and low in fiber) Multivitamin is mandatory	Gluten Lactose Reduced complex carbohydrates Alcohol	Open label study in mild to moderate pediatric CD (n=5)	Improvement in clinical symptoms and disease activity; decrease in fecal calprotectin

Source: Adapted Nazarenkov N, Seeger K, Beeken L, et al. Implementing Dietary Modifications and Assessing Nutritional Adequacy of Diets for Inflammatory Bowel Disease. *Gastroenterol Hepatol (N Y)*. 2019;15:133–144.

Legend: SCD, specific carbohydrate diet; CDED, Crohn's disease exclusion diet; EEN, exclusive enteral nutrition; PEN, partial enteral nutrition.

sit up for 1–2 hours after a meal. If no solids are tolerated, a pureed/liquid diet should be tried. In patients with diabetes, good control of the condition is important (Chapter 24). Finally, some children who fail all the above measures may need post-pyloric feeding.

Superior Mesenteric Artery (SMA) Syndrome

Superior mesenteric artery (SMA) syndrome is a rare condition that occurs when the duodenum is compressed between the aorta and a branch of the SMA. The most common cause of this condition is significant weight loss and also after surgery for scoliosis. In individuals with weight loss, the normal fat pad shrinks and causes the angle of the SMA to change, now putting pressure on the intestine.

Symptoms can include nausea, bilious vomiting, abdominal pain, and early satiety. This condition is diagnosed through an upper GI barium study which can identify the obstruction.

Nutritional therapy is delivered through post-pyloric feeding (through a nasojejunal tube) that can be used to feed past the obstruction. Weight gain alone can restore the mesenteric fat pad, thus relieving the obstruction.

TABLE 16.14
Common Food Eliminations for Patients with Crohn's Disease and Their Potential Nutrient Concerns

	Diet Treatment			
Excluded Diet Component	**SCD**	**CDED**	**CD-TREAT**	**Nutrient Concerns**
Animal fat		✓		Total dietary energy, iron, zinc, niacin, vitamins B_{12}, B_6
Lactose	✓	✓	✓	Calcium, vitamins D, A, B_{12}, B6, riboflavin, phosphorus, pantothenic acid, potassium, magnesium, iodine
Gluten	✓	✓	✓	Iron, thiamine, riboflavin, folate, niacin, vitamin B_6, biotin, zinc, selenium, magnesium, fiber
Other grains	✓			Iron, thiamine, riboflavin, folate, niacin, vitamin B_6, biotin, zinc, selenium, magnesium, fiber
Emulsifiers & preservatives	✓	✓		None

Legend: SCD, specific carbohydrate diet; CDED, Crohn's disease exclusion diet.

NUTRITION MANAGEMENT OF GI DISEASES

Nutrition plays a key role in the management and treatment of many GI diseases. A thorough nutrition assessment is essential to determine the appropriate course of treatment (i.e., EoE, IBD). GI diseases, and the treatment of these diseases, may result in nutrient deficiencies including those of energy, protein, and micronutrients. Malnutrition is common in many GI diseases. Careful nutrition assessment and intervention are critical to ensure growth, development, and treatment of disease.

Nutrition Assessment

A detailed diet history including types and amount of foods and beverages, intake of foods to be eliminated (i.e., gluten, FODMAPs, sucrose, etc.), vitamin and mineral supplementation, and screening GI symptoms can identify micronutrient deficiencies and/or adherence issues.

A nutrition-focused physical exam (NFPE) can be used to help identify deficiencies in children and should be completed at initial nutrition assessment and follow-up.

Laboratory assessment may help confirm specific nutrient deficiencies if they are suspected due to gaps in diet or NFPE (Chapter 2). Dual-energy X-ray absorptiometry (DXA) can be utilized to measure mineral density in bones, if osteopenia is suspected based on diet history or steroids are used long term. Follow-up monitoring of specific laboratory levels should be determined individually, and care should be made when assessing these levels as some lab values may not correlate with the body stores.

Nutrition Assessment of Elimination Diets

When using diet therapy to treat GI diseases, the dietitian plays a key role in ensuring adequate nutrient intake. Diet history that includes types and amounts of foods and liquids including formulas, symptoms related to food ingestion, and additional vitamin-mineral and herbal supplementation is helpful in assessing current nutrient intake and feeding behaviors. A detailed 24-hour recall of the child's intake with additional key questions regarding supplements, food preferences, food variety, feeding ability, and environment can help identify potential gaps in the diet. Laboratory assessment may help confirm specific nutrient deficiencies if they are suspected due to gaps in diet, NFPE, or location/severity of disease. Dual-energy X-ray is tool to measure bone mass and often used to assess bone health in IBD patients. Nutrition laboratory tests should be monitored regularly, and supplementation provided when found to be deficient.

Eosinophilic Esophagitis

The child's underlying nutrition status is one determinant of the form of dietary therapy offered to patients with EoE. If malnourished, further dietary restriction without adequate nutrition support may lead to worsening malnutrition. Nutrition assessment is therefore critical.

Diet history that includes types and amounts of foods consumed, food allergies, aversions and what medications and supplements are being taken is helpful in assessing current nutrient intake and feeding behaviors. A written 3-day food record including typical intake is valuable, but often not practical. At a minimum, a detailed 24-hour recall of the child's intake with additional key questions (Table 16.15) regarding supplements, food preferences, feeding ability, and environment will help determine if the child is malnourished (or at risk) and/or has undiagnosed pediatric feeding disorder, requiring additional supplementation and referrals. A major determinant of the success of the diet therapy is psychosocial, influencing adherence or motivation for diet therapy; hence, psychological assessment is a key part of nutrition assessment. Questions about patient and family lifestyle, activities, eating patterns, locations of meals (daycare, school), as well as food insecurity provide an opportunity for providers to provide resources including referring to social worker or psychologist for patients to be successful on diet therapy.

Attention must be given to macronutrient and micronutrient intake with elimination diets and elemental diet therapy. Although there is limited research on nutrition status following elimination or elemental diets, there are inherent nutrition risks with each nutrition therapy (see Chapter 15 for nutrient deficiencies associated with elimination of specific foods).

Lactose Intolerance

In avoiding lactose containing foods there is risk for inadequate intake of calcium, vitamin D, and riboflavin. Education should focus on managing a nutritionally complete lactose-free diet that

TABLE 16.15
Key Questions During Nutritional Assessment of Eosinophilic Esophagitis

Food impaction or sense of food getting stuck in throat?
Preference for liquids or specific textures (soft vs. crunch/chewy)?
Spits out food after chewing or pockets foods in cheek?
Choking or gagging?
Chewing excessively?
Drinks extra fluids to get solid down?
Fast or slow eater?
Food refusal or aversion?
Location of meals? (home, multiple households or outside home)
Is patient willing or able to make changes in diet?
Is caregiver able to purchase/prepare allowed foods or formula?

provides high-calcium, low-lactose foods, such as fortified foods and beverages. Calcium supplementation may be required to meet calcium needs.

Fructose Intolerance

Much of a child's intake of fructose can be from non-nutritive simple sugar beverages. Overall, there is a low risk of nutrition deficiencies when removing high-fructose containing foods when a balanced diet is provided.

Celiac Disease

The gluten-free diet is not without nutrition and non-nutrition risks (Table 16.16). It should be recommended only when necessary for gluten-related disorders and should be supervised by a dietitian.

TABLE 16.16
Gluten-Free Diet Nutrition and Non-Nutrition Concerns

Nutrient Concerns	Non-Nutrient Concerns	Non-Food Sources of Gluten (Rarely a Concern)
Micronutrients: Thiamine, riboflavin, niacin, folate, and iron	Cross-contact with gluten-containing foods at home:	Gluten must be ingested; hence, hand washing is important if handling gluten-containing beauty products (shampoo, skin lotions, etc.)
Many gluten-free (GF) grains are made with refined flours, not enriched with B-vitamins and iron	Proper hand washing/cleaning surfaces, cutting boards & utensils	
Encourage balanced diet www.choosemyplate.gov	Place gluten-free items above gluten-containing items in the pantry and refrigerator (so that gluten particles do not fall or settle into gluten-free foods)	
Supplement diet with GF multivitamin/mineral supplement	Identify gluten-free foods with an indelible pen or stickers	
May need additional folic acid supplementation	Thoroughly clean all dishes, pots, pans, and utensils between uses	
Iron:	Purchase a second, gluten-free toaster	
• Screening for anemia at diagnosis	Use a separate set of cutting boards for gluten-free food prep	
• Treat with supplemental iron as needed	Prepare allowed foods first, then cover	
• Encourage foods rich in iron: red meats, fish, legumes, leafy vegetables, and dried fruits	Separate condiments (avoid double dipping)	
• Foods containing vitamin C help with absorption	Use paper towels vs. sponges	
• Complete GF multivitamin/multimineral supplement	Designate safe areas to eat foods	
Vitamin D/calcium: Celiac disease increases risk for bone disease:	Cross contact with gluten outside home:	Prudent to avoid lip balm containing gluten
• Decreased intake due to lactose intolerance or taste	Ask about ingredients	
• Encourage calcium, vitamin D rich foods. (Regular or lactose free if needed temporarily)	Ask about meal preparation:	
• Monitor intake, and supplement Calcium and vitamin D as needed	In its own separate and thoroughly washed pot or pan	
Magnesium: found in cereals, gluten-containing foods	Using separate and thoroughly cleaned cutting boards and utensils	
• If poor quality GF diet consumed, encourage foods high in magnesium: nuts, seeds, dry beans, greens, GF oat bran	With care by the food handlers so that there's no cross-contamination of foods	
• Complete GF multivitamin/multimineral supplement	Cross contact with purchased foods:	Most medications contain no gluten-containing grains. Check with pharmacist to make sure medications are gluten-free
	Thorough label reading	
	Avoid bulk bin, salad bars with scoops that might be shared or containers that allow ingredients to leak through	
	When in doubt, call the manufacturer	

(*Continued*)

TABLE 16.16 (*Continued*)
Gluten-Free Diet Nutrition and Non-Nutrition Concerns

Nutrient Concerns	Non-Nutrient Concerns	Non-Food Sources of Gluten (Rarely a Concern)
Fiber: • GF grains often lower in fiber Encourage high-fiber GF grains: buckwheat, quinoa, legume based, GF oats, brown rice, or seed based Incorporate legumes, nuts, seeds, fruits and vegetables • Supplement with GF fiber supplementation (Nutrisource Fiber® Metamucil® powder or capsules)	Cost: GF foods are almost two times the price of gluten-containing foods. Tips on saving money on GF Diet: Choose naturally GF foods Cook with cheaper GF grains: corn, oats, rice Buy in bulk Batch cook and freeze One-pot meals Shop sales, clip coupons off food manufacturer websites Choose more whole foods, less processed foods	Check your toothpaste and mouthwash to ensure they are gluten free
Weight gain: GF processed foods: high in sugar/fat and low in nutrition Choose whole foods naturally gluten-free whole grains (i.e., amaranth, quinoa, buckwheat, teff), lean proteins, fruits, vegetables, healthy fats, dairy products, less processed foods	Adherence to diet: Education: understanding risk factors complications of not following diet Education on foods not allowed, appropriate substitutions, label reading, and cross-contamination Resource identification, support groups, positive reinforcement	Beware wheat starch as a filler; wheat maltodextrin is gluten free
Arsenic in GF foods: Arsenic is found in water, soil, and air Rice absorbs more arsenic than other crops Ways to decrease arsenic: Rinse rice before cooking: This lowers arsenic content 25%–30% since arsenic is water-soluble Alternate grains: quinoa, amaranth, corn, buckwheat, flax, millet, and GF oats Check your local water supply: if arsenic levels are high, recommend a water filtering system or using bottle water for cooking and drinking	Other caregivers, daycare, school, relatives Provide written explanation of diet/diagnosis Provide list of allowed and not allowed foods Bring own snacks/meals	Gluten-containing playdoh for young children who cannot reliably wash hands before touching mouth should be avoided

Source: Adapted from Dennis M, Lee AR, McCarthy T. Nutritional Considerations of the Gluten-Free Diet. *Gastroenterol Clin North Am*. 2019;48:53–72.

A number of nutrients, notably vitamin D and folate, are at risk for deficiency on a GFD, with lack of nutrient fortification being a contributing factor. In comparison to gluten-containing equivalents, the sugar and fat added into processed gluten-free foods to increases palatability, increases energy content and glycemic load, reduces diet quality, and contributes to the risk of becoming overweight or obese. Processed gluten-free foods have an acceptably low gluten content (<20 ppm) that nevertheless cumulatively, with excess daily intake, can lead to persistent enteropathy. Children may be uniquely at risk given processed foods remain a significant component of their diet. An all-natural GFD is healthiest and may strictly be required, at least in the short term, for patients with refractory celiac disease reporting dietary compliance.

Follow-up with a dietitian is a cost-effective way of providing patients with celiac disease education that can improve diet adherence and knowledge, and ability to read food labels. There is considerable added complexity for patients with celiac disease in reading food labels as the "may contain" statements are based on safety requirements for the (wheat) allergic population, rather than gluten content.

The role of infant feeding practices in the development of celiac disease is not clear. At this time, celiac disease will not emerge in any infant not consuming gluten, including the infant exclusively receiving human milk. Early introduction of gluten in complementary feeds does not seem to increase the risk of developing celiac disease; however, there may be a role for increased daily gluten intake in young children at genetic risk that warrants clarification.

Irritable Bowel Syndrome

While the data do support the efficacy of a low-FODMAP diet as a treatment for IBS, including potentially for children, there are important practical concerns and unanswered questions, especially for children. The diet is complex. While alternatives within the major food groups (e.g., alternate cereals, fruits, vegetables, and lactose-free products) can be substituted in order to maintain diet quality and nutrient adequacy, this would be almost impossible to do without the support of a dietitian. An exclusively low-FODMAP diet implemented incorrectly over a long term without gradual reintroduction of FODMAP groupings can lead to nutrient deficits, including of protein and energy in the face of dietary restriction without replacement, and micronutrient deficiencies: B group vitamins (due to avoidance of fructose and fructans), calcium and vitamin D (when avoiding lactose), fiber (due to avoidance of oligosaccharides), etc.

Inflammatory Bowel Disease

Not addressing nutrition issues caused by IBD can lead to malnutrition, vitamin/mineral deficiencies, linear growth stunting, and other poor outcomes. Obtaining mid-parental height can help determine expected linear growth and help identify growth problems (Chapter 1). NFPE can help identify deficiencies in children and should be completed at initial assessment and follow-up, if deficiencies are suspected. NFPE findings found in children with IBD may vary based on nutrition status, dietary/nutrition related history, and disease severity. Table 16.17 provides some physical findings that may help identify deficiencies.

Thorough monitoring of the patient's nutrition status and growth should be ongoing. In children with IBD, longitudinal linear growth reflects disease course and treatment success and should be assessed every 6 months by measuring height velocity z-scores or variations in height-for-age

TABLE 16.17
Nutrition-Focused Physical Examination Findings for Patients with IBD

Subcutaneous fat stores: orbital region, upper arm, thoracic/lumbar
Muscle loss: weakness, wasted appearance; temporal region, clavicle bone region
Bones: weakness, demineralization
Triceps skinfold thickness/mid-arm circumference
Digestive system: anorexia, diarrhea
Mouth: teeth present, in good condition? Does patient have mouth ulcers present?
Hair: dull, pluckable, thin, color
Skin: bruising
Ostomies/drains: Yes? Which ones?
Feeding access points: (Tube buttons, central venous access)

Source: Adapted from Pediatric Nutrition Care Manual. IBD Nutrition-Focused Physical Observations. Academy of Nutrition and Dietetics. https://www.nutritioncaremanual.org.

z-scores. Tanner staging is also beneficial in determining pubertal status (Chapter 1). Nutrition reassessment by a dietitian annually or sooner if needed for nutrition rehabilitation is essential to address nutrition issues caused by IBD.

Nutrition Diagnosis

Common nutrition diagnoses for patients following restricted diets include those related to energy intake, micro- and macronutrient deficiencies, and behavioral-environmental (e.g., knowledge, attitudes, beliefs, food safety, or access to food). Additionally, misconceptions about healthy eating patterns are common; food and nutrition knowledge related deficits, disordered eating, and less than desirable food choices might be diagnosed. Potential nutrition diagnoses include:

- Inadequate energy intake
- Inadequate vitamin intake (specify)
- Inadequate mineral intake (specify)
- Food and nutrition related knowledge deficit

Nutrition Intervention

The nutrition prescription for patients following restricted diets is similar to that of their healthy peers (Chapter 3). Energy, protein, and fluid needs can be calculated using standard equations. Specific micronutrient needs may be increased if deficiencies are noted during the nutrition assessment. Nutrition interventions for patients with GI diseases are based on diagnosis, treatment, and findings from the nutrition assessment.

Nutrition Education

The dietitian plays a key role in educating patients following restricted diets. Initial nutrition education should include written materials and specific examples that the patient can easily implement at home. Reassessment of understanding and compliance is important in ensuring the patient is following the diet appropriately.

Gastroesophageal Reflux Disease

Current guidelines promote a dietary manipulation, thickening of feeds, as first-line management for infants. Commercial formulas for infants with reflux have added rice starch, which is designed to thicken in the stomach and result in decreased vomiting. These formulas are most effective in patients that are not receiving pharmacological acid suppression. The use of thickening as an initial approach for GERD in infants has many advantages compared to the traditional approach of pharmacological acid suppression.

Infant feeding practices have an impact on GER, and interestingly GER impacts infant feeding. This is most often by prompting a switch in feeding mode (e.g., breast to bottle); a change in feeding type (e.g., human milk to formula or multiple formula changes); or attempted early introduction of complementary feeds (before 6 months of age). Feeding with human milk, via breast or bottle, appears to be associated with less apparent GER. Avoiding overfeeding and avoiding rapid bolus feeds (as with fast flow nipples) can reduce visible reflux and vomiting. In infants, there is overlap between GI food allergy (most often to cow's milk protein), EoE, and GERD. As such, a short-term trial (2–4 weeks) of an extensively hydrolyzed formula can be warranted in formula-fed infants at risk for atopy or with persistent or severe symptoms.

Dietary management of GERD continues beyond infancy and may include recommendations for smaller meals, avoiding high fat meals and acidic foods, not eating close to bedtime or to intensive exercise and avoiding frequent snacking.

Eosinophilic Esophagitis

Elemental diet is perhaps the most psychologically challenging for the patient and family given challenges of taste and monotony. Practically, careful consideration should be given to the volume of enteral formula prescribed to patients on elemental diet therapy and nutrition completeness of formula. Additional micro- or macronutrient (including protein or fiber) supplements may be needed to meet individual needs. While many elemental formulas are flavored for oral consumption, feeding tubes may be necessary to meet prescribed volumes that are unable to be consumed by mouth. During the elimination stage, patients can consume one food (low in allergenicity), usually a fruit or vegetable (i.e., apples, grapes, green beans) to allow for oral stimulation.

Once histological remission is demonstrated, foods are reintroduced individually or in groups (up to 3–4 foods/trial) based on extent of food eliminated and propensity to promote inflammation (see Table 16.18). Endoscopy is performed to assess histology and response to diet trials. The reintroduction stage can take a minimum of 9–12 months to achieve a significant variety in diet and allow for reduction of the elemental formula.

The different diet-elimination therapies follow a similar protocol: a remission stage in which food(s) are eliminated from the diet, followed by a reintroduction stage involving sequential introduction of one of the excluded foods every 8–12 weeks followed by endoscopy and biopsies to determine response. If there is a recurrence of inflammation, the incriminating trigger food is excluded from the diet with repeat endoscopy after 8–12 weeks. When inflammation has resolved, the next food(s) are individually added until all the excluded foods are reintroduced. In the maintenance stage, trigger food(s) identified during the reintroduction stage are excluded long term.

Elimination diet education involves identification of food allergens and appropriate food substitutions to ensure nutrient adequacy, which may involve supplementing with elemental formulas and vitamin and minerals. Education on how to read food labels follows the same principles as food allergy elimination diets and is the foundation of educating families on eliminating foods (Chapter 15).

TABLE 16.18
Reintroduction Phase: Elemental Diet Therapy

Start ----------→ End
(Least allergenic) (Most allergenic)

A	B	C	D
Vegetables (nonlegume):	**Citrus fruit**:	**Legumes**:	Fish/Shellfish
Carrots, squash (all types), sweet potato, white potato, string beans, broccoli, lettuce, beets, asparagus, cauliflower, Brussels sprouts	Orange, grapefruit, lemon, lime	Lima beans, chickpeas, white/black/red beans	Corn
Fruits (noncitrus, nontropical)	**Tropical fruit**:	**Grains**:	Peas
Apple, pear, peaches, plum, apricot, nectarine, grape raisins	Banana, kiwi, pineapple, mango, papaya, guava, avocado	Oats, barley, rye, other grains	Peanut
Vegetables	**Berries**	**Meat**	Wheat
Tomatoes, celery, cucumber, onion, garlic, any other vegetables	Strawberry, blueberry, raspberry, cherry, cranberry	Lamb, chicken, turkey, pork	Beef
	Grains		Soy
	Rice, millet, quinoa		Egg
			Milk

Source: Reprinted with permission from, Markowitz JE, Liacouras CA, Elimination Diets in the Management of Eosinophilic Esophagitis. *Gastroenterol Clin North Am*. 32:949–966, Copyright 2003, with permission from Elsevier.

Introduce food trials: 3–4 foods starting at least allergenic moving right through stages A to C until stage D. Once at stage D, consider 1 food trial at a time due to higher allergenicity. For each diet trail: trial one of the selected foods per week, sequentially introduce the other 3-selected foods one food at a time.

Individualizing meal planning involving grocery shopping, mealtime behaviors, eating outside home (school, daycare, multiple households, extracurricular activities, restaurants, and vacations), and avoiding cross contact is essential. Providing guidance on resources available from support group organizations (American Partnership for Eosinophilic Disorders [APFED], Consortium of Food Allergy Research [COFAR], CURED, FARE, GIKIDS.org, formula companies, and specialty foods companies) that include recipes and menu planning, help in getting formula provided, and support for improving quality of life of patients with EoE. A practical checklist for individualized education is shown in Table 16.19.

Fructose Intolerance

Provide education on fruits and vegetables with low fructose, appropriate portion sizes, and on how to read food labels to identify and avoid foods high in fructose.

Congenital Sucrose Isomaltase Deficiency

If EN is necessary to improve nutrition status of patient with CSID, care must be taken to choose a formula that does not contain sucrose, starch, or maltose. As previously discussed, human milk and infant formulas are appropriate, but for children over 1 year, there are no standard, commercially available formulas that are nutritionally complete without the offending carbohydrates (corn syrup solids, maltodextrin, or sucrose). Use of specialized metabolic formulas that contain very low or no carbohydrates may be indicated, with addition of allowed carbohydrate source (dextrose or fructose) and water.

Nutrition education is imperative to success of the dietary treatment. Guidance on how to eliminate sucrose, maltose, and starch to meet the individual child's nutrition needs during elimination, followed by slow reintroduction to determine levels of tolerance is essential to success. Families should be taught how to read labels and record intake and symptoms to help determine the individual child's tolerance to specific foods. Providing instruction on how to complete food/symptom diaries while reintroducing foods will help identify "trigger" foods. Formula or human milk feeding should continue until 1 year or longer to provide adequate nutrients for growth. Fructose and glucose, in addition to healthy fats such as vegetable oils, avocados and natural nut butters can be used in foods and beverages for added energy provision.

Irritable Bowel Syndrome and Constipation

The current approach to managing the low-FODMAP diet should be a limited period of elimination of all FODMAPs (4–8 weeks at most), followed by staged reintroduction within groupings, under the supervision of a dietitian, and finally a stage of individualized dietary management. At that stage

TABLE 16.19
Checklist for Education: Individualized to Each Patient and Family

- Label reading guidelines
- Appropriate food substitutes: shopping lists, meal planning (choosemyplate.gov), recipes, specialty foods products
- Cross-contact
- Correcting any micronutrient deficiencies – vitamin and mineral supplementation/formula supplementation
- Realistic diet plan: focus on balanced nutrition and whole foods
- Mealtime behaviors: structured meals times, avoid grazing, eating at the table, no force feeding
- Resource identification: websites, formula information, specialty food products, eosinophilic gastrointestinal disorders support groups, caregiver mentor programs
- Pantry items (cut up fruits/vegetables, trail mix made with allowed cereal, dried fruits/seeds, 90-second rice bags, canned beans, allergy free snacks)
- Batch cooking on weekends, prep-work
- Tips for school/daycare, eating out, social events, traveling
- Trouble shooting

only a few FODMAPs that have been recognized as the main triggers of symptoms should be avoided and only at the amounts that trigger symptoms. Clearly this approach requires careful monitoring of dietary intake and symptoms at all stages using food records or a food diary. Getting to the personalized stage is not a simple process and does require ongoing access to the expertise of a dietitian.

A high-fiber diet has been suggested to be useful for relief of abdominal pain in IBS, particularly for mild to moderate constipation-predominant IBS. This contrasts with the lack of efficacy for treatment of functional constipation. However, this finding has been inconsistent, likely given the different types and amounts of fiber used across studies and the heterogeneity of IBS presentations. It does appear that soluble fiber is more effective than insoluble fiber (Table 16.3). It is important to ensure patients are meeting maintenance fluid requirements when on a high-fiber diet. A gradual increase in soluble fiber is prudent to avoid increased distention, bloating, and pain.

Nutrition Monitoring and Evaluation

Patients with GI diseases require nutrition reassessment to ensure adequate nutrient intake and adequate growth. Serial measurements of growth are essential in ensuring that a patient is meeting her growth potential (Table 16.20).

This chapter has highlighted that an increasing number of specialized elimination diets are used in the management of GI diseases. A number of macronutrient and micronutrient concerns may arise and compromise the child's growth, pubertal development, and nutrition status. Children in many Western countries have poor diet quality, in part due to the widespread availability of

TABLE 16.20
ADIME for Gastrointestinal Diseases

- Assessment
  - Growth assessment
  - Nutrition-focused physical exam
  - Nutrient Intake
    - At risk of micronutrient deficiencies when following elimination diets
  - Labs
    - Consider laboratory measurement of specific micronutrients when deficiency is suspected
  - Gastrointestinal Findings
    - Gastroesophageal reflux disease: Tables 16.1 and 16.2
    - Celiac disease: Table 16.8
    - Inflammatory bowel disease: Table 16.12
  - Medications/side effects
- Diagnosis
- Intervention
  - Nutrition prescription
  - Common nutrition interventions
    - Education
      - Dietary fiber: Table 16.3
      - Low-lactose diet: Table 16.4
      - Low-fructose diet: Table 16.5
      - Low-sucrose, isomaltose diets: Tables 16.6 and 16.7
      - Gluten-free diet: Table 16.10
      - Low-FODMAP diet: Table 16.11
      - Crohn's disease: Tables 16.13 and 16.14
      - Eosinophilic esophagitis: See Chapter 15 and Table 16.18
- Monitoring and evaluation

processed foods. Poor diet quality and Western dietary patterns may be a factor in the development of some of the luminal disorders discussed in this chapter, notably constipation, IBS and IBD. The impact of any prescribed dietary intervention on nutrition status, nutrient intake and overall diet quality should be monitored over time in children and appropriate adjustments made to prevent adverse outcomes. Finally, it should be noted that new onset of IgE-mediated allergy has been an unexpected adverse outcome of protein elimination diets, consistent with our evolving understanding of the role of food exposure in determining tolerance. For all these reasons, elimination diets should be used with caution and under appropriate medical supervision, including the specialized nutrition expertise provided by a registered dietitian.

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17 Intestinal Failure

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CONTENTS

Intestinal failure is often defined as the reduction of functional intestine below the minimal amount necessary for digestion and absorption to adequately satisfy nutrient and fluid requirements. It is an umbrella term that can be used to describe anatomical causes, functional etiologies, or a combination of both. The most commonly recognized causes of pediatric intestinal failure – necrotizing enterocolitis, gastroschisis, malrotation/midgut volvulus, and congenital intestinal atresias (Chapter 4) – necessitate surgical resection and lead to a subtype termed short bowel syndrome. In addition to short bowel syndrome, there are many other etiologies that lead to intestinal failure such as intestinal aganglionosis, pseudo-obstruction syndromes, and congenital enteropathies. Intestinal failure may be classified as acute (type 1), prolonged acute (type 2), and chronic (type 3) – with the latter used to describe patients requiring intravenous supplementation for months to years. The North American Society for Pediatric Gastroenterology, Hepatology and Nutrition (NASPGHAN) recommends a definition of intestinal failure as the need for parenteral nutrition (PN) for >60 days due to intestinal disease, dysfunction, or resection. Specific criteria for intestinal failure are lacking,

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with varied case definitions complicating efforts to determine even the simplest demographics such as the incidence of intestinal failure.

Manifestations of intestinal failure include inadequate nutrient absorption resulting from impaired gut function, intestinal dysmotility, and bacterial overgrowth as well as consequences of prolonged PN such as intestinal failure-associated liver disease, central line-associated bloodstream infections, and loss of vascular access. New innovations such as the use of alternative lipid emulsions, medications, and bowel reconstructive surgeries have transformed the field of intestinal rehabilitation. For patients with irreversible intestinal failure, intestinal transplantation remains a possibility.

INTESTINAL ADAPTATION

The concept of intestinal adaptation is used to describe the process of structural and functional change that allows the remaining intestine to increase its absorptive capacity. Grossly, bowel lengthening and dilatation increase the mucosal surface area, while histologically this compensatory process is marked by increased villous height and crypt depth. Children, particularly neonates and especially preterm infants, are aided by the fact that the normal process of growth also helps facilitate intestinal growth and adaptation; this feature is absent in adults.

The goal of intestinal failure management is to facilitate the provision of adequate nutrition and hydration while minimizing the risk of complications/death and promoting adaptation. The ultimate aim is to achieve independence from PN and attain enteral autonomy and ideally, oral autonomy. Factors associated with higher likelihood of attaining enteral autonomy include longer residual small bowel, younger age at the time of intestinal resection, preservation of the ileocecal valve (ICV), underlying diagnosis of necrotizing enterocolitis, absence of severe liver disease, and normal gastrointestinal motility.

The Role of Nutrition in Management of Intestinal Failure

Nutritional therapies are the mainstay of treatment for pediatric intestinal failure. PN is largely supportive and provides substrates to meet fluid, electrolyte, and nutritional requirements and facilitate growth. Individualized PN to meet the patient's fluid, electrolyte, energy, macronutrient, and micronutrient requirements is vital. Enteral nutrition (EN) is supportive but also therapeutic. Until the recent introduction of glucagon-like peptide-2 (GLP-2) analogs, EN was the only known therapy that directly influenced intestinal adaptation.

NON-NUTRITIONAL MANAGEMENT OF INTESTINAL FAILURE

The importance of approaching the management of intestinal failure with a multidisciplinary team cannot be overstated. Formal intestinal failure programs greatly improve the quality of care provided to patients and reduce the morbidity and mortality associated with this condition. Ideally, the treatment team should include a registered dietitian, a nutrition support nurse skilled in the evaluation of central venous access, a pharmacist, a pediatric surgeon, a gastroenterologist specialized in nutrition, and a social worker.

Medical Interventions

There are multiple pharmaceutical therapies used in pediatric intestinal failure management. These therapies are used supportively and oftentimes empirically to normalize bowel function during adaptation (Table 17.1). Antacid therapies such as H2 receptor antagonists and proton pump

TABLE 17.1
Medical Therapies for Pediatric Intestinal Failure

Class and Examples	Uses
Antisecretory Agents	
Histamine-2 (H2) receptor antagonists	Reduce hyperacidity after massive resection
Proton pump inhibitors	Reduce hyperacidity after massive resection
Octreotide	Reduces intestinal secretion, anti-motility
Clonidine	Reduces intestinal secretion
Motility Agents	
Erythromycin, clarithromycin	Improve gastric emptying, prokinetic
Amoxicillin-clavulanic acid	Increases small bowel motility; prokinetic
Loperamide	Anti-motility agent
Diphenoxylate/atropine	Anti-motility agent
Tincture of opium	Anti-motility agent
Adjunctive Absorptive Agents	
Pancreatic enzyme replacement therapy	For exocrine pancreatic insufficiency
Bile Acid Sequestrants	
Cholestyramine	For bile salt malabsorption after terminal ileal resection
Appetite Stimulants	
Cyproheptadine	Increases gastric accommodation/appetite stimulant
Megestrol acetate	Appetite stimulant
Antibiotics	
Metronidazole, ciprofloxacin, neomycin, rifaximin, amoxicillin-clavulanic acid, others	For small intestinal bacterial overgrowth
Growth Factors	
Teduglutide	Induces intestinal adaptation

Source: Adapted from Duggan CP, Jaksic T. Pediatric Intestinal Failure. *N Engl J Med.* 2017;377:666–675.

inhibitors are used to counteract the gastric hypersecretion that occurs early following massive bowel resection. Motility agents are used to either slow motility (loperamide, diphenoxylate) when diarrhea is present or increase motility (erythromycin, amoxicillin-clavulanate) when slow motility is an issue. Bile acid sequestrants can be used when bile acid reabsorption is affected with terminal ileum resection. Pancreatic enzymes can be used when fat malabsorption is suspected. Small intestinal bacterial overgrowth (SIBO) is thought to be common in patients with short bowel syndrome, and broad-spectrum antibiotics are often used for empiric treatment of SIBO. All of these therapies are used both before and after intestinal transplantation.

GLP-2 is an endogenous gastrointestinal hormone secreted in the distal ileum and colon, inducing small bowel intestinal proliferation. Exogenous administration of the GLP-2 analog, teduglutide, induces intestinal adaptation and is currently the only FDA-approved hormonal therapy that specifically promotes intestinal adaptation. Teduglutide improves water and nutrient absorption by increasing villous height and crypt depth, thus promoting intestinal adaptation. Given the improvement in water and nutrient absorption, the dietitian needs to closely monitor fluid status and growth and adjust the nutrition intervention accordingly.

Surgical Interventions

A main priority of surgical management in intestinal failure is the maximal preservation of intestine, particularly small bowel. Intestinal sparing during the initial procedure by salvaging all viable intestine is key to optimizing long-term outcomes. However, inclusion of compromised bowel can also be a source of poor bowel function. Re-establishing bowel continuity through ostomy reversal is associated with improved enteral tolerance and a decreased risk of liver disease. A gastrostomy or gastrojejunostomy tube is often used to support EN. Surgical approaches to intestinal reconstruction such as serial transverse enteroplasty (STEP) and Bianchi lengthening procedures aim to increase the mucosal surface area available to enhance nutrient absorption, improve motility, and limit bacterial overgrowth. Lastly, intestinal transplantation may be offered to patients with little to no chance of enteral autonomy, recurrent or life-threatening catheter-related blood stream infections, loss of venous access, or severe intestinal failure-associated liver disease. Transplantation offers an alternative to lifelong dependence on PN, but is fraught with its own challenges including that of long-term graft survival.

Expected Clinical Course

Although once considered a fatal condition, the natural history of intestinal failure has improved dramatically over the last few decades. Enteral autonomy often requires years to achieve. Home PN and intestinal transplantation are the main treatment options for irreversible intestinal failure. Children with intestinal failure who require prolonged PN can incur significant morbidity and mortality. Complications include intestinal failure-associated liver disease (IFALD), catheter-related blood stream infections, central line thrombus, and loss of vascular access. These are the indications which lead to intestinal transplantation.

NUTRITION MANAGEMENT OF INTESTINAL FAILURE

There are two main goals of nutrition management: (1) supportive – supply adequate nutrients, electrolytes, vitamins, and minerals as needed to maintain fluid and electrolyte homeostasis, prevent deficiencies, and achieve growth, and (2) therapeutic – provide substrate to the intestinal lumen to promote intestinal health and adaptation. Further complexity arises as nutrition support therapy must be adjusted to prevent complications such as oral aversion, excessive stool losses, and IFALD. The key to approaching nutritional success is to adequately assess the patient with intestinal failure, diagnose specific needs, and then apply the appropriate nutrition interventions.

Nutrition Assessment

Anatomical Considerations

Assessment of a patient's nutrition status first requires a thorough understanding of individual anatomy, especially with short bowel syndrome. Different parts of the gastrointestinal tract are responsible for the absorption of specific nutrients. A longer residual bowel length is generally associated with a greater ability to undergo sufficient intestinal adaptation leading to enteral autonomy. An estimate of the length of remaining bowel is the critical factor in assessment. As total bowel length differs based on patient age/size, expressing remaining bowel length as a percentage of total bowel length can often be useful.

A patient with short bowel syndrome may be at risk for nutrient deficiencies based on which segments of the bowel have undergone resection. Fortunately, most micronutrients (vitamins and minerals) are absorbed along a gradient throughout the length of the gastrointestinal tract. This allows for some redundancy when there is resection of specific segments. A notable exception is iron absorption, occurring primarily in the duodenum, a segment rarely resected but oftentimes not

TABLE 17.2
Sites of Nutrient Absorption

Anatomical Site	Nutrient
Duodenum	• Iron, folate
Proximal Jejunum	• Carbohydrate, protein
	• Folate, water-soluble vitamins
	• Calcium, phosphorus, magnesium
	• Zinc, copper
Distal Jejunum	• Carbohydrate, protein
	• Water-soluble vitamins
	• Calcium, magnesium
Ileum	• Vitamin B_{12}
	• Fat-soluble vitamins (A, D, E, K)
	• Bile salts
	• Fatty acids
Colon	• Fluids and electrolytes (especially sodium)
	• Short-chain fatty acids

utilized when enteral feeds are not possible. Most micronutrient absorption occurs in the jejunum with differential absorption occurring in proximal segments compared to distal segments. Ileal resection requires particular attention to the absorption of vitamin B_{12}, fat-soluble vitamins, bile salts, and fatty acids. The presence or absence of the ICV is of importance. Loss of the ICV often results in decreased intestinal transit time and may contribute to SIBO, further affecting nutrient absorption. The colon is responsible for reabsorption of fluids and electrolytes, especially sodium. Starches are converted to short-chain fatty acids (SCFA) in the colon, allowing for enteral salvage and may play a greater role as a means for supplying energy than previously thought. A summary of these anatomic considerations can be found in Table 17.2. Lastly, it is important to consider the location and type of stomas, as feeding/re-feeding a distal mucous fistula is gaining popularity as a way to increase the intestinal contribution of energy provision and to prepare the epithelium for re-establishment of continuity.

The anatomy of a child after intestinal transplantation affects the approach to EN. While most transplant patients attain enteral autonomy without the need for PN, their nutrition status must also be closely monitored as nutritional deficiencies such as those of zinc, copper, and iron can occur.

Anthropometric Measurements

Careful assessment of growth is an essential component of the nutrition management of patients with intestinal failure. Energy delivery is controlled "artificially" when nutrition is delivered parenterally and care must be given not to over- or under-nourish. This makes the longitudinal monitoring of anthropometric data on appropriate age- and sex-specific growth curves critical to assessing progress. Longitudinal growth tracking can help to differentiate malnutrition due to energy deprivation from other causes of growth failure.

Nutrition-Focused Physical Examination

A thorough physical exam is an important part of the nutrition assessment. A Nutrition-Focused Physical Exam (NFPE) includes careful global assessment of patient attributes as they pertain to nutritional status. The correlation of physical exam findings with nutritional deficiency is described in Chapter 2. Potential micronutrients that may be deficient in patients with intestinal failure include iron, zinc, copper, vitamin C, protein, and essential fatty acids. Due to the nature of intestinal failure and the push for enteral autonomy, these deficiencies can be found in greater frequency and in

combination. Assessment for sarcopenia has garnered increased interest in the field of intestinal failure and transplant recently, though its relationship to outcomes is still unknown.

Laboratory Evaluation

Patients with intestinal failure require regular monitoring of labs to assess electrolytes, micronutrients, vitamins, minerals, and trace elements (Chapter 9). Trace elements should be included in routine monitoring, as current trace element preparations are imperfect with chronically administered PN. Urinary markers can also be valuable in assessment. For example, total body sodium deficit can correlate with poor growth in patients with ostomies. Low urine sodium levels may indicate a total body sodium deficit despite normal serum sodium values. While 24-hour collections are more accurate, a random urine sodium level is often used as a surrogate marker. In addition to monitoring micronutrient labs for patients on PN, patients with intestinal failure should also have periodic laboratory monitoring after weaning from PN. After weaning, all micronutrients are administered orally or enterally and these patients are at high risk of micronutrient deficiencies.

Intake/Output Assessment

The importance of a thorough evaluation of intake and output cannot be overstated. Intake includes assessment of oral intake, EN, and PN. Output includes stool output (ostomy, if applicable), vomiting, and gastrostomy tube output. While "normal" ostomy output varies considerably in individual patients, a "rule of thumb" is 30 mL/kg per day. Optimizing EN while maintaining appropriate fluid balance is a priority.

Nutrition Diagnosis

Based on the results of the nutritional assessment, specific nutrition diagnoses are assigned to the patient to guide interventions. Common nutrition diagnoses that can be considered include:

- Altered gastrointestinal function
- Inadequate enteral nutrition infusion
- Inadequate parenteral nutrition infusion
- Inadequate fluid intake
- Increased nutrient needs
- Inadequate protein-energy intake (related to malabsorption)
- Impaired nutrient utilization
- Underweight

Other diagnoses are also used based on specific aspect of nutrition being addressed.

Nutrition Intervention

Nutrition Prescription

Patients with intestinal failure have increased nutrient and fluid requirements due to poor absorption. Daily EN/oral feeding goals for infants are 100–140 kcal/kg and 150–200 mL fluid/kg. Older children may also have increased nutrient and fluid needs due to poor absorption. Consistent assessment of EN tolerance and growth are essential to ensuring adequate nutrient intake for patients with intestinal failure. PN nutrient requirements are less likely to be increased as the gastrointestinal tract is bypassed, thereby avoiding the thermic effect of food, in patients receiving their nutrition solely from PN. However, PN fluid requirements may still be increased due to high output. See Chapter 9 for nutrient requirements for patients receiving PN.

Enteral Nutrition

Initiation of Enteral Nutrition

Providing EN is a priority in patients undergoing intestinal rehabilitation as it not only provides nutrition, but also stimulates intestinal growth and adaptation. Prompt initiation of EN as soon as appropriate following bowel resection surgery is encouraged. The deprivation of EN (also known as "gut rest") following surgical intervention likely contributes to intestinal mucosal atrophy. Even minimal, or trophic, feeds are encouraged to maintain mucosal health.

Type of Formula

Human milk is considered the gold standard in infant nutrition (Chapter 5). Despite a lack of clear data in short bowel syndrome, consensus surrounding the use of human milk has grown. Limitations of using human milk, especially donor human milk, include lower levels of protein and non-uniform energy density. Additionally, as most infants with intestinal failure have closely regulated fluid goals, human milk is typically expressed and given at prescriptive volumes.

If human milk is unavailable, there are several types of infant formulas to choose from (Chapter 5). Many centers use elemental formula based on the simplified components and ease of absorption. Others will use hydrolysate formulas based on the enteral workload theory that suggests adaptation is greater when the intestinal epithelium is more active in digestion. Age-appropriate formulas are used after infancy for nutritional supplementation as they offer more efficient energy delivery. The choice of "the best" formula after human milk remains unanswered and in the end depends mostly on how well a child tolerates a specific formula.

Long-chain triglycerides (LCTs) are of special consideration as they are a major trophic factor for intestinal adaptation, but require micelle formation and are not absorbed well in the small intestine. The optimal fat source to facilitate optimal absorption in patients who have undergone significant intestinal resection may be a combination of medium-chain triglycerides (MCTs, which do not require micelle formation) and LCTs. Patients without a colon tolerate diets that are high in fat (30%–40% of total energy intake). Those with an intact colon may experience steatorrhea and magnesium/calcium loss with high-fat intake due to the process of saponification. Saponification occurs when the unabsorbed fat combines with calcium and/or magnesium to form soaps. The soaps prevent these ions from interacting with oxalate as they would in normal individuals. This, in turn, enhances oxalate absorption in the colon and needs excretion by the kidneys, increasing risk for oxalate renal stone formation. It may be necessary to restrict oxalate intake or provide calcium supplements to reduce the risk of oxalate renal stone formation.

Patients 1 year of age and older typically transition to pediatric enteral formulas. During this transition, it is important to consider the current enteral formula, reasons for selecting this formula, and future nutrient needs. Patients on elemental infant formulas typically transition to elemental pediatric formulas. For patients without a milk allergy, a standard pediatric toddler formula or a pediatric formula with high-MCT content may be considered (Chapter 8).

The role of food-based formulas is also currently being evaluated. They may allow for more uniform emptying of the stomach, thereby preventing rapid emptying or "dumping". They often thicken stool due to their high fiber content. These formulas can be beneficial, especially when oral feeds are unable to be successfully advanced due to high stool output. Finally, they may enhance adaptation by increasing enteral workload. A complete nutrition assessment should be completed before prescribing food-based formulas to patients with intestinal failure. Close monitoring is required to ensure adequate absorption and intake of key nutrients, including protein (Chapter 8).

Mode of Feeding

EN is given as continuous feeds, intermittent bolus feeds, or a combination of the two. The advantages of continuous feeds include improved enteral absorption as carrier proteins are maximally saturated,

thereby optimizing intestinal function. Slow continuous administration of EN reduces the risk of osmotic diarrhea when compared with bolus delivery. Continuous feeds require secure enteral access such as a gastrostomy tube. As some patients have delayed gastric emptying, evaluating the ability to tolerate gastric feeds can be achieved via a nasogastric tube prior to placement of a longer-term gastric feeding tube. If nasogastric feeds are poorly tolerated, a post-pyloric feeding tube allows for feeding past the stomach, into the jejunum. In patients with a very short amount of small bowel, jejunal feeds may be disadvantageous as the amount of remaining bowel for absorption may be minimal.

The advantages of bolus feeds include lifestyle benefits as patients are not required to be attached to a feeding pump and feeds can be aligned with mealtimes allowing for improved family functioning. Bolus feeds also more closely resemble oral feeding, including physiologic hormonal regulation. However, bolus feeds must be administered to the stomach and this may not be well-tolerated and lead to either distention or dumping. An approach employing a combination of bolus and continuous feedings (e.g., continuous feeding at night and bolus feeding during the day) is often chosen to utilize the benefits of both. Regardless of the mode of feeding, as the volume of EN is increased, nutrients provided from PN should be decreased.

Advancement of Enteral Nutrition

After initiating EN, volumes should be advanced by small amounts, allowing the bowel to gradually adapt to progressively larger volumes. The advancement of EN is based on a multitude of clinical factors including the consistency and amount of stool/ostomy output, vomiting, abdominal distension, irritability, and the presence of skin breakdown. When feeding intolerance is encountered, the feeds should be reduced rather than discontinued. Unless there is concern for systemic illness or sepsis, the practice of starting and stopping feeds limits intestinal adaptation by enteral stimulation and complicates the assessment of how much is tolerated enterally. Concrete evidence-based guidelines for advancement are lacking, but generally speaking, stool output >40 mL/kg body weight per day is a relative contraindication to advancing EN as is an increase in stool output by >50%. EN should be advanced cautiously if daily stool output is between 30 and 40 mL/kg body weight. Some guidelines have more conservative thresholds for holding feed advancement for lower stool outputs. See Table 17.3 for guidelines on advancing EN.

Role of Fiber

Patients with intestinal failure often benefit from dietary fiber supplementation. Soluble fiber slows gastric emptying and decreases intestinal transit time, thereby reducing diarrhea and allowing more time for absorption. It is fermented by colonic bacteria, creating SCFA that may be utilized for energy salvage by colonocytes. SCFA, by nature of their absorption, stimulate the re-uptake of sodium and water in the colon, thereby decreasing fluid loss and resulting in improved tolerance of EN in patients with an intact colon. Fiber should be considered, especially when feeding advancement is hindered by increased stool losses. Pectin, pureed green beans, and guar gum are all sources of soluble fiber.

Oral Feeding

Oral feeding is often neglected early in the treatment of a critically ill child such as one who has undergone massive intestinal resection. Delayed oral stimulation can lead to oral aversion. When medically and developmentally appropriate, promoting oral feeding, even with small volumes, should be a priority. In neonates with short bowel syndrome, oral feedings are typically not started until the patient is tolerating full continuous EN. However, feeding therapy should be started as soon as possible. The transition from continuous feedings may be initiated by holding tube feeds for 1 hour and offering the equivalent volume orally by bottle. Initially this may be trialed once or twice per day, then gradually increased in frequency, if tolerated well. See Table 17.3 for additional guidelines on advancing oral feedings.

TABLE 17.3
Guidelines for Enteral and Oral Feeding Advancement in Infants with Intestinal Failure

Feeding Advancement Principles

- Quantify feeding intolerance by stool or ostomy output
- Assess tolerance no more than twice per 24-hour period. Advance no more than once per 24-hour period
- Ultimate daily goals: 150–200 mL/kg and 100–140 kcal/kg
- If stool/ostomy output precludes advancement of 20 kcal/oz for 7 days, then increasing energy density of the formula can be performed
- As feeds are advanced, PN should be reduced such that weight gain velocity is maintained

Guidelines for Feeding Advancement:

Stool output:

- If <10 mL/kg per day or <10 stools/day, advance rate of feeds by 10–20 mL/kg/day
- If 10–20 mL/kg per day or 10–12 stools/day, no change
- If >20 mL/kg per day or >12 stools/day, reduce rate or hold feeds[a]

Ostomy output:

- If <2 mL/kg per hour, advance rate by 10–20 mL/kg/day
- If 2–3 mL/kg per hour, no change
- If >3 mL/kg per hour, reduce rate or hold feeds[a]

Stool reducing substances:

- If <1%, advance feeds per stool or ostomy output
- If 1%, no change
- If >1%, reduce rate or hold feeds[a]

Signs of dehydration:

- If absent, advance feeds per stool or ostomy output
- If present, reduce rate of hold feeds[a]

Gastric aspirates:

- Less than four times previous hour's infusion, advance feeds
- Greater than four times pervious hour's infusion, reduce rate or hold feeds[a]

Oral feeds may be offered as follows:

1. Infant is developmentally able to feed by mouth (PO)
2. One hour's worth of continuous feeds may be offered PO 2–3 times daily after 5 days of continuous feeds. During this time, tube feeds should be held
3. More than 1 hour worth of continuous feeds may be offered PO once the infant has reached full volume of feeds by continuous route and is demonstrating weight gain and at least 7 days have passed on the feeding advancement protocol

Source: Reprinted from Gosselin KB, Duggan C. Enteral nutrition in the management of pediatric intestinal failure. *J Pediatr*. 2014;165:1085–1090, with permission from Elsevier.

[a] Feeds should generally be held for 8 hours, then restarted at 75% of the previous rate. Supplemental IV fluids may be needed.

The advantages of encouraging oral feeding stretch beyond the provision of nutrition. When deemed safe, oral feeding stimulates oral-motor development and allows the child to foster feeding skills that might otherwise be lost or significantly delayed. Even small amounts of oral feeds that do not provide appreciable nutritional value may be invaluable in the prevention of oral aversion. For these reasons, the timely introduction of solids at the same developmental age as healthy infants is encouraged. The most appropriate solid foods are dependent on age, type of bowel resection, remaining function bowel length, and general health. Feeding therapy with speech/occupational therapists may be required to help establish motor skills.

The "short-gut diet" that is often encouraged is one that is low in simple sugars including juices and fruits. Patients with intestinal failure often tolerate complex carbohydrates better than

simple sugars. Further, they are at risk for SIBO, highlighting the importance of limiting dietary carbohydrates.

One disadvantage of oral feeding is intestinal failure-induced hyperphagia, characterized by over-eating. Hyperphagia can lead to overcoming the absorptive ability of the intestine and cause a largely osmotic diarrhea.

Parenteral Nutrition

Initial Management

PN is a mainstay of supportive nutritional therapy in intestinal failure. In the case of surgical causes of short bowel syndrome, in the immediate post-operative phase focus is on active fluid resuscitation/management. This period may be associated with high gastric output followed by excessive ostomy output, necessitating fluid resuscitation. Once fluid needs are more clearly determined, full PN is started and advanced accordingly. Fluid management involves providing maintenance fluid volumes in addition to fluid replacement based on careful measurement of fluid losses. Oftentimes, PN is started and advanced at a maintenance rate with supplemental intravenous fluids given simultaneously to account for variable losses. Over time, as fluid status stabilizes, these fluids can be discontinued or added in to the total volume of PN.

Macronutrient Considerations

General macronutrient recommendations for PN are described in Chapter 9. Lipid injectable emulsions (ILE) provide a very efficient source of energy for growth. Although excesses in any of the macronutrients have been implicated in liver injury, ILE in chronic PN administration have become the focus in the development of cholestasis and subsequent end-stage liver disease. Many chronic PN protocols are designed specifically to protect the liver using lipid-reduction strategies. Patients receiving the traditional soy-based ILE for long periods are at particularly high risk for developing cholestasis, a hallmark of IFALD. Alternative ILE (fish oil-based or a combination of soy, MCT, olive, and fish oil) and lipid minimization strategies have emerged to reduce the risk of developing IFALD. The safety and long-term efficacy of various lipid strategies with regard to growth, neurodevelopmental outcomes, and the development of IFALD are an active area of investigation.

Micronutrient Considerations

General PN micronutrient considerations are described in Chapter 9. Children with intestinal failure are prone to micronutrient deficiencies. Therefore, it is important to ensure adequate amounts of vitamins and minerals are being provided. Combination multivitamin additives are available based on age and weight and for the most part provide adequate supplementation. Potential exceptions to this rule are fat-soluble vitamins which sometimes have to be replaced enterally (vitamins A, D, and E). Vitamin K may be given as a separate additive, especially when there is an increased bleeding risk as occurs in end-stage liver disease. Multiple trace element products are also available based on age and weight, but may not meet the needs of the individual patient. When needed, individual minerals such as zinc, copper, manganese, chromium, and selenium may be dosed separately and added to a patient's PN recipe, based on serum levels. Iron is not included in PN formulations and can be supplemented orally or with routine iron infusions. Iodine and fluoride are also not available for administration in PN formulations and should be given orally if possible, especially if a patient is not receiving EN or oral nutrition. Patients with intestinal failure continue to remain at risk for nutrient deficiencies following the transition to full EN.

Cycling Parenteral Nutrition

Initially, PN is administered continuously over 24 hours. As fluid status equilibrates and EN is started, cycling of PN is often attempted. Cycling denotes a reduction in the total duration of PN, often with a "ramping up" and "ramping down" period so as to minimize reactive or rebound

hypoglycemia. Young patients and patients with a high glucose infusion rate are particularly prone to develop rebound hypoglycemia if PN is abruptly discontinued as insulin levels are dependent upon the amount of glucose being infused. The number of hours over which PN is given may be decreased gradually until a target duration is reached. The benefits of cycling PN have both physiologic and psychologic advantages. Giving patients a duration of time during which they are off of PN allows them freedom from the infusion pump temporarily. It also allows time for "metabolic rest" and may be associated with a decreased risk of IFALD. Close monitoring during the transition to cycled PN is crucial. Hyperglycemia during infusions due to a high glucose infusion rate or edema and other signs of fluid imbalance necessitates a more cautious approach to cyclic infusion.

Weaning Parenteral Nutrition

A major goal in the management of children with reversible intestinal failure is the weaning of PN and establishment of enteral tolerance. In patients with short bowel syndrome, as the remaining bowel gradually adapts, the amount of enterally administered nutrients is increased. PN should be decreased if EN volumes are well-tolerated (e.g., minimal vomiting, appropriate stool volumes), provided that weight gain is appropriate. It is important to recognize that enteral absorption may not be as efficient and increased energy provision may be necessary. If early re-establishment of intestinal continuity is possible, optimization of growth with PN may be preferred over advancement of EN until after surgical reconnection is completed. Frequent laboratory monitoring of fluids, electrolytes, and micronutrients is recommended during the transition from PN to full EN.

Complications of Parenteral Nutrition

General complications of pediatric PN are described in Chapter 9. Chronic PN increases the risks of long-term complications. The development of these complications is often the driving force and indication for evaluation of small bowel transplantation. When complications develop, early referral to a transplant center is preferred to prevent the potential need for a combined liver-small bowel transplant or transplantation in a critically ill child. Loss of central venous access is a particularly ominous complication as complete loss of access can be considered a contraindication for transplantation.

Other Complications of Intestinal Failure

In addition to complications specifically related to PN administration, children with intestinal failure are subject to other complications as well. Contributing factors for IFALD, other than PN, include bloodstream infections and gallbladder disease. SIBO is often the result of altered motility and can be an issue in intestinal transplant as well as intestinal failure. Symptoms include increased diarrhea, vomiting, excessive gas, as well as D-lactic acidosis. In SIBO, excessive numbers of small bowel bacteria produce negative consequences. The diagnosis is usually made clinically based on symptoms, although hydrogen breath tests or small bowel aspirates can be obtained as confirmatory testing.

Patients with extremely short bowel and an intact colon who have been advanced to full diets are prone to D-lactic acidosis. This is due to the inability to absorb carbohydrates, providing substrate to colonic bacteria that convert these substrates into D-lactic acid. Renal abnormalities such as nephrocalcinosis and nephrolithiasis can develop in intestinal failure. The neurodevelopmental outcomes of long-term survivors of intestinal failure and transplantation are also an active area of research in this population.

Nutrition Education

Caring for a child with intestinal failure often comes with significant physical, emotional, and financial burdens to patients and their families. Education for primary caregivers is crucial throughout the process of intestinal rehabilitation and nutritional management. Particularly if a child requires long-term or home PN, education should begin soon after this need becomes apparent. Appropriate

central line care is a critical aspect of preventing central line-associated blood stream infection (CLABSI). The use of antibiotic and ethanol lock therapy may be recommended in patients with recurrent CLABSIs. When developmentally appropriate, it is also crucial to provide patients with nutrition counseling such that they are empowered to make healthy decisions.

Specialty Referrals

Referrals for speech therapy, occupational therapy, and physical therapy should be considered. These referrals should be made early to optimize development in the early years. Early referral to feeding therapy is also recommended to those children at risk for feeding difficulties. Occupational therapists may additionally assist with optimizing feeding and mobility. They may be able to recommend backpacks designed for EN and PN pumps to allow for school participation and activities

TABLE 17.4
ADIME Summary for Patients with Intestinal Failure

- Assessment
  - Growth assessment
  - Nutrition-focused physical exam
    - Look for signs of deficiency: iron, zinc, copper, vitamin C, protein, essential fatty acids
  - Nutrient intake
  - Labs
    - See tables in Chapter 9
  - Gastrointestinal findings
    - Assess output (stool, gastrostomy tube, vomiting)
  - Medications/side effects
    - See Table 17.1
- Diagnosis
- Intervention
  - Nutrition prescription
    - Enteral/oral feeding goals for infants:
      - Calories: 100–140 kcal/kg
      - Fluid: 150–200 mL/kg
  - Common nutrition interventions
    - Oral
      - Provide small volume oral feedings to prevent oral aversion
      - Limit simple carbohydrates
    - Enteral nutrition
      - See Table 17.3
    - Parenteral nutrition
      - Wean parenteral nutrition as enteral nutrition increases
      - Focus on preserving liver function
    - Laboratory monitoring
      - See Chapter 9
    - Supplements
      - Soluble fiber
      - Micronutrient supplements to correct deficiencies
    - Other specialty referrals
      - Multidisciplinary team including dietitian, gastroenterologist, surgeon, nurse, pharmacist, social work
      - Feeding therapy
- Monitoring and evaluation
    - Laboratory monitoring
    - Symptom monitoring

of daily living. Patients with suspected short stature should be referred to an endocrinologist for further evaluation.

Nutrition Monitoring and Evaluation

Lab Monitoring

Meticulous laboratory monitoring while on PN as well as during the transition to EN is crucial. Precise monitoring of electrolytes, micronutrients, minerals, and trace elements is key, especially in children dependent on PN. Urine sodium levels should be checked periodically as levels <25 mmol/L are associated with poor growth. Enteral sodium supplementation with sodium chloride or sodium citrate (if in addition, bicarbonate levels are <20 mEq/L) may be needed. Chapter 9 provides guidelines on laboratory monitoring of patients on PN including recommended intervals. Even after successful weaning off PN and achievement of enteral autonomy, labs should be monitored periodically to screen for essential micronutrient deficiencies.

Symptom Monitoring

In patients with intestinal failure, nutritional management is often based on the presence or absence of symptoms such as increased stool or G-tube output, abdominal distension, and perianal skin breakdown. These symptoms may indicate feeding intolerance, although other causes such as SIBO should be considered (Table 17.4).

Medical nutrition therapy is an important part of the treatment plan for patients with intestinal failure. PN is a supportive therapy, providing macronutrients, micronutrients, and fluids needed to meet nutrient needs and support growth. EN is supportive but also therapeutic, as it promotes intestinal adaptation. Nutrition intervention is an important part of intestinal rehabilitation, and the dietitian is an essential part of the multidisciplinary team caring for patients with intestinal failure.

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18 Chronic Liver Disease

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CONTENTS

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The liver is a complex organ with several critical nutrition functions. It plays a role in the metabolism of all the macronutrients. It stores glucose as glycogen for future use in the fasting state and synthesizes the majority of the proteins in the body. The liver also produces bile which is necessary for the breakdown and absorption of long-chain fats and fat-soluble vitamins. It also stores vitamins A, E, K, and B_{12} and has a role in the conversion of vitamin D to its active form. Children with chronic liver disease may have impairments in these vital functions, with clinically apparent impact on their nutrition status. Furthermore, for children who require liver transplantation, optimizing pre-transplant nutrition may reduce transplant complications and improve patient outcomes. This chapter reviews common liver diseases in children, the nutrition implications of these diseases, and common nutrition interventions utilized.

CHOLESTATIC LIVER DISEASES

Biliary Atresia

Biliary Atresia (BA) is a progressive inflammatory fibrotic process affecting the entire biliary tract which results in infantile cholestasis. Over time, impairment to bile flow results in biliary cirrhosis. BA is the most common cause of obstructive jaundice in infants. If untreated, BA is uniformly fatal by 2 years of age due to complications of end-stage liver disease. Table 18.1 outlines common definitions used in patients with pediatric liver disease.

BA presents with neonatal cholestasis and evidence of biliary obstruction, namely jaundice and acholic (pale or clay-colored) stools. The treatment for BA is a Kasai hepatoportoenterostomy (HPE), which attempts to restore bile flow. The Kasai HPE successfully re-establishes long-term bile flow in approximately one-third of patients. Early diagnosis of BA is essential, as infants <30–45 days of age at the time of Kasai HPE are more likely to have surgical success. Children with BA, even after the Kasai HPE, may have persistent cholestasis and ongoing fibrosis. With

TABLE 18.1
Definitions of Liver Disease

Term	Definition
Jaundice	Yellowing of the skin secondary to elevated blood levels of bilirubin. Bilirubin is produced from the breakdown of red blood cells and is cleared by the liver and secreted into bile; elevated bilirubin can occur in a number of liver diseases
Cholestasis	A decrease in bile flow, either due to impaired secretion by hepatocytes or due to obstruction of bile ducts. Cholestasis is characterized by an elevated conjugated bilirubin and may manifest clinically with jaundice, itching, fat-soluble vitamin deficiency, and poor fat absorption
Cirrhosis	The end-stage of any chronic liver disease, defined by severe fibrosis (scarring) of the liver. Cirrhosis is a histologic diagnosis, characterized by diffuse hepatocyte injury, regenerative nodules, and bridging fibrosis
Hepato-splenomegaly	Enlarged liver and spleen. The term "organomegaly" may also be used to refer to an increased size of the liver and spleen
Portal hypertension	An increase in portal venous pressure; most commonly occurs secondary to cirrhosis but can also result from blood clots forming in the portal vein or hepatic veins, heart disease, or other rare causes which lead to abnormal blood flow through the liver. Portal hypertension can result in splenomegaly, ascites, and the formation of varices
Transaminases	Aspartate transaminase (AST) and alanine transaminase (ALT) are enzymes which function in the liver. Levels of these enzymes in the blood are typically elevated when there is liver inflammation or injury
Hepatic steatosis	Infiltration of fat into liver cells (hepatocytes)
Acute liver failure	Acute liver dysfunction characterized by vitamin K refractory coagulopathy (INR >2.0 or >1.5 *with* encephalopathy) occurring within 8 weeks after the onset of liver injury

progressive hepatic fibrosis, children often develop complications of portal hypertension, including splenomegaly, ascites, and variceal bleeding. Patients who develop complications of portal hypertension, or alternatively never achieve adequate bile flow, will require liver transplantation. BA is the leading indication for liver transplantation in childhood.

Alagille Syndrome

Alagille syndrome is caused by a mutation in either the *JAG1* (approximately 95% of cases) or *NOTCH2* gene (<5% of cases), with an estimated prevalence of 1 in 30,000–70,000 live births.

Patients with Alagille syndrome present with at least one of the following anomalies: characteristic facies, liver disease, cardiovascular defects, skeletal malformations, ocular anomalies, and renal anomalies. Liver disease results from abnormal development of the intrahepatic bile ducts and can cause severe pruritus (itching), xanthomata (cholesterol deposits in skin), and cholestasis.

Management of liver disease in Alagille syndrome focuses on supportive care, including managing cholestasis, portal hypertension, severe/intractable pruritus, disfiguring xanthomata, and growth failure. Approximately 20%–50% of children with Alagille syndrome who present with cholestasis will require liver transplantation.

Alpha-1-Antitrypsin Deficiency

Alpha-1-antitrypsin (A1AT) deficiency, the most common inherited cause of neonatal cholestasis, occurs due to an autosomal recessive mutation in the gene encoding the A1AT protein. The abnormal protein cannot be secreted from liver cells, and its accumulation causes hepatocyte death, inflammation, and fibrosis. A1AT deficiency occurs in approximately 1 in 5,000 people in the United States. Not all people with A1AT have liver disease; neonatal cholestasis occurs in 10%–15% of affected individuals and may be transient. Approximately 2.5% of affected children will develop cirrhosis in childhood. Patients can also present later in childhood or adulthood with cirrhosis-related complications, without a history of neonatal cholestasis. The management of A1AT deficiency focuses on supportive care of cholestasis and complications of cirrhosis. Liver transplantation may be required in the minority of patients who develop severe liver disease and portal hypertension.

Progressive Familial Intrahepatic Cholestasis

The term progressive familial intrahepatic cholestasis (PFIC) encompasses a group of rare genetic disorders characterized by abnormal bile synthesis or transport, leading to cholestasis. There are at least eight separate disorders classified as PFICs, several of which have been recently discovered and can be diagnosed by genetic testing. Treatment is supportive to manage complications of cholestasis, such as fat-soluble vitamin deficiency, pruritus, and growth failure. When medical management is inadequate, however, liver transplantation may be needed.

OTHER PEDIATRIC LIVER DISEASES

Autoimmune Liver Disease – Autoimmune Hepatitis and Primary Sclerosing Cholangitis

Autoimmune hepatitis (AIH) is a progressive, immune-mediated inflammatory condition of the liver. There is a wide spectrum of presentation for AIH, including asymptomatic transaminase elevation; elevated transaminases associated with malaise, fever, rash, arthritis, abdominal pain, and gradual onset of jaundice; acute liver failure; or end-stage liver disease with complications of cirrhosis such as ascites and gastrointestinal bleeding. AIH should be suspected in patients with elevated transaminases, elevated IgG, and positive autoantibodies, especially if there is a personal

or family history of autoimmunity. The diagnosis of AIH is confirmed by liver biopsy. AIH is treated with long-term immunosuppressive medications. Liver transplantation may be required in medication-refractory or clinically advanced disease.

Primary Sclerosing Cholangitis (PSC) is a condition driven by abnormal immune response, in which progressive inflammation and fibrosis of the intrahepatic and/or extrahepatic bile ducts lead to stricturing of the biliary tree and abnormal bile flow. Patients may present with pruritus, jaundice, abdominal pain, fatigue, weight loss, pale stools, or steatorrhea. Diagnosis of PSC requires the presence of characteristic biliary abnormalities on magnetic resonance imaging (MRI) or liver biopsy. Management of PSC is primarily supportive and affected individuals may require liver transplantation if complications of end-stage liver disease develop.

Cystic Fibrosis Liver Disease (CFLD)

Cystic fibrosis (CF) is a genetic disorder caused by a mutation in the cystic fibrosis transmembrane conductance regulator (CFTR) (Chapter 19). Dysfunction in this enzyme leads to abnormally thick secretions in the lungs (resulting in chronic pulmonary infections and injury), pancreas (resulting in pancreatic insufficiency), and bile ducts. There are varied hepatobiliary manifestations of CF, including neonatal cholestasis, gallbladder disease, mild transaminase elevation, steatosis, and very rarely, cirrhosis. While management of CF has historically been supportive, emerging therapies such as highly effective CFTR modulators are changing the overall outcomes of children with CF. The impact of these new therapies on liver disease is currently unknown. See Chapter 19 for more information on CF.

Glycogen Storage Disease

Glycogen storage disease (GSD) encompasses several enzymatic defects involved in the metabolism of carbohydrates. Hepatic forms of GSD (i.e., defects in enzymes located in the liver) cause severe fasting hypoglycemia, growth failure, and hepatomegaly. These include type I (glucose-6-phosphatase deficiency), type III (debranching enzyme deficiency), type VI (hepatic phosphorylase deficiency), and type IX (phosphorylase kinase deficiency). GSD type IV (branching enzyme deficiency) and some type IX can also present with hepatic cirrhosis. Treatment of GSD centers on prevention of hypoglycemia and the accumulation of secondary metabolites. See Chapter 23 for more information on GSD.

Wilson's Disease

Wilson's disease is an inherited copper-storage disease caused by a mutation in the *ATP7B* gene. The inability to adequately excrete copper leads to excessive copper accumulation in liver cells and deposition in other tissues, including the brain and eyes. Patients may present with an acute or chronic hepatitis, cirrhosis, or even acute liver failure (typically associated with renal failure and hemolysis). Neuropsychiatric symptoms can also occur due to copper deposition in the brain, including declining school performance, changes in mood, dysarthria (disturbance in speech), dysphagia (trouble swallowing), or tremor. Kaiser-Fleischer rings, which are brown bands located between the iris and cornea, may develop in the eyes. Without treatment, the liver and neurologic disease is progressive and life-threatening.

Fulminant Wilson's disease should be suspected in any patient over 3 years of age who presents with acute liver failure (ALF) associated with renal failure and hemolysis. Additionally, screening using ceruloplasmin should be performed in patients presenting with unexplained chronic liver disease, as there may be no other associated symptoms. The diagnosis is confirmed by genetic testing or significant copper deposition in the liver detected by biopsy. Medications to reduce copper absorption or to allow for copper chelation are used to treat Wilson's disease, along with dietary copper restriction.

Acute Liver Failure

ALF is characterized by acute liver dysfunction occurring within eight weeks after the onset of liver injury and accompanying hepatic encephalopathy. The common causes of ALF vary by age. In infants, viral and metabolic diseases are the most common causes. In older children and adolescents, viral infections are still an important consideration, as are autoimmune hepatitis, drug toxicity (e.g., acetaminophen), and Wilson's disease. The definitive cause of ALF is often not identified. Diagnosis and careful management of ALF require prevention of potentially fatal complications, including coagulopathy and bleeding, severe hypoglycemia, renal failure, and encephalopathy or coma, together with treatment of the underlying etiology, if identified. Early liver transplantation may be lifesaving in patients with progressive disease.

Non-Alcoholic Fatty Liver Disease

Concurrent with the obesity epidemic, non-alcoholic fatty liver disease (NAFLD) has become the most common chronic liver disease in children in the USA and one of the most frequent indications for liver transplantation in adults. The prevalence is estimated to be 25% of the worldwide population, and 29%–38% in obese children in North America. Prevalence varies by race/ethnicity and sex, with Hispanic males carrying the highest risk. Although the prevalence is higher in children with obesity, not all children with NAFLD are obese.

NAFLD can be divided based on histology into non-alcoholic fatty liver (NAFL), in which there is bland steatosis (without inflammation), and non-alcoholic steatohepatitis (NASH), characterized by steatosis *with* inflammation and hepatocyte injury. With time, the excessive fat accumulation and inflammation in the liver results in progressive scaring. In adults, 4% of patients with NAFL and 20% of patients with NASH will progress to cirrhosis, while the natural history of NAFLD is less clear in children. Serum alanine transaminase (ALT), a simple and inexpensive screening test for NAFLD, should be considered for children over 9 years of age who are obese or who are overweight with additional risk factors (central adiposity, insulin resistance, prediabetes or diabetes, dyslipidemia, sleep apnea, or a family history of NAFLD). Other chronic liver diseases should be excluded in patients with suspected NAFLD. Treatment of NALFD focuses on lifestyle modifications (Chapter 25).

NUTRITION MANAGEMENT

Nutrition Assessment

Assessing growth in infants and children with liver disease requires careful attention to growth charts, anthropometric measurements, and visual assessment. Caution should be exercised when interpreting weight gain in patients with liver disease, as weight may be falsely elevated due to ascites and/or organomegaly. Assessment of linear growth, and head circumference in infants, are also essential tools for assessing long-term nutrition status in this population, as they may plateau with malnutrition and as liver disease progresses. In addition to anthropometric measurements recommended for all pediatric patients (Chapter 1), these patients require mid-upper arm circumference (MUAC) and triceps skinfold thickness (TSFT) measurements at each visit. MUAC and TSFT are more accurate measurements of nutrition status in chronic liver disease than weight as they are less likely to be affected by fluid status and ascites. Serial measurements can help assess subtle changes in growth that may be missed by weight and length measurements. MUAC reflects lean body mass and adipose tissue, whereas TSFT measures subcutaneous fat, which correlates to total body fat. TSFT will change more rapidly with changes in nutrition status, such as fat loss with acute malnutrition and fat deposition with nutrition rehabilitation. For patients with obesity, extended-body mass index (BMI) growth charts should be used (Chapter 25).

Fat-Soluble Vitamin Deficiency

Fat-soluble vitamin deficiencies are common in children with cholestatic liver disease. A high degree of suspicion is required to detect fat-soluble vitamin deficiencies as they may be initially asymptomatic. Vigilance in detection, treatment, and monitoring can prevent clinical manifestations of fat-soluble vitamin deficiencies. Table 18.2 outlines recommendations for monitoring and supplementation of fat-soluble vitamins in patients with cholestatic liver disease.

Vitamin A deficiency can manifest as night blindness, xerophthalmia (dry eyes), Bitot spots (white plaques on the conjunctiva), and follicular hyperkeratosis (a rough, raised rash located on the extremities). Ideally, the serum retinol level and retinol to retinol-binding protein molar ratio (retinol:RBP) are used to assess vitamin A status. Serum retinol of <20 μg/dL with a molar ratio of <0.8 indicates vitamin A deficiency.

Vitamin D can cause hepatic osteodystrophy and lead to bone fractures. Rachitic rosary may also be noted on physical exam.

Vitamin E is an antioxidant that plays a role in the health of the nervous system, retina, and skeletal muscle. Vitamin E deficiency can lead to neurologic impairment, characterized by hyporeflexia, peripheral neuropathy, ataxia, and proximal muscle weakness. Vitamin E deficiency can be assessed by the serum vitamin E level. Vitamin E, however, circulates in lipoproteins, and as such can be falsely elevated in cholestasis. Therefore, ideally a vitamin E to total lipid ratio (α-tocopherol:total lipid) should be used in children with cholestasis to screen for deficiency, with a ratio of <0.6 mg/g in children <1 year of age and <0.8 mg/g in children >1 year of age indicating deficiency. Alternatively, an α-tocopherol:cholesterol ratio has been proposed, with a cutoff of <2.47 mg/g indicating deficiency.

Vitamin K activates a number of blood clotting factors and deficiency leads to coagulopathy, characterized by a prolonged INR. Coagulopathy due to vitamin K deficiency must be distinguished from that caused by synthetic liver dysfunction (i.e., inability of the liver to synthesize adequate clotting factors). This distinction can be determined based on response to intravenous or intramuscular vitamin K supplementation. Newborns are at particularly high risk for vitamin K deficiency due to poor in utero placental transport of vitamin K.

Specific Diagnoses and Effect on Nutrition

The malnutrition that occurs in children with chronic liver disease is multi-factorial. They often have inadequate enteral intake due to anorexia, nausea, vomiting, delayed gastric emptying, abdominal distention, organomegaly, and ascites. They experience altered nutrient metabolism with increased energy expenditure, limited glycogen stores, insulin resistance, and abnormal macronutrient oxidation. These physiologic states may be further compounded by malabsorption and maldigestion due to altered intraluminal bile acids, portal hypertensive enteropathy, and increased diarrheal losses.

Cholestasis

Bile plays a critical role in fat absorption, particularly of long-chain fatty acids, in the small intestine by promoting the emulsification of fat and formation of mixed micelles. In the presence of abnormal bile flow, mixed micelles are not formed, placing patients at risk for both fat and fat-soluble vitamin (A, D, E, and K) malabsorption.

Cirrhosis

Cirrhosis leads to a state of hypermetabolism, with affected children having higher energy needs than expected. Furthermore, due to the increased resistance to blood flow through the fibrotic liver, portal hypertension with progressive organomegaly and ascites develops. Organomegaly and fluid accumulation contribute to perceived weight gain, confounding measurements of weight and BMI or weight-for-length. Anthropometric measurements, including MUAC and TSFT, are critical to assess growth in this population. Sodium restriction is necessary to effectively manage ascites associated with portal hypertension. Limiting daily sodium intake to 2 mEq/kg can help control ascites.

TABLE 18.2
Fat-Soluble Vitamin Supplementation and Monitoring in Children with Cholestatic Liver Disease

Fat-Soluble Vitamin	Laboratory Monitoring	Index of Assessment	Individual Supplementation	Monitoring
Vitamin A	• Retinol • Retinol-binding protein (RBP) • Calculate vitamin A molar ratio = (Retinol ÷ RBP × 0.0734)	Deficiency: Molar ratio <0.8 or serum retinol <20 mcg/dL	1,500–83,000 mcg (5,000–25,000 IU) per day	Check vitamin levels 1 month after making changes Check every 3 months in ongoing cholestasis for 1–2 years If persistently deficient: • Check adherence • Check medication interactions • Consider other diseases (i.e., celiac disease)
Vitamin D	25-OH vitamin D	Deficiency: 25 OH vitamin D <20 ng/mL Insufficiency: 25 OH vitamin D <30 ng/mL	Vitamin D3 (cholecalciferol) Up to 12.5–25 mcg (500–1,000 IU)/kg/day or If 25 OH vitamin D remains low, add calcitriol: 0.05–0.2 mcg/kg/day, and then begin monitoring 1.25 $(OH)_2$ vitamin D levels	
Vitamin E	• α-Tocopherol • Total lipids • Calculate vitamin E: Total lipids ratio = (α-Tocopherol ÷ Total lipids × 100)	Deficiency: Vitamin E: Total lipids ratio <0.6 mg/g (age <1 year) and <0.8 mg/g (age >1 year) If unable to check total lipids, supplement if α-tocopherol is low/low normal. If α-tocopherol is well within normal limits, unclear if/when supplementation is needed	TPGS vitamin E is preferred: d-alpha tocopherol polyethylene glycol 1,000 succinate (TPGS) 6.75–11.25 mg α-tocopherol (15–25 IU vitamin E)/kg/day or If unable to get TPGS, can use standard as follows: α-tocopherol (acetate) 11.25–90 mg α-tocopherol (25–200 IU vitamin E)/kg/day	
Vitamin K	INR	Deficiency: INR > 1.2	Oral phytonadione 2.5 mg three times per week to 10 mg/day or IM phytonadione 2–5 mg every 4 weeks	

Of note, d-alpha tocopherol polyethylene glycol 1000 succinate (TPGS vitamin E) is a water-soluble amphipathic formulation of natural vitamin E, which allows it to form its own micelles and is taken up into enterocytes in the absence of bile salts. Dosing all other fat-soluble vitamins concurrent with the TPGS vitamin E will help with their absorption as well.
This is for children with cholestatic liver diseases. For other children, refer to Chapter 2.

Alagille Syndrome

Children with Alagille syndrome have growth failure that is more profound than seen with other cholestatic liver diseases of childhood. Height trends remain below average in children with Alagille syndrome, even after liver transplantation, indicating that factors beyond their liver disease also contribute to abnormal growth.

Autoimmune Liver Diseases

Both AIH and PSC can occur in isolation or together with inflammatory bowel disease. The chronic inflammation of bowel mucosa seen in inflammatory bowel disease can lead to malabsorption and diarrhea, potentially contributing to malnutrition in these patients (Chapter 16). In addition, with disease progression, cirrhosis and its accompanying complications may further impact nutrition.

Cystic Fibrosis Liver Disease (CFLD)

Patients with CF may require higher energy intake due to the hypermetabolic state caused by recurrent lung infections, which may be further compounded by CF liver disease. Furthermore, most patients with CF also have pancreatic insufficiency and require pancreatic enzyme supplementation to ensure adequate fat absorption. Additionally, some patients may develop endocrine pancreatic insufficiency with subsequent insulin-dependent diabetes. See Chapter 19 for more information on CF.

Acute Liver Failure

Patients with ALF can rapidly develop profound and life-threatening hypoglycemia. To prevent hypoglycemia, all patients with ALF should be maintained on a constant infusion of glucose with a goal glucose infusion rate (GIR) of 6–8 mg/kg per minute. Hyperglycemia (persistent blood glucose of 150–180 mg/dL) should be tolerated in order to avoid hypoglycemia. Patients with acute liver failure are at high risk of developing fluid overload, which contributes significantly to their mortality. Thus, this high GIR requirement must be balanced with appropriate fluid goals and may require fluids with high glucose concentration to be given through a central venous line. Protein restriction is not necessary unless hyperammonemia is present, in which case protein can be restricted to 1 g/kg per day for children and the Dietary Reference Intake (DRI) for infants (Chapter 3).

Non-Alcoholic Fatty Liver Disease

NAFLD is oftentimes associated with central or generalized obesity as well as other obesity-related co-morbidities, such as the metabolic syndrome, diabetes, hypertension, and dyslipidemia. These common co-morbidities may require specific nutrition guidance and interventions.

Nutrition-Focused Physical Exam (NFPE) Findings

Patients with suspected or known liver disease should be assessed for hepatosplenomegaly, ascites, caput medusa (cluster of engorged veins branching out from the umbilicus), clubbing, and skin findings associated with liver disease (jaundice, petechiae, bruising, excoriations). Exam findings specific to each disease process are discussed below.

Cholestasis

Children with abnormal bile flow will typically have jaundice and scleral icterus. Itching can be severe, with excoriations, most commonly noted on the abdomen and around the ears that bleed or can become infected. The exam findings associated with fat-soluble vitamin deficiencies are discussed above.

Cirrhosis

In patients with cirrhosis, a careful physical exam can identify the presence and progression of portal hypertension. In addition to a firm and nodular liver, patients may develop ascites and splenomegaly.

Thrombocytopenia due to hypersplenism may lead to petechiae and easy bruising or bleeding. Dilated blood vessels on the abdomen ("caput medusae") and telangiectasias (tiny spider-like skin lesions caused by dilated capillaries) may also be apparent, including on the face.

Alagille Syndrome

Patients with Alagille syndrome have characteristic facies which may provide a diagnostic clue (prominent forehead, deep-set eyes, and a pointed chin). These facial features may be less obvious in infants. Cholestasis leads to jaundice and scleral icterus, but children with Alagille syndrome may also have xanthomas (cholesterol deposits in the skin), which can be progressive and severe. Xanthomas on the face may be disfiguring and can impair vision if located around the eyes. Xanthomas on the extremities may impair development by limiting the use of the fingers/hands or by inhibiting walking.

Non-Alcoholic Fatty Liver Disease

Patients with NAFLD are usually obese and may have central obesity in particular. Concurrent insulin resistance can result in acanthosis nigricans, a velvety, darkening of the skin occurring in skin folds and creases such as the posterior neck and axilla. Rapid weight gain may also result in striae on the trunk or extremities.

Nutrient Intake

Due to ascites, organomegaly, and overall deconditioning, anorexia and a progressive decrease in oral intake are common as liver disease progresses. Although oral feeding is preferable when possible, supplemental enteral nutrition (EN) may be necessary to counter inadequate oral intake and enhance growth. Occasionally, patients are unable to attain adequate growth with EN or have significant intolerance, and parenteral nutrition (PN) is required.

Tolerance of oral feedings and EN should be assessed by asking questions regarding vomiting, abdominal distention, irritability with feeds, and stooling. As organomegaly and ascites worsen, patients may become more sensitive to feeding volumes. This may require increasing the energy density of EN (formula or human milk) in order to reduce the required volume, utilizing continuous EN, or considering post-pyloric feeding. As the energy density of EN is increased, some children may develop significant diarrhea, preventing further concentration of formula. Assessing the frequency and consistency of stools (i.e., if the stools are "watery") can be helpful to make this determination. A gradual and stepwise approach to altering the energy density of feeds will allow most children to accommodate these changes.

Parenteral Nutrition

The specific PN recipe should be reviewed carefully. In addition, the rate, total duration of PN, and time used to ramp this rate up and down are important to consider for each patient. Symptoms of hypoglycemia (jitteriness, irritability, sleepiness/decreased responsiveness, or even seizures) should also be assessed frequently, especially during the time period when a child is off the PN. Some children may become hypoglycemic when off feeds but remain asymptomatic, so periodic monitoring of fasting serum glucose levels is necessary as liver disease progresses.

Laboratory Monitoring

Total protein, albumin, and pre-albumin have limited utility in reflecting overall protein and nutrition status in the setting of abnormal synthetic liver function. Anthropometric measurements provide a more reliable means of monitoring overall protein-energy status. Children with cholestasis should be monitored for fat-soluble vitamin deficiencies every 1–3 months (Table 18.2). Patients with an identified deficiency will require supplementation and monthly monitoring to assure adequate and timely dose adjustments. Once vitamin deficiencies resolve, monitoring can be spaced to every 3–6 months.

Gastrointestinal Findings

Children with hepatosplenomegaly, cirrhosis, or ascites often have poor appetite and poor tolerance of oral feedings and EN, characterized by fussiness, abdominal distension, vomiting, or diarrhea with feeds. Increasing the energy density and subsequently reducing the volume of oral formula and EN can be helpful, but high-energy-density feeds may worsen diarrhea.

Infants and children with cholestasis may have acholic stools, which are pale or clay-colored due to the lack of normal bile in the stool. Patients with cirrhosis can develop clinical signs and symptoms of portal hypertension, including ascites and a caput medusa. Esophageal or gastric varices may present with obvious hematemesis (vomiting blood) or melena (stool that is dark/black and tarry from digested blood), but the bleeding may be occult. Gastrointestinal bleeding in patients with cirrhosis is a medical emergency and can be life-threatening.

Medications and Side Effects

An important part of nutrition assessment is a review of medications. Table 18.3 outlines common medications and side effects, which may affect nutrient intake and utilization.

Nutrition Diagnosis

Table 18.4 summarizes the nutrition diagnoses most relevant to the care of children with liver disease.

TABLE 18.3
Frequently Used Medications in Pediatric Liver Disease

	Function	Notes
Ursodeoxycholic acid	Naturally occurring, water-soluble bile acid that is used to treat cholestatic liver disease by promoting bile flow	Although usually well-tolerated, diarrhea may occur with initial use and decreases over time in almost all instances
Cholestyramine	Bile acid sequestrant which can be used to manage bile acid-driven diarrhea	It must be given separate from other medications and vitamins because it will also bind them and reduce absorption and efficacy
Rifampin	An antibiotic used to treat pruritus associated with cholestasis	Generally well-tolerated but can cause diarrhea
Diuretics	Critical in the management of ascites	Potential to cause dehydration or electrolyte derangements Furosemide may cause hypokalemia, hypomagnesemia, hypocalcemia, and hyponatremia Spironolactone is a potassium-sparing diuretic can be used in concert with furosemide, both to augment the diuresis and to balance the potassium-wasting effect
Corticosteroids	May be used to treat immune-mediated liver conditions as well as following liver transplantation to prevent rejection	Long-term corticosteroid use increases the risk of osteoporosis. This may compound hepatic osteodystrophy in children with cholestasis and vitamin D deficiency, increasing the risk of fractures. High-dose corticosteroids may also lead to obesity, insulin resistance, and diabetes
Tacrolimus	Immunosuppressive medication used following transplant to prevent organ rejection. Can also be used to treat other immune-mediated liver diseases such as autoimmune hepatitis	Causes renal magnesium wasting and magnesium supplementation is frequently needed for those taking this medication

TABLE 18.4
Nutrition Diagnoses for Common Liver Conditions

Cholestatic liver disease	• Inadequate energy intake • Inadequate oral intake • Excessive fluid intake • Malnutrition (undernutrition) • Inadequate vitamin intake (specify) • Excessive mineral intake (sodium) • Altered gastrointestinal function • Impaired nutrient utilization
Cirrhosis	• Inadequate energy intake • Inadequate oral intake • Excessive fluid intake • Malnutrition (undernutrition) • Excessive mineral intake (sodium) • Altered gastrointestinal function • Impaired nutrient utilization
Cystic fibrosis-related liver disease	• Inadequate energy intake • Inadequate oral intake • Malnutrition (undernutrition) • Inadequate vitamin intake (specify) • Altered gastrointestinal function
Glycogen storage disease	• Excessive energy intake • Altered gastrointestinal function • Impaired nutrient utilization • Overweight/obesity
Wilson's disease	• Altered gastrointestinal function • Food and nutrition-related knowledge deficit
Acute liver failure	• Inadequate oral intake • Altered GI function
Pre-liver transplant	• Inadequate oral intake • Malnutrition (undernutrition) • Food and nutrition-related knowledge deficit
Post-liver transplant	Perioperatively: • Inadequate oral intake • Malnutrition (undernutrition) • Food and nutrition-related knowledge deficit Long-term: • Excessive energy intake • Overweight/obesity
Non-alcoholic fatty liver disease (NAFLD)	• Excessive energy intake • Overweight/obesity • Food and nutrition-related knowledge deficit

Nutrition Intervention

Cholestatic Liver Diseases

Energy needs are increased in the presence of cholestasis due to malabsorption, maldigestion, and increased metabolic rate. Goal energy intake should be 120%–150% of the Estimated Energy Requirements (EER, see Chapter 3) for age based on ideal body weight (IBW). In addition to overall increases in energy needs, it is critical to maintain protein intake to promote growth and prevent a catabolic state. Therefore, protein requirements are also increased, with the goal to provide

120%–150% of DRI (see Chapter 3). Carbohydrates typically comprise 40%–60% of total energy intake. Fat accounts for 30–50% of energy intake, of which a substantial amount of total fat should be derived from medium-chain triglycerides (MCT), which do not require bile acids for absorption. However, long-chain triglycerides (LCT) are still necessary to prevent essential fatty acid deficiency (EFAD). Finally, those with cholestatic liver disease experience significant fat malabsorption, necessitating careful monitoring and supplementation of fat-soluble vitamins.

Enteral Nutrition

Children with cholestatic liver diseases may initially consume a regular and age-appropriate diet, with a goal to meet >130% energy requirements. If this goal cannot be achieved, based on tolerance and/or growth, then increasing energy using other methods is necessary. Human milk may be used and supplemented with MCT, specifically by administering MCT oil alone or by fortifying expressed human milk with MCT-containing formula or an MCT product. It may be difficult to meet the nutrition needs of an infant even with fortified human milk, requiring a change to an MCT-containing formula (Table 18.5). Most MCT-containing formulas are hydrolyzed products, and due to the sour/bitter taste of the peptides, they are often less palatable. Infants will generally accommodate their palate to these changes. Pregestimil® is the preferred MCT-containing infant formula for term infants as it has the highest percentage of fat as MCT. Similarly, Similac Special Care® is preferred for premature infants, given the high MCT content. Human milk fortifiers with MCT are also available, although use is typically restricted to the hospital setting.

Stepwise increases in the energy density of formula are often necessary to meet the high energy demands in this population. Formula alone can be concentrated up to 28–30 kcal/oz (0.93–1 kcal/mL), but further concentration is not recommended due to the resultant high renal

TABLE 18.5
Commercially Available MCT-Containing Formulas for Supplementation

Age	Formula Name (Brand)	Fat Source	Protein Source	Carbohydrate Source	Additional Info
Premature	Similac Special Care (Abbott)	50% MCT	Cow's milk protein	Corn syrup solids and lactose	Only for hospitalized preterm infants up to 3.6 kg
Infant (0–12 months)	Pregestimil (Mead Johnson)	55% MCT	Hydrolyzed casein	Corn syrup solids	
	Gerber Good Start Extensive HA (Nestle)	49% MCT	Hydrolyzed whey	Maltodextrin	
	Similac Alimentum (Abbott)	33% MCT	Hydrolyzed casein	Maltodextrin and sucrose	Has better calcium: phosphorus ratio for former premature infants
	Elecare Infant (Abbott)	33% MCT	Free amino acids	Corn syrup solids	Complex infants, special circumstances
Pediatric (1–10 years)	Peptamen Junior (Nestle)	60%–70% MCT	Hydrolyzed whey	Maltodextrin	1.0–1.5 kcal/mL, with and without fiber
	Pediasure Peptide (Abbott)	60% MCT	Hydrolyzed whey	Maltodextrin and sugar	1.0–1.5 kcal/mL
	Kate Farms Pediatric Peptide 1.5 (Kate Farms)	50% MCT	Organic hydrolyzed pea protein	Organic brown rice syrup solids and organic agave syrup	1.5 kcal/mL
	Kate Farms Pediatric 1.2 (Kate Farms)	40% MCT	Organic pea protein	Organic brown rice syrup solids and organic agave syrup	1.2 kcal/mL, standard formula (not hydrolyzed) so tastes better

TABLE 18.6
Commercially Available Medium-Chain Triglyceride (MCT) Products for Supplementation

Product (Brand)	Form	Additional Information
MCT oil (multiple brands)	Oil	Oil can stick to bottles or feeding bag/tubing; recommend bolus of MCT oil orally via syringe
MCT Procal (VitaFlo)	Powder form	Contains small amount of milk protein and glucose syrup
Liquigen (Nutricia)	Emulsified MCT oil	
Beta quik (VitaFlo)	Emulsified MCT oil	

solute load. Some infants taking higher-energy-density formula will develop diarrhea due to the high carbohydrate load of the concentrated formula. If formula concentration is not tolerated, additional MCT-containing products can be used to concentrate formula up to 30 kcal/oz, assuming the infant is meeting her protein, vitamin, and mineral needs from formula. Using a powdered or emulsified MCT product is preferred as it remains in solution once mixed (Table 18.6).

In infants unable to meet their nutrition needs with oral intake alone, placement of a nasogastric (NG) tube should be considered. EN can be used to supplement with human milk or formula after oral feeds to meet intake goals, particularly in infants with organomegaly and ascites who may be limited by volume. Initiating continuous overnight feeds helps improve tolerance and increase total intake volumes, by decreasing the daytime bolus volume delivery, maximizing total hours that nutrition can be delivered, and preventing hypoglycemia. Formula supplementation via EN using an NG tube may be prolonged, as placement of a gastrostomy tube is relatively contraindicated because of the increased risk of gastrointestinal bleeding with portal hypertension.

For older children, a high-energy, high-protein diet is also necessary, but implementation is slightly different. Regular eating patterns with 3 meals and 2–3 scheduled snacks are encouraged. The energy density of foods can also be increased with MCT products, as they can be used in cooking and baking. Pediatric MCT-containing formulas can also be supplemented after meals and snacks to maximize total energy intake. Choosing a higher-energy 1.5 kcal/mL product is often necessary due to early satiety.

At each clinic visit (typically every 2–4 weeks with severe malnutrition and every 8–12 weeks with less severe disease), assessment and evaluation of growth and nutrition tolerance is imperative to inform further clinical decision making. When assessing feeding tolerance and anthropometric data, it is also essential to ensure the patient is receiving the prescribed diet, including correct formula mixing, volumes, and delivery, at every clinic visit. If MUAC and TSFT measurements indicate lack of true weight gain, then the delivered energy need to be increased, which may occur by either increasing the volume or concentration of feeds. These options may be limited by gastrointestinal intolerance (vomiting, excessive stooling, and hypoglycemia). Vomiting is often due to an inability to tolerate large volumes in the presence of ascites and organomegaly. Increased stooling can be seen with large volumes and excessive carbohydrate load and/or a high-fat diet. Smaller, more frequent feeds may be necessary in the setting of organomegaly and ascites due to early satiety.

Parenteral Nutrition

If growth failure persists or hypoglycemia develops despite aggressive EN, PN must be considered. When initiating PN, EN may be discontinued to minimize complexity of care, but oral intake is encouraged to promote gut health and development of oral-motor skills. The energy goal used when on PN should be based on the EER for age (using IBW), since it is directly delivered and does not contend with malabsorption. Fluid balance and ascites will help determine goal fluid intake with PN and is typically 75% of maintenance fluid needs in those with end-stage disease. Daily sodium

should be limited to a maximum of 2–3 mEq/kg as many children with end-stage liver disease are chronically hyponatremic and attempts at aggressive correction will only promote ascites. Copper and manganese are normally excreted in bile. Ongoing monitoring is necessary to assess for deficiencies or toxicities that would require their changes to the prescribed PN. Due to lack of enteral zinc intake and urinary zinc losses seen in cholestasis, additional zinc may also be added to the PN.

Initially, PN is run for 12–16 hours/day to optimize nutrition while still allowing patients to continue to consume foods orally and maintain a good quality of life. However, infants with end-stage liver disease on PN may have difficulty self-regulating blood glucose, necessitating ramping PN both up and down to allow for accommodation of insulin and glucose. In severe disease, infants may become reliant on a constant glucose infusion and quickly become hypoglycemic off PN, resulting in need for 24-hour continuous infusions.

Practical Approach to Fat-Soluble Vitamin Supplementation

Multiple approaches exist to supplement fat-soluble vitamins in infants/children with cholestatic liver diseases. Critical points in this process include the recognition of the risk of deficiency, aggressive supplementation, and serial monitoring to allow for adjustments in dosing. Our suggested approach is to immediately begin all infants diagnosed with cholestasis on oral supplementation with 1 mL twice per day of a fat-soluble multivitamin supplement (Table 18.7) and 2.5 mg of vitamin K three times per week (Table 18.8). These doses may need modification in premature infants. After 1 month, if fat-soluble vitamin levels suggest deficiencies, supplementation may occur as suggested in Table 18.2.

Cirrhosis

Nutrition interventions for patients with cirrhosis should follow the general principles recommend for their specific underlying disease process. In addition, cirrhosis may require an overall

TABLE 18.7
Fat-Soluble Multivitamin Supplements

Product	Brand	Vitamin A	Vitamin D	Vitamin E	Vitamin K
DEKAs Essential Liquid (1 mL)	Callion	750 mcg (2,498 IU)	50 mcg (2,000 IU)	50 mg (74 IU)	2,000 mcg
DEKAs Plus Liquid (1 mL)	Callion	1,727 mcg (5,751 IU)	18.8 mcg (750 IU)	33.6 mg (50 IU)	500 mcg
AquADEKs Liquid (1 mL)	Allergan	1,727 mcg (5,751 IU)	15 mcg (600 IU)	33.6 mg (50 IU)	400 mcg
GenADEK Liquid Drops (1 mL)	MVW Complete Formulation	1,730 mcg (5,751 IU)	19 mcg (760 IU)	34 mg (50 IU)	500 mcg
DEKAs Essential Capsules (1 capsule)	Callion	600 mcg (2,000 IU)	50 mcg (2,000 IU)	100.5 mcg (150 IU)	1,000 mcg
DEKAs Plus Chewable Tablets (1 tablet)	Callion	5,450 mcg (18,149 IU)	50 mcg (2,000 IU)	67 mg (100 IU)	1,000 mcg
DEKAs Plus Softgels (1 softgel)	Callion	5,450 mcg (18,149 IU)	75 mcg (3,000 IU)	101 mg (150 IU)	1,000 mcg
AquADEKs Chewable Tablets (2 tablets)	Allergan	5,455 mcg (18,167 IU)	30 mcg (1,200 IU)	67 mg (100 IU)	700 mcg
GenADEK Step 1 Softgels (1 softgel)	MVW Complete Formulation	5,450 mcg (18,149 IU)	75 mcg (3,000 IU)	100.5 mg (150 IU)	1,000 mcg
GenADEK Step 2 Softgels (1 softgel)	MVW Complete Formulation	5,450 mcg (18,149 IU)	125 mcg (5,000 IU)	100.5 mg (150 IU)	1,000 mcg

TABLE 18.8
Commercially Available Specialized Individual Fat-Soluble Vitamin Supplements

Product (Brand)	Concentration	Additional Information
Micellized Vitamin A Liquid (Klaire Labs)	1,507 mcg (5,018 IU) retinol activity equivalents (RAE) per drop	Liquid vitamin A is easy and more precise to administer than a soft gel, which is administered by snipping it open and squirting out
Aqua-D concentrate (Callion)	10 mcg (400 IU) vitamin D per 0.2 mL	Water-miscible due to addition of TPGS vitamin E
Vitamin D (Carlson Labs and other brands)	• 10 mcg (400 IU) per drop • 25 mcg (1,000 IU) per drop • 50 mcg (2,000 IU) per drop	Smaller more concentrated dose: 1 drop vs. 1 mL for traditional infant vitamin D liquid formulations
Aqua-E (Callion)	9 mg α-Tocopherol (20 IU vitamin E) per mL	TPGS vitamin E
Aqua-E concentrate (Callion)	33.75 mg α-Tocopherol (75 IU vitamin E) per mL	TPGS vitamin E
Aqua-K concentrate (Callion)	200 mcg vitamin K per 0.2 mL	Water-miscible due to addition of TPGS vitamin E

higher-energy diet to prevent wasting, due to increased metabolic rate. In pediatrics, protein restriction is not recommended. In addition, children who develop cirrhosis may have concurrent portal hypertension with ascites, requiring fluid and sodium restriction, which must be managed on an individual basis.

Autoimmune Hepatitis and Primary Sclerosing Cholangitis

There is no specific dietary treatment for AIH and PSC. A normal healthy and age-appropriate diet is recommended. In those who progress to ESLD, increased energy to promote appropriate weight gain and prevent catabolism is recommended.

Cystic Fibrosis Liver Disease

Ensuring optimal nutrition in a patient with CF-related liver disease is important, as liver disease can compound the malabsorption and malnutrition already associated with CF. Dietary therapy is consistent with typical treatment of CF, following high-energy, high-protein diet with fat-soluble vitamin supplementation, but now with emphasis on even more fat and MCTs, along with adequate pancreatic enzymes for optimal absorption. Fat is preferred over carbohydrate for increasing energy intake to decrease the risk for CF-related diabetes. Salt supplementation is limited, as it can lead to ascites. Medication may be used to increase bile flow and diuretics may be used to decrease fluid retention. Additional information about the nutrition management of CF can be found in Chapter 19.

Glycogen Storage Disease (GSD)

GSD types I and III are treated by dietary management focused on both preventing hypoglycemia and promoting normal growth and development. For GSD type 1, this includes a diet restricted in lactose, galactose, sucrose, and fructose, hence, excluding all milk and dairy products, sugar, fruit, and fruit juices. Dietary management of GSD type III does not require restriction of fructose, galactose, or other carbohydrates, although avoidance of simple sugars is recommended. Both GSD types I and III require avoidance of fasting by routine consumption of small frequent meals combined with the use of uncooked cornstarch (UCCS) to maintain glycemic control. UCCS provides a steady supply of glucose to the bloodstream, and hence, nocturnal UCCS supplementation and/or overnight continuous feeds may also be indicated. The high carbohydrate requirements in affected patients can result in obesity. Micronutrient supplementation may also be necessary in cases where

high doses of UCCS are needed. More detailed information for the dietary management of GSD can be found in Chapter 23.

Wilson's Disease

The intervention for Wilson's disease is a combination of chelation therapy and dietary avoidance of copper-containing foods. Chelation therapy is used initially and can be continued as maintenance therapy or while some patients transition to oral zinc. Zinc binds excess copper in the body and increases urinary copper excretion. Both chelators and zinc should not be administered within 1 hour of eating. The dietary restriction of copper-containing foods includes avoiding organ meats, shellfish, chocolate, nuts, and mushrooms. Patients should also avoid copper-containing multivitamins with mineral supplements.

Acute Liver Failure

Children with acute liver failure are typically well nourished at time of onset given the acute nature of the condition. The goal of nutrition therapy should therefore be to maintain an adequate nutrition state in the setting of catabolic disease. Metabolic and electrolyte derangements are common and require careful monitoring and replacement. A common but ominous symptom of acute liver failure is hypoglycemia, which occurs because of increased glycolysis, impaired gluconeogenesis, hyperinsulinemia, and rapidly depleting glycogen stores. A constant GIR of 4–6 mg/kg per minute is recommended to prevent catastrophic hypoglycemia. This can become challenging as fluid restrictions may be needed to prevent fluid overload and cerebral edema. EN is preferred, but PN can be used if necessary. In either case, with the exception of those experiencing significant hepatic encephalopathy, protein restriction should not occur.

Post-Liver Transplantation

The nutrition rehabilitation of patients post transplantation is influenced by their nutrition status entering transplant and the complexity of their peri-transplant course. In general, it becomes easier to provide nutrition to children after transplant without confounding factors such as fluid restrictions and organomegaly. Goal energy intake should be 100%–120% of the EER, depending on if catch-up growth is needed. Protein requirements are increased after surgery to promote healing, with the goal to provide 150% of the DRI for age. Once the transplanted graft is functioning well, patients can be transitioned back to a regular age-appropriate diet. Some children may have suboptimal oral intake in the initial post-transplant period. Nasogastric tube feeds may be needed for some period of time to adequately meet nutrition needs. Long-term recommendations focus on eating a balanced diet post-transplant and monitoring for poor or excessive weight gain. Post-transplant monitoring of both calcium and vitamin D should be considered because of steroid exposure, as well as magnesium due wasting that occurs with Tacrolimus, and supplemented as needed.

NAFLD

The focus of treatment for NAFLD is lifestyle interventions, focusing on improving both dietary intake and physical activity. Current pediatric data does not support a specific diet, but adult studies have shown the merits of the Mediterranean diet. A healthy, well-balanced diet is recommended for children with NAFLD, with a focus on decreasing simple sugars, high-energy foods, and high-fat foods. Avoidance of sugar-sweetened beverages has been shown to decrease adiposity in children, which may in turn treat NAFLD. Daily moderate-to-high intensity exercise is recommended, knowing that both aerobic and resistance training can be beneficial. Activity goals also include limiting screen time to less than 2 hours/day.

A multidisciplinary approach to these lifestyle modifications with increased contact hours has been shown to be most effective with weight management (Chapter 25). Adult studies have suggested that a weight loss of ≥7%–10% is associated with improvement in liver tests.

TABLE 18.9
ADIME Summary for Pediatric Liver Diseases

- Assessment
  - Growth assessment
    - Use standard growth charts
    - Extended BMI charts for patients with NAFLD
    - MUAC and TSFT for all patients
  - Nutrition-focused physical exam
    - May have large abdomen – look for signs of malnutrition on extremities and face
    - Look for signs of fat-soluble vitamin deficiencies
  - Nutrient intake
  - Labs
  - Gastrointestinal findings
    - Feeding intolerance common (vomiting, diarrhea)
  - Medications/side effects (see Table 18.3)
- Diagnosis
  - See Table 18.4
- Intervention
  - Nutrition prescription
    - Patients with cholestatic liver disease have increased protein and energy needs
    - See Chapter 25 for patients with NAFLD
  - Common nutrition interventions
    - Oral
      - Cholestasis: high MCT formula or human milk fortification
    - Enteral nutrition
      - NG tube may be prolonged as G tube placement may be contraindicated
      - Consider overnight feedings
    - Parenteral nutrition
      - Assess for hypoglycemia
    - Education
      - Wilson's disease: copper restriction
      - NAFLD: lifestyle modifications
    - Laboratory monitoring
      - Cholestatic disease: fat-soluble vitamins every 1–3 months (Table 18.2)
    - Supplements
      - Consider fat-soluble vitamin supplementation (Tables 18.2, 18.7, & 18.8)
- Monitoring & evaluation
  - Anthropometrics
  - Laboratory values of fat-soluble vitamins
  - Feeding tolerance

Nutrition Monitoring and Evaluation

Monitoring nutrition in children with chronic liver disease is an iterative process which requires close follow-up to assess weight changes, anthropometric measurements, intake, and fat-soluble vitamin levels, as outlined above in the Intervention section. Similarly, patients with NAFLD should be monitored to assess for changes in intake and exercise and weight loss (Table 18.9).

Patients with chronic liver disease are at risk of nutrient deficiencies due to the liver's vital role in the metabolism of macronutrients and fat-soluble vitamins. Patients with cholestatic liver disease are at risk of fat-soluble vitamin deficiencies and malnutrition. Nutrition assessment and NFPE are especially important in this population due to the risk of ascites and organomegaly which can skew weight measurements. Overweight and obese patients with NAFLD benefit from nutrition

counseling to promote improvements in BMI-for-age *z*-score. The dietitian plays an important role in the multidisciplinary care team of patients with chronic liver disease.

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19 Cystic Fibrosis and Pancreatic Disease

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CONTENTS

CYSTIC FIBROSIS

Cystic fibrosis (CF) is a genetic disease that affects multiple organ systems, including the lungs and pancreas. Given the role of the pancreatic enzymes in digestion of nutrients, patients with CF and other diseases affecting the pancreas are at risk of malnutrition and deficiency of specific nutrients. Pancreatic enzyme replacement therapy (PERT) and fat-soluble vitamin supplementation are critical in promoting adequate growth and preventing vitamin deficiencies.

More than 30,000 people in the USA are living with cystic fibrosis, and 1,000 people/year are diagnosed with CF. Newborn screening accounts for two-thirds of all diagnoses in the USA. Newborn screening is a nationwide program that tests newborn infants for certain health conditions during the first few days of life, including CF. Early detection of CF can help prevent serious complications of untreated conditions including pancreatic insufficiency and malnutrition with early interventions. CF is included in the newborn screening in all 50 states. A positive newborn screen for CF needs to be confirmed with sweat chloride testing. Clinicians should be familiar with the screening process and be frequently reminded that while exceptionally helpful in identifying newborns with CF, there are rare situations where an infant may not be identified through the screening process. When a child has symptoms similar to CF or pancreatic insufficiency and has a negative newborn screen, a sweat chloride test remains the gold standard for diagnosis of CF.

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TABLE 19.1
Cystic Fibrosis Mutation Classes

Class	Defect	Typical Mutation
I	No protein produced	G542X, R553X
II	Protein misfolded	F508del
III	Improper channel function	G551D
IV	Limited channel function	R117H
V	Limited overall channels	A455E

CF is an autosomal recessive, genetic multi-system disease caused by mutations in the cystic fibrosis transmembrane conductance regulator (CFTR) gene. The CFTR gene produces protein that functions as a channel across the membrane of cells that produce bodily secretions such as mucus, sweat, saliva, and digestive enzymes. Since this channel transports chloride ions into and out of cells, it controls the flow of water and hence the amount of liquid in these bodily secretions. Mutations in the gene lead to defective proteins that prevent the flow of chloride and of water producing abnormally thick mucus. These mutations are classified by the part of the protein pathway that is defective (see Table 19.1) and lead to varying phenotypes of disease. These are responsible for the prominent pulmonary and gastrointestinal manifestations. The most common mutation is F508del that leads to an abnormally folded CFTR protein.

As most children are diagnosed through newborn screening, they are likely to be asymptomatic or minimally symptomatic when initially seen. However, as CFTR dysfunction in utero can lead to gastrointestinal (GI) complications, infants can be born premature and at low birth weight. Meconium ileus, where the intestines are blocked by meconium (the infant's first stool) can be seen in 10%–20% of newborns and may be complicated by intestinal atresia. Children with severe CFTR mutations develop early exocrine pancreatic insufficiency (EPI) and poor growth in infancy. Approximately 90% of individuals with CF will develop EPI over their lifetime and the majority by 1 year of age. The fat malabsorption caused by untreated EPI leads to malnutrition, deficiencies of fat-soluble vitamins, and essential fatty acid deficiency (Table 19.2). Symptoms of fat malabsorption include abdominal pain, distention, bloating, and steatorrhea (bulky, greasy, and foul-smelling stools due to fat malabsorption). Respiratory insufficiency may be present even in asymptomatic infants and can progress to chronic obstructive airway disease complicated by chronic bronchitis and bronchiectasis, as well as acute infectious exacerbations.

The complex management of respiratory disease due to thickened secretions and airway changes causes significant burden of disease. Primary interventions for pulmonary manifestations of CF focus on mitigating obstructive airway disease, including bronchodilators, anti-inflammatory therapies, antibiotics for acute and chronic infection, and airway clearance therapies. Vest therapy (high-frequency chest wall oscillation) is frequently used for airway clearance and is used twice a day for about 30 minutes at a time. Ideally, it is done on an empty stomach or at least an hour after meals to prevent emesis, especially in younger children.

Recent advances in therapeutics for CF include CFTR modulator drugs (Table 19.3), which target the abnormal CFTR protein in the cell to either correct its misfolding to allow it to reach the cell surface or potentiate its insufficient function at the epithelial membrane surface. The available therapies offered to a particular patient depend on age and specific CFTR mutation. It is important for the dietitian to be aware of the patient's mutations, eligibility for CF-related medications, and their likely response to these medications as nutrition plans are developed. As symptoms improve with medical management of their disease, the patient's nutrient needs may also change.

As CF is a multiple system disease, interventions are also needed to target sinus disease, CF-related liver disease (CFLD, see Chapter 18), CF gallbladder disease, CF-related diabetes (CFRD, see Chapter 24), constipation and abdominal pain, infertility, and decreased bone density, among others. Of particular relevance to this chapter are interventions for poor growth and

TABLE 19.2
Signs/Symptoms of Deficiencies Associated with Cystic Fibrosis

Nutrient	Signs/Symptoms of Deficiency
	Associated with Pancreatic Disease
Vitamin A	Xerophthalmia (xerosis, keratomalacia, night blindness, retinopathy); poor bone growth; insufficient immune responses
Vitamin E	Neuropathy (ataxia, hyporeflexia); myopathy; hemolytic disease
Vitamin D	Bone demineralization, fractures
Vitamin K	Coagulopathy (easy bruising and bleeding)
Essential fatty acids	Dermatitis, alopecia, thrombocytopenia
	Not Associated with Pancreatic Disease
Sodium	Anorexia, abdominal pain, weakness, headache, nausea
Zinc	Anorexia, poor growth, acrodermatitis enteropathica
Iron	Pallor, fatigue, anemia
Calcium	Muscle cramps, numbness/tingling, bone fractures, confusion

TABLE 19.3
CFTR Modulator Medications

Generic	Brand	Mutation Indications	Approved Ages
Ivacaftor	Kalydeco	G551D, other gating, residual function	4 months and older
Lumacaftor/ivacaftor	Orkambi	Homozygous F508del	2 years and older
Tezacaftor/ivacaftor	Symdeko	Homozygous F508del, residual function	6 years and older
Elexacaftor/tezacaftor/ivacaftor	Trikafta	At least one F508del	6 years and older

Legend: CFTR, cystic fibrosis transmembrane conductance regulator.

nutrition due to increased energy utilization and malabsorption from pancreatic disease and EPI. For those with EPI, PERT is critical to optimize nutrition and decrease pain related to malabsorption. Fat-soluble vitamin supplementation in its water-miscible formulation will be needed as some degree of fat malabsorption may still exist. Dosing of PERT and vitamin supplementation is discussed in more detail in the intervention section.

Initial surgical interventions may include disimpaction of meconium ileus and repair of any associated intestinal atresia or perforation. For those patients with poor growth over time, feeding tube placement may be required to supplement additional energy. Bronchoscopy with broncho-alveolar lavage may be indicated during acute exacerbations. For those with declining lung function and advanced CF lung disease, double lung transplantation is a consideration if aggressive therapies have failed. As CFTR modulators become more available at younger ages, it is possible that some surgical interventions will become less frequent.

When CF was first recognized and described in the 1930s, few children lived past the age of 5 years due to severe malnutrition and lung disease. With advances in disease therapeutics, more than half the current population of those with CF is >18 years old. It is predicted that the median age of survival of people with CF born after 2018 will be 47 years, with advanced lung disease still significantly contributing to morbidity and mortality. CFTR modulator therapies bring immense optimism to nearly 90% of persons with CF.

ACUTE PANCREATITIS

An overall increased incidence of acute pancreatitis has been seen over the last few decades. This may be due to increased awareness among clinicians of the likelihood of pancreatic disease in children leading to increased utilization of laboratory and radiographic testing, but also due to rising biliary disease due to childhood obesity. Recent studies cite an incidence of 12.3/100,000 persons per year.

Risk factors for acute pancreatitis include biliary disease, medications, metabolic and systemic disease, trauma, viral infections, and idiopathic causes. Toxic exposures, such as alcohol and tobacco, are much less common in children in comparison to adults.

Clinical signs and symptoms result from effects of pancreatic duct obstruction or direct pancreatic acinar cell injury that lead to premature activation of the pancreatic digestive enzymes in the pancreas itself rather than in the intestines. The resulting inflammation leads to symptoms of epigastric pain which may radiate to the back, as well as nausea and vomiting. If due to biliary disease such as gallstones, children may have associated jaundice and scleral icterus. However, in younger children, symptoms can be non-specific and may include non-focal pain or irritability. Thus the diagnosis is made clinically with a combination of two out of three of the following: suggestive abdominal pain or symptoms, levels of serum amylase and/or lipase that are greater than three times the upper limit of normal, and imaging findings such as a diffusely enlarged pancreas and surrounding fluid (Table 19.4).

For an episode of acute pancreatitis, medical management includes aggressive fluid resuscitation, appropriate pain control measures, and early oral intake as tolerated. Children should be allowed to eat as they desire, with initiation of early enteral nutrition (EN) associated with shorter length of stay and lower rate of progression to severe acute pancreatitis. Parenteral nutrition (PN) may be added (as primary or adjunctive support) if prolonged intolerance to enteral intake; however, EN is preferred.

Surgical interventions may be required during an acute episode to address biliary disease. This may include an endoscopic retrograde cholangiopancreatography (ERCP), if obstructive jaundice or cholangitis, and/or a cholecystectomy for non-obstructing gallstones.

The majority of pediatric patients with pancreatitis have mild to moderate disease with improvement in symptoms noted in average of 3–5 days, but up to 25% may go on to develop severe disease and 10% may require admission to a pediatric intensive care unit due to cardiovascular, respiratory, or renal complications.

Mortality in pediatric pancreatitis is rare. A proportion of children, 15%–35%, may go on to develop acute recurrent episodes of pancreatitis within a few months, driven by their underlying

TABLE 19.4
Diagnosis of Pancreatitis

Acute pancreatitis (AP)	Requires at least two out of three criteria: • Abdominal pain suggestive of, or compatible with, AP • Serum amylase and/or lipase >3xULN • Imaging findings characteristic of, or compatible with, AP
Acute recurrent pancreatitis (ARP)	Requires at least two episodes of AP, plus: • Complete resolution of pain (>1 mo pain-free between diagnoses) OR • Complete normalization of amylase and lipase between episodes
Chronic pancreatitis (CP)	Requires at least one of the following three: • Abdominal pain consistent with pancreatic origin and imaging findings suggestive of chronic pancreatic damage • Evidence of exocrine insufficiency and suggestive imaging findings • Evidence of endocrine insufficiency and suggestive imaging findings

risk factors or incomplete functional recovery of the pancreas. Of these children, 20%–40% may progress to chronic pancreatitis within 2–5 years.

CHRONIC PANCREATITIS AND EXOCRINE PANCREATIC INSUFFICIENCY

The incidence of chronic pancreatitis in children is 1.9/100,000 persons per year. Chronic pancreatitis is the continuation of progressive inflammatory damage to the pancreas that has resulted in irreversible acinar and ductal change, which can eventually cause corresponding loss of exocrine or endocrine function. Children with acute pancreatitis may progress from their initial attack to chronic pancreatitis in months to years.

The most commonly used classification system for risk factors for chronic pancreatitis is the TIGAR-O risk factor classification system, which includes Toxic/metabolic, Idiopathic, Genetic, Autoimmune, Recurrent/severe acute pancreatitis, and Obstructive etiologic risk factors. Over 20% of children with chronic pancreatitis have more than one risk factor for its development, but the exact etiology may, in many cases, only be partially known. As children progress through the stages of acute to acute recurrent and then to chronic pancreatitis, proportionality of underlying risk factors shifts toward genetic disease. 73% of children with chronic pancreatitis have at least one gene mutation compared to 48% of those with acute recurrent pancreatitis, but this likely underestimates the true percentage. Progressive irreversible pancreatic damage leads to significantly impaired quality of life and intractable pain. Children with chronic pancreatitis report frequent opioid usage, high healthcare utilization, and decreased scores of mental and physical well-being.

For a diagnosis of chronic pancreatitis to be established, one of three conditions must exist: (1) abdominal pain consistent with pancreatic origin and imaging findings suggestive of chronic pancreatic damage; (2) evidence of exocrine insufficiency (most commonly identified as fecal elastase-1 <100 μg/g stool) and suggestive imaging findings; or (3) evidence of endocrine insufficiency (most commonly defined as fasting glucose ≥126 or ≥200 mg/dL after glucose load) and suggestive imaging findings. Imaging findings may include changes of the pancreatic duct (irregularity, intraductal filling defects or calculi, stricture, dilatation) or the gland itself (enlargement, atrophy, irregular contour, calcifications). Once the diagnosis has been made, further history taking and testing is necessary to establish the risk factors.

Chronic pancreatitis is the most common cause of EPI in adults, while CF is the most common cause in children. EPI, as previously discussed, causes fat malabsorption leading to steatorrhea, weight loss, and nutrition deficiencies. Pancreatic exocrine function has a huge reserve and symptoms only begin to manifest when the functional reserve of the pancreas falls below 10%. However, exocrine function is most commonly assessed through use of fecal elastase-1 and when it suggests insufficiency, particularly in CF, PERT is begun. In addition, in infants with CF, if their CF genotype suggests pancreatic insufficiency, PERT is begun while awaiting confirmation of a low fecal elastase-1.

The chronic abdominal pain that develops in the setting of chronic pancreatitis is multifactorial and requires management from both a pharmacologic and non-pharmacologic standpoint. It should include a multidisciplinary approach with psychologists/psychiatrists, integrative medicine providers, and physical/occupational therapists.

For those with EPI, PERT is critical to optimize nutrition and decrease pain related to malabsorption. Fat-soluble vitamin supplementation in its water-miscible formulation will be needed as some degree of fat malabsorption may still exist. Dosing of PERT and vitamin supplementation is discussed in more detail in the intervention section.

Surgical interventions are guided by underlying risk factors and should be tailored to the patient's presentation. ERCP with sphincterotomy, ductal dilatation, stenting, and/or stone removal can help relieve pancreatic obstructive processes. Adolescents with gallstone pancreatitis should undergo cholecystectomy to reduce progression of pancreatic inflammation and prevent further episodes of

acute-on-chronic pancreatitis. Additional surgical procedures include those that improve pancreatic drainage such as a lateral pancreaticojejunostomy (Puestow) or those that resect a mass such as a pancreaticoduodenostomy (Whipple). These procedures are less commonly done in children versus adults due to different disease presentation and should be avoided in children with hereditary pancreatitis.

When patients have failed to respond to maximal medical therapy, endoscopic procedures, or other surgical procedures, total pancreatic (TP) resection can be considered to remove the source of chronic unrelenting pain and improve quality of life. This will lead to brittle diabetes if completed alone, thus it is coupled with islet auto-transplantation (IAT) to minimize development of pancreatogenic diabetes. However, not all patients will have access to this procedure nor would be appropriate candidates.

Despite the available medical and surgical interventions, ongoing disease burden can be high in children with chronic pancreatitis. This leads to frequent emergency department evaluations, hospital stays, missed days of school or work, decreased participation in activities, and diminished quality of life. Abdominal pain, which may initially be episodic, progresses to chronic pain. Pain relief post-TPIAT is accomplished in a high percentage of individuals and health-related quality of life is significantly improved in dimensions of physical and social functioning as well as bodily pain.

NUTRITION MANAGEMENT

The following sections will discuss key considerations for the nutrition management of cystic fibrosis; sections on management of EPI may also apply to those with chronic pancreatitis.

Nutrition Assessment

The Cystic Fibrosis Foundation (CFF) has recommended at minimum quarterly CF Center visits for infants and children greater than 1 year of age, which should always include assessment of anthropometric measurements. Infants are to be seen monthly until they are 6 months of age and every 2 months from 6 to 12 months of age. More frequent assessments are needed in higher-risk or malnourished individuals.

Additionally, the CFF has recommended at minimum an annual assessment by a dietitian to include anthropometric measurements and trends, nutrition intakes, assessment of malabsorption, usage of PERT and CF-specific multivitamins, laboratory testing, psychosocial status, and co-morbidities that may impact nutrition status including CFRD, CFLD, constipation or distal intestinal obstruction syndrome (DIOS), and obesity among others.

Growth Charts

WHO growth charts are used for children 0–2 years of age, with a goal recommended by the CFF to achieve a weight-for-length >75th percentile for age by 2 years of age. CDC growth charts are used for children >2 years of age, with a goal recommended by the CFF to achieve and maintain BMI ≥50th percentile for age. Higher BMI is associated with better pulmonary status and disease outcomes.

While obesity historically has been relatively uncommon, prevalence is increasing in the CF population as overall life expectancy increases and with new highly effective CFTR modulator therapy. Nutrition assessment should include monitoring for overweight and obesity.

Nutrition Considerations for Specific Diagnoses

Malnutrition, as manifested by poor weight gain and slowing of linear growth, is common in people with CF who may not have the benefit of CFTR modulator therapy and/or have advanced disease. This is multifactorial, with contributions from hypermetabolism (chronic inflammation or infections, increased work of breathing and coughing, pulmonary exacerbations), malabsorption,

problematic mealtime behaviors (picky eating, food refusal, grazing), or disordered eating behaviors. To prevent malnutrition and improve outcomes, a high-energy, high-fat diet is recommended, when indicated.

CF is the main etiology of EPI in children, although it can also be caused by pancreatitis as discussed. EPI is present at birth in the majority of those with CF; some individuals that are born pancreatic sufficient may transition to pancreatic insufficiency at an early age. Approximately 90% of people with CF have EPI. Due to EPI and related malabsorption, individuals need PERT, fat-soluble vitamin supplementation, and increased energy intake.

Children with CF often struggle with constipation due to a lack of fluid in the intestinal tract and salt losses. Related abdominal pain and distention may lead to poor intake. Adequate hydration, salt supplementation, and appropriate use of PERT should be encouraged. Individuals may still need osmotic and stimulant laxatives as well as behavioral management of constipation.

DIOS is caused by salt and fluid losses with increased mucus, inspissated stool, and decreased motility in the intestine leading acutely to an incomplete or complete blockage at the ileocecal junction. The etiology is multifactorial with contributions from inadequate PERT, dehydration, and intestinal dysmotility. This may cause loss of appetite, nausea, vomiting, and abdominal pain with the presence of a right lower quadrant mass. Acutely, hydration and disimpaction (with osmotic laxatives or enemas) may be needed. Preventive measures may include a healthy diet with adequate fluid and fiber intakes, daily laxative use, and adherence to PERT.

CF increases the risk for dehydration due to increased salt and fluid losses through sweat and respiration. Insufficient salt intake may cause nausea, poor appetite, and abdominal pain. Fluid and salt intake should be increased during activity, exercise, warm weather, or during illness such as CF pulmonary exacerbations.

CFRD shares features of both type 1 (decreased insulin production) and type 2 diabetes (insulin resistance) from pancreatic inflammation and fibrosis and leads to poor nutrition status. Annual screening for CFRD is recommended with an oral glucose tolerance test starting at least by 10 years of age, with initiation of insulin therapy for those diagnosed with CFRD. A high-energy density diet is still recommended, but individuals should limit sugar-sweetened beverages and candy, space carbohydrate intake throughout the day, pair carbohydrate intake with protein or fat, and perform carbohydrate counting. Chapter 24 provides additional information about CFRD.

For information about CF-related liver disease, see chapter 18.

Nutrition-Focused Physical Exam

Physical exam findings of EPI may include poor weight gain, short stature, loss of subcutaneous fat, decreased muscle mass, edema, abdominal pain, and bloating. Specific exam findings related to malabsorption and vitamin/mineral deficiencies are described in Table 19.2.

Nutrient Intake

During nutrition assessment, a review of intake should be performed. This may be accomplished through a 3-day food journal or 24-hour diet recall. The clinician should review intakes from all nutrition avenues (oral diet, EN, or PN) and assess for adequacy. Appetite and factors potentially limiting appetite or affecting nutrition intakes (i.e., pulmonary illness, gastrointestinal dysfunction, medications, psychosocial/behavioral stressors) should be assessed at each visit. A review of barriers, such as socioeconomic (financial difficulties, utilization of food pantries or nutrition assistance programs), education needs (decreased awareness of nutrition goals or needs), and behavioral issues (picky eating, grazing, lack of family mealtimes, etc.), should be completed with patients and caregivers.

Due to pancreatic insufficiency or the potential to develop pancreatic insufficiency over time, a review of gastrointestinal symptoms should be completed. An assessment of baseline stool frequency, consistency, and appearance, in addition to gastrointestinal symptom review, may help identify malabsorption. If malabsorption is noted and/or poor weight gain is documented, confirming

PERT doses and timing (i.e., at beginning of meal), and identifying any potential barriers to adherence will be critical.

Patients with EPI will require increased amounts of fat-soluble vitamin supplementation. Fat-soluble vitamin intakes and adherence should be discussed during a visit, especially if abnormal laboratory values have been identified. Similar to PERT, confirming dosing of vitamins/minerals, how vitamins are taken (i.e., with or without enzymes), and potential barriers to adherence should be assessed. People with CF may also require additional zinc, calcium, and iron due to the malabsorptive process and CF-related co-morbidities. Due to increased sodium losses from sweat, a high-salt diet is recommended. Infants should be supplemented with ⅛ tsp salt from 0 to 6 months and ¼ tsp salt from 6 to 12 months. After 1 year of age, salt-containing food should be consumed and food should be salted liberally. Subsequently, dietary assessment of salt and fluid intake should be completed.

Laboratory Monitoring

Guidelines for laboratory monitoring of nutrition status have been proposed (Table 19.5). Fat-soluble vitamin monitoring along with iron status should occur at least annually. When a deficiency has been recognized and treated, monitoring frequency should increase. In the setting of poor growth, screening for iron deficiency, sodium depletion, thyroid disease, celiac disease, and CFRD, among others, should also occur. Screening for CFRD should occur annually starting by at least 10 years of age with an oral glucose tolerance test.

Gastrointestinal Findings

Abdominal symptoms suggestive of underlying gastrointestinal disease (Table 19.6) are frequent in individuals with CF and can have an impact on their growth and nutrition. During assessment, patients should be asked about nausea, vomiting, abdominal pain, distention/bloating, greasy stools, diarrhea, and constipation.

Medications and Side Effects

The medication list should be carefully reviewed to determine potential effects on appetite and growth. It is important to recognize medications that may be used off-label as appetite stimulants (including, but not limited to cyproheptadine, mirtazapine, megestrol acetate, dronabinol) or medications with weight gain as possible side effects (corticosteroids, new highly effective CFTR

TABLE 19.5
Monitoring of Nutrition Status

Nutrient	Annually	Additional Indications
Vitamin A	X	Xerophthalmia
Vitamin D	X	Fractures
Vitamin E	X	Neuropathy, hemolytic disease
Vitamin K		At diagnosis, in patients with hemoptysis, hematemesis, liver disease
Essential fatty acids		Chronic malabsorption, poor growth
Calcium/bone status		>8 years old with risk factors
Iron	X	Poor appetite, poor growth
Zinc		Diarrhea, acrodermatitis, poor growth
Sodium		Poor appetite, dehydration

Source: Adapted from Borowitz D, Baker RD, Stallings V. Consensus Report on Nutrition for Pediatric Patients with Cystic Fibrosis. *J Pediatr Gastroenterol Nutr*. 2002;35:246–259.

See Chapter 2 for recommended laboratory tests.

Legend: INR, international normalized ratio; PT, prothrombin time.

TABLE 19.6
Gastrointestinal Symptoms and Etiologies in Cystic Fibrosis

Symptom	Etiologies in Patients with CF
Abdominal pain	Constipation, DIOS, SIBO, GERD, gastritis, pancreatitis, cholecystitis, medications
Nausea	GERD, medications, insufficient salt intake
Vomiting	GERD, medications, post-tussive emesis, DIOS
Distension	Constipation, DIOS, SIBO, inadequate PERT
Diarrhea	Overflow (constipation), inadequate PERT, celiac disease, SIBO, IBD
Constipation	Dehydration, inadequate PERT, dysmotility, intestinal salt/fluid losses

Legend: DIOS, distal intestinal obstruction syndrome; GERD, gastroesophageal reflux disease; IBD, inflammatory bowel disease; PERT, pancreatic enzyme replacement therapy; SIBO, small intestinal bacterial overgrowth.

modulators, certain antidepressants). Medications may also contribute to appetite suppression (stimulant medications for attention-deficit hyperactivity disorder, certain antidepressants, metformin) or affect taste or sense of smell (antibiotics, antifungals, antivirals, antihistamines, bronchodilators, thyroid hormone, diuretics). The primary CF therapy should be noted; if the patient is on one of the CFTR modulators (Table 19.3), these should be taken with fat (recommendations vary between 10 and 20 g/dose) and PERT to optimize absorption.

Nutrition Diagnosis

Given the numerous challenges people with CF face to meet estimated nutrient intakes and with underlying malabsorption and malnutrition, the nutrition diagnosis should address these challenges. Common nutrition diagnoses include:

- Increased energy expenditure
- Inadequate oral intake
- Increased nutrient needs (specify)
- Altered gastrointestinal function

Nutrition Intervention

Nutrition Prescription

The nutrient needs of people with CF are highly variable. With CF modulator therapies improving health and increasing lifespan, there may be movement away from the "traditional" CF diet. At this time, there is no literature suggesting that CF patients should be exempt from nutrition recommendations for the general population. However, many CF patients continue to have higher nutrient needs. The degree of lung disease, malabsorption, medications, activity levels, and co-morbidities associated with CF can lead to increased energy expenditure. Although there is no set method for estimating the nutrition needs in people with CF, energy and protein needs are typically estimated at approximately 1.2–2 times the EER for age (Chapter 3). A high-fat diet is recommended, with 35%–40% total energy from fat, to meet these increased needs. Protein needs are generally met if energy goals are met.

Common Nutrition Interventions

To achieve CFF goals of weight-for-length or BMI-for age, a well-balanced, energy-dense diet should be implemented. Anthropometric measurements should be trended and discussed with patients and

caregivers at each visit. If anthropometric measurements are not meeting age-appropriate goals, nutrient intakes (energy, protein, fat, salt, vitamins/minerals) should be increased. Increasing fat additives, energy-dense foods, and frequency of meals and snacks may be first-line interventions. The addition of oral nutrition supplements (homemade or commercial) to the prescribed regimen should be considered. Optimizing PERT and gastrointestinal regimen(s), including use of osmotic laxatives, acid suppression, and/or appetite stimulants, can be beneficial if malabsorption or gastrointestinal dysfunction is present. EN to augment oral diet can be implemented and modified as needed. If nutrition status is being impacted by socioeconomic stressors, resources to assist patient(s) and/or caregivers should be discussed and provided. Emphasis should be placed on individualizing the nutrition care plan with a collaborative team approach to care.

Oral Intake

For infants, human milk and/or standard infant formula (unless otherwise indicated) is recommended. Fortification of human milk and/or infant formula beyond 20 kcal/oz is warranted for infants with slow weight gain and growth. Complementary foods are introduced when developmentally appropriate, typically around 6 months of age. When beginning solids, pureed meats are recommended as a first food due to higher energy, protein, zinc, and iron content. Adding oils/butter, preparing cereals with formula or human milk, and adding carbohydrate and protein modulars can be utilized to increase energy of infant foods. The early introduction of nut butters and eggs can be advantageous for additional energy and allergen exposure. Salt supplementation should be added to the infant's diet as previously discussed.

A generally healthy, high-energy, high-protein, high-fat, and high-salt diet is recommended beyond 1 year of age. Regular meals and multiple snacks should be encouraged on a set routine and schedule throughout the day, which may prevent the development of difficult mealtime behaviors. Increasing the caloric density of foods may be accomplished by adding additional fat sources such as oils/butters, nut butters, and utilizing full-fat dairy sources. Oral nutrition supplements may be utilized to promote additional energy and protein in addition to meals and snacks.

Enteral Nutrition

EN should be pursued when encountering ongoing poor growth despite adherence to therapies, maximizing oral intake, treating malabsorption, addressing psychosocial barriers, completing feeding therapy if indicated, and optimizing management of co-morbid disease. EN is the preferred form of nutrition support therapy for CF patients with a functional gastrointestinal tract and is often used to supplement oral intake. Due to the chronicity of CF, long-term tube placement is preferable to a short-term tube (Chapter 7). However, short-term tube placement may be indicated during acute illness or trial of EN prior to gastrostomy tube placement. The decision to pursue gastrostomy tube placement should be a team approach including the patient and caregivers.

When initiating tube feeds, 30%–65% of total estimated energy needs are commonly provided by EN and the patient continues to eat by mouth for the remainder of her energy intake. This may be achieved through nocturnal feedings to allow oral intake or through intermittent daytime bolus feeds. The feeding regimen should be tailored to the patient/family's needs and schedule. Standard polymeric age-appropriate formula is recommended; energy-dense formula can be used in those over 1 year of age if needing to maximize energy delivery. Pancreatic enzymes are needed with tube feeds. This will be discussed in more detail in the supplement section.

Parenteral Nutrition

PN should be considered for children with CF who are unable to be fed enterally due to a non-functional GI tract. PN is not the preferred form of nutrition support therapy due to potential risks and complications associated with use. PN may be used in rare cases such as premature birth, or meconium ileus with bowel resection and subsequent short bowel syndrome.

Nutrition Education

Nutrition education typically includes the following topics:

1. The long-term relationship between nutrition and lung function
2. High-energy/protein/fat/salt diet
3. Usage and importance of pancreatic enzymes
4. Fat-soluble vitamin supplementation
5. The importance of maintaining nutrition health for improved CF outcomes

Specialized diet education may be completed when indicated (i.e., CFRD, CFLD, picky eating/behavioral eating, weight management, etc.).

Laboratory Monitoring

Abnormal laboratory values should be addressed and rechecked following intervention (Table 19.5).

Supplements

The use of high-energy oral nutrition supplements in addition to meal and snack intakes is a common nutrition intervention in the care of someone with CF. A variety of energy-dense oral nutrition supplements may be utilized to assist patients in meeting their high-energy/protein needs. Patients may choose to utilize commercially available or homemade supplements. Many supplements are available to pancreatic insufficient patients through an enzyme company's nutrition program. These programs provide supplements at no-cost to patients with commercial insurance plans who utilize the company's enzymes (i.e., Creon, Zenpep, Pertzye). The registered dietitian and medical team should work with patients to help recommend and access appropriate high-energy supplements.

The recommended vitamin supplementation for individuals with CF and/or EPI is higher than that for the general population (Tables 19.7 and 19.8); however, dosing tends to be based on actual laboratory values rather than the patient's age. Several commercial brands of water-miscible fat-soluble vitamin supplementation currently exist (MVW Complete Formulation, http://mvwnutritionals.com; DEKAs, http://dekasvitamins.com) and in formulations such as liquid drops, chewables, or softgels. These preparations also contain water-soluble vitamins and, in certain products, zinc. Importantly, they usually do not contain calcium or iron. To improve absorption, vitamins should be taken with food and PERT and the total daily dose can be divided.

In people with CF, vitamin D deficiency leading to bone disease may be due to usage of steroids, chronic inflammation, and malabsorption among other factors. Standard monitoring and

TABLE 19.7
Recommended Vitamin A, E, and K Supplementation

Age	Vitamin A (IU)	Vitamin E (IU)	Vitamin D [IU (mcg)]	Vitamin K (mg)[a]
0–12 months	1,500	40–50	400 (10)	0.3–0.5
1–3 years	5,000	80–150	400–800 (10–20)	0.3–0.5
4–8 years	5,000–10,000	100–200	400–800 (10–20)	0.3–0.5
>8 years	10,000	200–400	400–800 (10–20)	0.3–0.5

Source: Reprinted with permission from Borowitz D, Baker RD, Stallings V. Consensus Report on Nutrition for Pediatric Patients with Cystic Fibrosis. *J Pediatr Gastroenterol Nutr*. 2002;35:246–259.

[a] Currently, commercially available products do not have ideal doses for supplementation. In a recent review, no adverse effects have been reported at any dosage level of Vitamin K. Clinicians should try to follow these recommendations as closely as possible until better dosage forms are available. Prothrombin time or, ideally, PIVKA-II levels should be checked in patients with liver disease, and vitamin K dose titrated as indicated.

TABLE 19.8
Recommended Vitamin D Supplementation

Age	Routine Dosing with CF-Specific Vitamins	Step 1: Dose Increases	Step 2: Dose Titration Maximum	Step 3
0–12 months	400–500 IU (10–12.5 mcg)	800–1000 IU (20–25 mcg)	Not more than 2,000 IU (50 mcg)	Refer
>12 months to 10 years	800–1,000 IU (20–25 mcg)	1,600–3,000 IU (40–75 mcg)	Not more than 4,000 IU (100 mcg)	Refer
>10 years to 18 years	800–2,000 IU (20–50 mcg)	1,600–6,000 IU (40–150 mcg)	Not more than 10,000 IU (250 mcg)	Refer
>18 years	800–2,000 IU (20–50 mcg)	1,600–6,000 IU (40–150 mcg)	Not more than 10,000 IU (250 mcg)	Refer

Source: Reprinted from Tangpricha V, Kelly A, Stephenson A, et al. Cystic Fibrosis Foundation Vitamin D Evidence-Based Review Committee. An Update on the Screening, Diagnosis, Management, and Treatment of Vitamin D Deficiency in Individuals with Cystic Fibrosis: Evidence-Based Recommendations from the Cystic Fibrosis Foundation. *J Clin Endocrinol Metab*. 2012;97:1082–1093. With permission from Oxford University Press.

Notes:
Step 1: for levels 20–30 ng/mL.
Step 2: for levels <20 ng/mL or persistently 20–30 ng/mL after treatment.
Step 3: for levels persistently <30 ng/mL after treatment, refer to specialist.

intervention is critical (Table 19.8); referral to an endocrinologist should occur with persistent deficiency despite treatment.

In those with poor growth, consider empiric zinc supplementation with 1 mg/kg per day of elemental zinc (up to 25 mg) for 6 months and then reassess.

PERT should be started as soon as EPI is diagnosed; without the specific EPI diagnosis, it can also be started in the presence of severe CFTR mutations. Several FDA-approved formulations are currently available in the USA; however, these are not clinically interchangeable and are not bioequivalent due to varying amounts of lipase, amylase, and protease per capsule strength and brand. The CFF does not recommend use of non-proprietary formulations (such as those found in health-food stores) as these are not regulated by the FDA and may contain different amounts of enzymes than advertised and/or may contain ingredients that interact with other medications. The current FDA-approved formulations consist of:

- Capsules with enteric-coated microbeads/tablets that protect the enzymes from gastric acid degradation and are designed to release the enzymes in the alkaline environment of the small intestine (Creon, Abbvie, Inc.; Pancreaze, Vivus, Inc.; Zenpep, Nestle Health Science; Pertzye, Digestive Care, Inc.).
- A non-enteric-coated tablet (Viokace, Nestle Health Science) that should be paired with acid suppression and can be crushed and added to EN (although not FDA approved for this purpose).
- An enzyme cartridge containing lipase only (Relizorb, Alcresta) that is approved for in-line use with continuous EN.

Of the enteric-coated capsules, Pertzye is unique in that it is bicarbonate-buffered, which may allow better release if the intestinal milieu is too acidic due to the impaired bicarbonate secretion in CF. Acid suppression may be needed for this reason if PERT dosing has been optimized but there are still signs and symptoms of malabsorption and other factors (improper usage, lack of adherence,

TABLE 19.9
Pediatric PERT Dosage Recommendations

Weight-Based Dosing

500–2,500 lipase units/kg per meal

250–1250 lipase units/kg per snack

Notes:

- Dosing for infants is unique and can range from 2,000 to 4,000 lipase units/120 mL of human milk or formula
- Children <4 years old may require a high initial starting dose in this range, or 1000 lipase units/kg per meal
- Children >4 years old can be started at the lower end of the range

Fat Gram-Based Dosing

500–4,000 lipase units/g of fat consumed

Notes:

- Adjusted dose based on response (growth, malabsorptive symptoms)
- Total daily dosing should not exceed 2,500 lipase units/kg per meal or 10,000 lipase units/kg per day due to historical concerns for fibrosing colonopathy when patients routinely consumed >6,000 lipase units/kg per meal

grazing behaviors, small intestinal bacterial overgrowth or enteritis, celiac disease, etc.) have been ruled out.

Dosing is a range based on the amount of lipase units provided and can either follow a regimen based on the individual's body weight or on the number of fat grams consumed at a time (Table 19.9).

For young children and infants unable to swallow an intact capsule, the capsule contents can be sprinkled on a small amount of acidic soft food (examples: applesauce, yogurt, commercially prepared bananas or pears) to assist with administration. Contents should not be crushed or chewed. The mouth should be carefully examined afterwards for remaining beads as these may cause oral irritation if left in place.

Enzyme supplementation is required for fat-containing EN. However, minimal evidence exists on the preferred administration method. PERT dosing is typically based on total grams of fat in the enteral formula. A recommended dosing range of 2,000–4,000 units lipase/g fat is generally accepted. Enzymes with tube feeding will depend on the patient and their feeding regimen as well as insurance coverage.

Enteric-coated enzymes can be administered with EN by the fat gram method of dosing. PERTZYE™ 4000 USP lipase unit capsule is currently the only FDA-approved PERT for direct administration into a gastrostomy tube sized 14 French or larger. One to two capsules of PERTZYE™ 4000 may be opened, mixed with a small amount of juice/nectar-thick liquid and pushed into the gastrostomy tube at a time. Another method of PERT and tube feeding administration includes giving enteric-coated capsules orally at the start, midway through, and at the end of a feed.

If using the lipase-only cartridge (Relizorb®) with EN, the manufacturer recommends one cartridge per every 500 mL of formula delivered, with use of up to two cartridges per day. The Relizorb cartridge connects in-line with the enteral feeding set. The cartridge containing immobilized lipase breaks down fat in the enteral formula prior to infusing into the body. Formula and infusion rate compatibility as well as insurance coverage should be checked prior to implementing Relizorb. Relizorb's website offers up-to-date information on formula compatibility, insurance coverage, and product support.

Another approach to enzyme administration with tube feeding is to use Viokace. This non-enteric-coated PERT tablet is crushed into a fine powder and added directly to formula to create a "predigested" feed. This method may be useful for patients infusing nocturnal drip feeds who do not wish to take enzymes orally. Hang times for feedings may vary by institution.

If the above methods are unavailable or not possible, there is one other non-FDA-approved method for administering PERT with tube feeding. This can be done by mixing crushed enzyme beads or enzyme beads activated with bicarbonate with the formula in a feeding bag. If crushing

the enzyme beads, it is also advisable to allow the active enzymes and formula to "rest" at least 30 minutes prior to infusing the tube feeding to allow the formula to "digest".

Due to variable methods available, many practitioners rely on best practice when implementing enzymes and tube feedings. It is always recommended that patients/caregivers be involved in decision making to tailor the enzyme and feeding regimen to their needs.

Other Specialty Referrals

A gastroenterology referral may be indicated in patients with ongoing malabsorption, abdominal pain, recalcitrant constipation or DIOS, gastroesophageal reflux disease, and/or CFLD. An endocrinology referral may be indicated in patients with CFRD, persistent vitamin D deficiency, short stature, decreased bone mineral density, and/or hypothyroidism. A psychology/psychiatry referral may be indicated in the presence of mood disorders or body image issues as these may interfere

TABLE 19.10
ADIME Summary for Cystic Fibrosis and Pancreatic Disease

- Assessment
  - Growth assessment
    - CF goals
      - <2 years old: >75th percentile weight/length on WHO chart
      - >2 years old: >/= 50th percentile BMI/age on CDC growth charts
  - Nutrition-focused physical exam
  - Nutrient Intake
  - Labs – see Table 19.5
  - Gastrointestinal findings
    - Constipation
    - Malabsorption
  - Medications
    - PERT
    - Fat-soluble vitamin supplementation
    - Appetite stimulants
    - CFTR modulators
- Diagnosis
- Intervention
  - Nutrition prescription
    - Energy: 1.2–2×EER for age
  - Common nutrition interventions
    - Oral
      - High-calorie, high-fat, high-protein, high-salt diet
    - Enteral nutrition
      - May be indicated if unable to meet nutrient goals orally
    - Parenteral nutrition
    - Education
    - Laboratory monitoring – see Table 19.5
    - Supplements
      - Oral nutrition supplement (commercial or homemade)
      - Fat-soluble vitamins (Tables 19.7 and 19.8)
      - Zinc
      - Calcium
      - Iron
      - PERT (see Table 19.9 for dosing)
    - Other specialty referrals
- Monitoring and evaluation

with intake and growth goals, or to help with adjustment to chronic disease. A social work referral may be indicated to discuss barriers to care, access to community resources, and to provide family and patient support.

A genetic counseling referral should occur at diagnosis of CF or for family planning considerations. A speech-language pathology, occupational therapy, or feeding therapy referral should occur with maladaptive feeding behaviors, swallowing difficulties, or other concerns.

A physical therapy referral should occur for physical deconditioning related to chronic illness, and/or for the need to establish an exercise regimen and improve lean body mass.

Nutrition Monitoring and Evaluation

Monitoring and evaluation of anthropometric measurements, energy and protein intakes, macro/micronutrient intakes from oral nutrition and nutrition support therapy, laboratory data, nutrition-focused physical findings, patient knowledge/beliefs, and progress toward nutrition-focused goals should be assessed at appropriate time intervals determined by nutrition assessment and follow-up (Table 19.10).

Patients with CF and other pancreatic diseases are at risk of poor weight gain and fat-soluble vitamin deficiencies. The CFF has set weight/length and BMI/age guidelines to promote optimal health and nutrition status for patients with CF. The nutrition assessment can reveal nutrition risks and the dietitian should provide targeted nutrition interventions to address the patient's specific nutrition risks. High-energy diets and oral supplements can help meet energy needs. The dietitian should also identify the need for PERT and vitamin/mineral supplementation. Close monitoring and follow-up is required to ensure the patient is meeting their nutrition goals.

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20 Renal Disease

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Renal disease in children is due to a wide variety of diseases and encompasses different clinical presentations. One of the most important functions of the kidney is to excrete metabolic waste products by generating protein-poor ultrafiltrate of the plasma at about 100–120 mL/minute per 1.73 m^2 with reabsorption of nearly 99% of this ultrafiltrate in the tubules. Due to this function, kidneys are an integral part of maintaining the equilibrium of body fluids; alterations to the function of the kidney lead to a variety of metabolic and electrolyte changes requiring careful planning and treatment. Kidney function is commonly determined by measurement of blood urea nitrogen (BUN) and serum creatinine and by assessing urine output. Since creatinine is completely filtered by the kidney and very little is secreted in the tubules, serum creatinine measurement can be used to estimate glomerular filtration rate (eGFR). There are many types of renal diseases in children, which are described in detail in this chapter.

ACUTE KIDNEY INJURY

Acute Kidney Injury (AKI) is defined as an acute decrease in kidney function. This translates to a rise in serum creatinine or a decrease in urine output. AKI is considered to have three defined stages

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(Table 20.1). In non-critically ill children, AKI has been reported to occur in 0.4%–5% of all hospitalized children. In critically ill children, the incidence seems to vary from 10% to 82% depending upon the severity of the illness and seems to be associated independently with increased mortality and morbidity. Though it was previously thought that intrinsic diseases of the kidney such as acute glomerulonephritis or hemolytic uremic syndrome are the most common causes of AKI, systemic illness or its treatment, such as sepsis, nephrotoxic medications, and ischemia due to other organ involvement, seem to be the most common cause of hospital-acquired pediatric AKI.

The approach to etiology entails that AKI etiologies are considered under three major categories: prerenal, renal intrinsic causes, and postrenal causes. Common etiologies under this rubric are shown in Table 20.2.

A detailed history and focused physical exam along with examination of urine sediment and urinary indices may help discern the cause of AKI. An active urinary sediment in the form of red cells and casts indicates an intrinsic cause of AKI whereas urinary indices showing tubular reabsorption

TABLE 20.1
Acute Kidney Injury Network Definition of AKI

	Serum Creatinine & Estimated Glomerular Filtration Rate	Urine Output
Stage 1	Increase in serum creatinine of ≥0.3 mg/dL or 150%–200% from baseline	<0.5 mL/kg per hour for >6 hours
Stage 2	Increase in serum creatinine to more than 200%–300% from baseline	<0.5 mL/kg per hour for >12 hours
Stage 3	Increase in serum creatinine to more than 300% from baseline (or serum creatinine of more than or equal to 4.0 mg/dL with an acute increase of at least 0.5 mg/dL)	<0.3 mL/kg per hour for >24 hours or anuria for >12 hours

Source: Reproduced from Mehta RL, Kellum JA, Shah SV, et al. Acute Kidney Injury Network: Report of an Initiative to Improve Outcomes in Acute Kidney Injury. *Crit Care*. 2007;11:R31. This is an open access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/2.0).

TABLE 20.2
Etiology of Acute Kidney Injury

Prerenal

Intravascular volume depletion
- Hemorrhage
- Severe dehydration
- Diarrhea/vomiting/gastrointestinal losses

Decreased effective intravascular blood volume
- Congestive heart failure
- Nephrotic syndrome
- Liver failure

Intrinsic

Acute tubular necrosis – *direct damage to the tubules*
- Hypoxic/ischemic injury
- Drug-induced/exogenous toxins
- Endogenous toxins (Rhabdomyolysis, hemolysis, tumorlysis)
- Hemolytic uremic syndrome
- Acute glomerulonephritis
- Acute interstitial nephritis (drug, idiopathic)
- Vascular injury (cortical necrosis, thrombosis)
- Malignant hypertension

Postrenal
- Urethral obstruction (posterior urethral valves)
- Obstruction of solitary kidney

points to a prerenal cause AKI. Ultrasound examination of the kidney and the urinary bladder helps to differentiate an obstructive cause of AKI.

The management of AKI depends on the etiology of AKI. A prerenal cause due to inadequate perfusion should be treated with prompt volume expansion. Prompt relief of obstruction is essential in reversing the postrenal cause of AKI. Intrinsic causes of AKI including acute tubular necrosis require careful attention to urine output and electrolyte derangements with attention to maintaining normal blood pressure, avoiding fluid overload, and avoiding further nephrotoxic exposure, while providing targeted therapy as needed for conditions such as acute glomerulonephritis.

If complications such as fluid overload, uncontrolled metabolic acidosis, and electrolyte disturbances including hyperkalemia cannot be addressed by medical management, then kidney replacement therapy in the form of dialysis should be considered. The forms of dialysis are:

1. Hemodialysis
2. Peritoneal dialysis
3. Continuous renal replacement therapy (CRRT)

Principles of hemodialysis and peritoneal dialysis are explained under the chronic dialysis section later in this section. CRRT is an extracorporeal therapy administered in the hospital setting. It utilizes vascular access similar to hemodialysis but with clear advantages in unstable patients since fluid and metabolic control can be maintained continuously and adjusted depending on patient needs. However, it requires much more careful monitoring and collaboration between the intensive care and nephrology teams.

Stage 2 or 3 AKI is associated with nearly a 70% increase in mortality in critically ill children. There is increasing awareness that even with resolution of AKI, hypertension or proteinuria as a part of chronic kidney disease (CKD) can occur as a result of AKI.

Chronic Kidney Disease (CKD)

CKD is defined as abnormalities of kidney structure or function, present for ≥3 months. The chief markers of kidney damage include either decreased glomerular filtration rate (GFR) <60 mL/min per 1.73 m^2 or albuminuria. CKD is staged to assess severity and guide management, since certain manifestations and complications of CKD arise at certain GFR levels (in mL/min per 1.73 m^2) irrespective of the etiology of CKD. These levels include:

G1: Kidney damage with normal or high GFR (≥90)
G2: Kidney damage with mildly decreased GFR (60–89)
G3a: Mildly to moderately decreased GFR (45–59)
G3b: Moderately to severely decreased (30–44)
G4: Severely decreased (15–29)
G5: Kidney failure (<15)

In 2012, Kidney Disease Improving Global Outcomes (KDIGO) modified this staging to include albuminuria with a caveat that in children, proteinuria can be substituted for albuminuria.

True prevalence data is lacking in children; however, some registry estimates incidence of pediatric CKD to be 11–12 per million of age-related population (pmarp) and a prevalence of 55–60 pmarp. In younger children, the most common causes of CKD are congenital abnormalities of the kidney and urinary tract such as renal hypo-dysplasia and/or obstructive uropathy. The most common obstructive lesions are posterior urethral valves and prune belly syndrome, both of which only occur in boys. Other causes include renal cystic diseases, juvenile nephronophthisis, or genetic causes such as cystinosis or oxaluria. Glomerular diseases such as focal segmental glomerulosclerosis (FSGS), membranoproliferative glomerulonephritis, or lupus nephritis cause significant renal

TABLE 20.3
Complications of Chronic Kidney Disease

Complication	Management Approach
Growth impairment	Ensure adequate nutrition, treat acidosis and sodium depletion, address mineral bone disorders, consider growth hormone therapy
CKD-mineral bone disorder	Ensure maintenance of calcium, phosphate, calcium×phosphate product, and parathyroid hormone (PTH); if plasma 25-OH vitamin D is low, supplement with calciferol; correct metabolic acidosis
Neurocognitive delay, reduced quality of life	Encourage school attendance, recognize importance of daytime fatigue and sleep disturbances, anticipatory counseling of children and parents
Anemia	Parenteral erythropoietin, iron supplementation
Hypertension	Start treatment if BP>90th percentile for age, gender, and height; treat hypertension with pharmacologic agents to attain blood pressure (BP)<50th percentile for age, gender, and height; preferred agent is angiotensin converting enzyme inhibitor or angiotensin receptor blockade
Hyperlipidemia	Therapeutic life style modifications
Metabolic acidosis	Supplemental bicarbonate or citrate solutions
Hyponatremia	Salt supplementation, if ensured it is not dilutional hyponatremia
Hyperkalemia	Dietary potassium restriction, potassium-binding resins
Hypophosphatemia	Phosphate supplementation
Hyperphosphatemia	Diet restriction and phosphate binders

disease in later childhood and teenage years. Manifestations of CKD and complications arise due to alteration in kidney function. Table 20.3 provides a list of complications and its management.

The natural course of CKD is that after the initial inciting event or injury, there is gradual deterioration of kidney function. This decline does not occur in a linear fashion. The initial decline is somewhat slow, while later stages of CKD are associated with more persistent decline with rapid progression near stage 5 CKD.

Kidney Replacement Therapy

Management of children with CKD stages 2+ must recognize that for the majority of these children progression to end-stage kidney disease is to be expected. Families should be counseled regarding this eventuality and provided with appropriate emotional support to prepare for it. Discussion concerning the appropriate choice of kidney replacement modality should be started when CKD stage 3 is reached so that the families are appropriately educated about the relative benefits and adverse effects of each.

Chronic Dialysis

Chronic dialysis in children is nearly always a bridge to kidney transplantation. It is always managed at experienced centers with a multidisciplinary team available for treatment and guidance for both the child and the family. There are three potential modalities to choose from: in-center hemodialysis, home hemodialysis, and home peritoneal dialysis (Table 20.4).

Hemodialysis can be performed at home by caregivers but requires extensive involvement and education on vascular access and technical aspects of hemodialysis.

Kidney Transplantation

Preemptive kidney transplantation is now the preferred treatment for many children with progressive CKD, with longer graft function and reduced mortality observed with preemptive transplantation

TABLE 20.4
Hemodialysis vs. Peritoneal Dialysis

	Hemodialysis	Peritoneal Dialysis
Access	Central venous catheter, arterio-venous fistula or a graft	Peritoneal catheter
Schedule	3–4 times/week, lasting 3.5–4-hour session each time	Nightly with daytime long dwell with continuous cycle (preferred in children) or manual cycles – 7 days a week
Technical details	Uses a dialyzer membrane for diffusive clearance	Uses peritoneal membrane with a specialized glucose containing fluid such as Dianeal® for diffusive clearance and osmosis for fluid removal
Pros	Efficient and quick removal of solutes, in-center hemodialysis can be performed in situations where no caregivers can do therapy at home	Better preservation of residual kidney function, since performed at home less disruptive, preferred choice for young children since vascular access required for hemodialysis is difficult
Cons	Since intermittent, requires much more fluid and diet restrictions, much more disruptive as it requires spending 3–4 hours on dialysis three times a week rather than in school	Medical contraindications such as intra-abdominal adhesions, requires a conducive home and burden of treatment falls on caregivers

when compared to children who receive chronic dialysis prior to transplantation. Preemptive transplantation is relatively easy to arrange for patients with a prospective matched living donor. For patients in whom a living donor is not available, preemptive transplantation should still be considered; however, in this situation, a patient must be placed on the transplant list at an appropriate time, which by definition is prior to his or her development of end-stage kidney disease requiring dialysis.

Kidney transplantation is performed after a child reaches ~9–10 kg in weight. It could be either living-donor (LD) or deceased-donor (DD) transplantation. DD transplantation has clear outlines on allocation practices with children getting preference over adults. Wait times after accepted to an allocation list vary and are dependent on ABO blood group, sensitization, and HLA matching. Transplant graft survival has been increasing with 1, 3, and 5 year survival ~97%–98%, 90%–91%, and 80%–83% for DD, and 98%–99%, 90%–94%, and 90%–91% for LD, respectively. Survival for younger children weighing <15 kg is also excellent. See Chapter 18 for common transplant medications and nutrition implications.

NEPHROTIC SYNDROME

Nephrotic syndrome (NS) is characterized by massive proteinuria (>50 mg/kg per day), hypoalbuminemia, edema, and hyperlipidemia. The most common cause in children is minimal change disease, which in a majority of children responds to steroids. Initially, steroids are given daily, then on an alternate day for about a 12-week period. The majority of children do relapse but remain steroid responsive with ultimate resolution by 10–15 years of age. Other causes include genetic causes of nephrotic syndrome, FSGS, or membranous variety, which do not respond to steroids. Children with steroid-resistant NS develop CKD in a large proportion of cases.

NEPHROLITHIASIS

Nephrolithiasis (kidney stones) is a relatively common health disorder in all parts of the world with an estimated lifetime prevalence of approximately 10%–12% in men and 5%–6% in women. In the 1950s to the 1970s, the estimated incidence of pediatric urolithiasis in the United States was 1%–2%

that of adults; however, some recent studies have suggested that this prevalence has nearly doubled over the last few years with most of the increase occurring in teenage years. There are considerable geographic differences in both prevalence and type of stones both within the USA and worldwide; the southern part of the USA has a much higher prevalence of stones. In some areas of the world such as Saudi Arabia, the incidence is nearly twice as the USA. Calcium stones are the majority of stones reported in the USA. Nearly half of pediatric patients who form stones have some form of metabolic risk factor such as hypercalciuria, hyperoxaluria, hypocitraturia, or hyperuricosuria. Hyperoxaluria deserves a special mention as it can be caused by increased dietary intake (dietary hyperoxaluria), overabsorption in patients with fat malabsorption (enteric hyperoxaluria), and the autosomal recessive inherited enzyme deficiencies, the primary hyperoxalurias, types I, II, and III. Among the inherited varieties, type I accounts for nearly 75% of cases and is due to deficiency of alanine: glyoxylate aminotransferase. This leads to oxalate overproduction causing kidney stones and progressive CKD. It is paramount that this diagnosis be considered as an etiology in any child presenting with kidney stones so that appropriate treatment measures including hydration is instituted. Recently a small interfering RNA that targets oxalate has been granted FDA approval for treatment of this condition raising hopes that such targeted therapy can change the bleak prognosis of this condition (Table 20.5).

RENAL TUBULAR DISORDERS

The tubules of the kidney not only reabsorb 99% of glomerular filtrate; they are critical in maintenance of electrolyte and mineral balance and serve as one of the two vital organs in maintaining the correct acid base milieu. Disorders of the tubule therefore have varied manifestations. Table 20.6 gives some examples of such defects highlighting the protean manifestations.

NUTRITION MANAGEMENT

Nutrition Assessment

Malnutrition and poor growth are common in pediatric CKD, especially with progression to later stages and with dialysis. Furthermore, height has been identified as an independent predictor of mortality in children with CKD. Anthropometric measurements remain an integral part of any pediatric nutrition assessment. While standard assessments are used, an important difference in the care of patients with CKD is the use of dry weights and height-adjusted BMI for age.

Anthropometrics

Dry Weight

Dry weight is defined as body weight when a patient is in a euvolemic state. This can be difficult to assess with one parameter; it should be reassessed frequently with multiple parameters to confirm. These parameters can include but are not limited to: blood pressure, urine output, physical assessment of edema, laboratory markers related to fluid status, and non-invasive monitoring (specific to HD).

Dry weight should be utilized when calculating and plotting children on the BMI-for-age growth chart. Mortality risk is increased in overweight and underweight patients with kidney disease.

Height for Age Adjusted BMI Percentile/Z-Score

Short stature can be an inherent complication related to CKD. Thus, height-for-age adjustment is recommended when assessing appropriateness of BMI and an ideal body weight calculation to ensure appropriate goals associated with appropriate proportionality of body composition. When height-for-age z-score < -2, it is recommended that the BMI plot for the height age be adjusted to where the measured height intersects the 50th percentile. See Chapter 1 for more information about height age.

TABLE 20.5
Nutrition Management of Kidney Stones

Calcium-based stones	Increase fluid intake[a]
	Increase fruit and vegetable intake
	Limit acid-based foods
	Limit animal meats and excessive protein
	Limit sodium
	Provide DRI for calcium[b]
Oxalosis or hyperoxaluria with calcium-based stones	Increase fluid intake[a]
	Increase fruit and vegetable intake
	Limit acid-based foods
	Limit animal meats and excessive protein
	Limit sodium
	Provide DRI for calcium[b]
	Limit oxalate[c]
Uric acid stones	Increase fluid intake[a]
	Increase fruit and vegetable intake
	Limit acid-based foods
	Provide DRI for protein, especially limit purines
Cystine stones	Increase fluid intake[a]
	Increase fruit and vegetable intake
	Limit acid-based foods
	Limit animal meats and excessive protein
	Limit sodium
Struvite stones	Increase fluid intake[a]
Other	Increase fluid intake[a]
	Limit animal meats and excessive protein

Source: Adapted from Nelms CL, Juarez M, Warady BA. Renal Disease. In: Corkins MR, Balint J, Bobo E, Plogsted S, Yaworski JA, eds. *The A.S.P.E.N. Pediatric Nutrition Support Core Curriculum*. 2nd ed. Silver Spring, MD: American Society for Parenteral and Enteral Nutrition; 2015:351–385.

[a] At least 1 oz/kg or ensure urine output >2 L/m^2 body surface area.

[b] Avoidance of excessive or inadequate intakes of calcium are especially important in these types of kidney stones notated.

[c] Limit of oxalate also includes limiting excessive vitamin C intake that would form oxalate through metabolic processes.

TABLE 20.6
Renal Tubular Disorders

Disorder	Manifestation
Proximal tubular disorders (isolated proximal renal tubular acidosis (RTA) or generalized disorder called Renal Fanconi syndrome)	RTA, or in generalized condition causes glycosuria, aminoaciduria, hypophosphatemia due to phosphaturia, Rickets in addition to RTA
Distal tubule acid secretion defects	Distal RTA also causes nephrocalcinosis
Thick ascending loop (Bartter) or distal tubular NaCl receptor defects (Gilteman)	Hypochloremia, hypokalemia, alkalosis
Collecting tubule (ADH receptors) –Nephrogenic diabetes insipidus	Polyuria, hypernatremia due to loss of free water

Disorders of the tubule have varied manifestations. This table provides some examples of such defects highlighting the protean manifestations.

Growth Velocity

The measurement of growth velocity is helpful when assessing need for growth hormone therapy (Chapter 1).

Mid-Parental Height

Assessing mid-parental height should also be considered when assessing appropriate growth velocity in children with CKD (Chapter 1). This can give insight on appropriate growth parameter goals or utilized in the discussion on when growth hormone therapy is warranted.

Mid-Upper Arm Circumference (MUAC)

MUAC should be measured and tracked when the child is at a euvolemic state such as after dialysis. Although MUAC has been shown to change less significantly with dramatic volume shifts compared to weight, MUAC still exhibits slight changes with volume status. Additionally, as MUAC is measured on a long bone, it is important to consider the effect that short stature may play in the corresponding circumference if not adjusted for height age. See Chapter 1 for more information about obtaining MUAC.

Growth Charts

Similar to standard pediatric anthropometric and growth assessment, WHO growth charts are recommended for children less than 24 months of age (weight, length, head circumference, weight for length). Once children are greater than 2 years of age, the CDC growth charts are recommended for plotting of dry weight, height, and BMI.

Protein-Energy Wasting

Protein-energy wasting (also referred to as kidney cachexia) has been implicated as a significant risk factor in cardiovascular-related mortality in CKD. Protein-energy wasting is a state of decreased muscle and fat mass that is characterized not only by inadequate intake but also includes inflammation and metabolic abnormalities that may not be reversed with only nutrition intervention (Table 20.7). This terminology difference remains imperative to be able to discern malnutrition versus protein-energy wasting. The presence of three or more criteria is recommended for the diagnosis of protein-energy wasting in children with CKD. The criteria are as follows: (1) poor growth, (2) decreased appetite, (3) reduced muscle mass, (4) reduced body mass, or (5) inflammation.

Growth assessment and nutrition-focused physical exam (NFPE) are important components of a thorough nutrition assessment for patients with renal disease. Table 20.8 provides recommendations for the frequency of anthropometric measurements for these patients. Table 20.9 identifies NFPE findings unique to patients with renal disease.

TABLE 20.7
Protein-Energy Wasting in Chronic Kidney Disease

Criteria	Definition – 1 Time Point	Definition – 2 Time Points
Biochemical	C-reactive protein >3 mg/L	
Reduced body mass	BMI for height/age <5th percentile	Decrease >10% in BMI for height/age percentile × 1 year
Reduced muscle mass	MUAC for height/age <5th percentile	Decrease >10% in MUAC for height/age percentile × 1 year
Decreased appetite	Fair, poor, or very poor over week prior to visit	
Poor growth	Height/age <3rd percentile	Decrease in height/age >10% × 1 year

Legend: BMI, body mass index; MUAC, mid-upper arm circumference.

TABLE 20.8
Parameters and Frequency of Anthropometric Assessment in Children with Chronic Kidney Disease Stages 3b-5D

	Age 0–1 year		Age 1–3 years		Age >3 years	
	Minimum Interval (weeks)		Minimum Interval (months)		Minimum Interval (months)	
Measure	**CKD 3b-5**	**CKD 5D**	**CKD 3b-5**	**CKD 5D**	**CKD 3b-5**	**CKD 5D**
Height or length for age (centile or *z*-score)	6	2–4	2	1	3	3
Height or length (centile or *z*-score)	8	4	3	2	6	6
Height velocity for age (*z*-score)	N/A	N/A	3	2	6	6
Estimated euvolemic weight and weight for age (centile or *z*-score)	6	4	2	1	3	3
BMI for height age (centile or *z*-score)	N/A	N/A	2*	1*	3	3
Weight for length* (centile or *z*-score)	6	6	2*	1*	N/A	N/A
Head circumference for age (centile or *z*-score)	6	4	2	2	N/A	N/A

*Weight-for-length should be used for children <2 years of age, or up to 3 years if accurate standing height measurement is not possible.

Laboratory Assessment

Biomarkers for nutrition assessment in children with CKD are individualized to the stage or dialytic therapy (Table 20.10). Hypoalbuminemia is a marker of mortality in this patient population and remains an important biomarker to track. However, it is not indicative of the presence of malnutrition but rather sensitive to fluid status, proteinuria, or inflammation. Prealbumin should also be used with caution as an assessment of nutrition status in children with renal dysfunction. Those on dialytic therapy are known to have inherent inflammation. As prealbumin is a negative acute phase reactant, this could also be reflective of the ongoing inflammation related to their care and disease.

Dietary Intake

Assessment of appetite and dietary recall of patients with CKD is extremely important and predictive of malnutrition in this patient population. Appetite levels reported as anything less than "good" act as an early predictor of malnutrition in children with CKD. Standard 3-day diet recall and 24-hour recalls are also helpful in analyzing inadequate or excessive nutrient intake in children with CKD where clearance of electrolytes and minerals is excessive or restricted. Inclusion of fluid intake (or more specifically thirst and desire for water intake) can be an important item to ask with respect to evaluation of adherence to fluid requirements or displacement of nutrient intake for fluid. Inadequate intake in children with CKD is extremely common. Gastroesophageal reflux, gastroparesis, uremia, medication burden or taste, thirst for water, and dysregulation of appetite hormones act as contributory factors to poor oral intake in children with CKD. Earlier diagnosis of CKD in life and increased medical complexity can also contribute to delayed oral motor skills in children with CKD. Parenteral nutrition is less common in the CKD population and is largely driven by their primary disease or confounding disease that would limit gastrointestinal motility, function, or absorption.

TABLE 20.9
Common Physician Exam Findings/Micronutrient Deficiencies

Site	Physical Examination	Potential Nutrition/Metabolic Status
Overall	Cachexia	Protein-energy wasting/malnutrition in CKD
	Cushingoid appearance	Glucocorticoid use
	Obesity	Glucocorticoid use; increased absorption of peritoneal dialysis dialysate; decreased physical activity levels
	Lethargy	Anemia, uremia
Adipose	Atrophy of orbital fat or loss of subcutaneous fat	Protein-energy wasting/malnutrition in CKD
	Excess subcutaneous fat	Glucocorticoid use; increased absorption of peritoneal dialysis dialysate; decreased physical activity levels Note: abdominal distribution of fat tends to increase with CKD progression
Musculoskeletal	Atrophy	Decreased conditioning, gross motor delays Progressive with increasing CKD stage
	Muscle weakness or tingling in feet/hands	Folate deficiency
	Cramping	Rapid or excessive ultrafiltration; low fluid intake in polyuric patient
	Muscle twitching: face vs. carpal muscles, Chvostek vs. Trosseau signs	Vitamin D deficiency with hypocalcemia
Skin	Pallor	Iron, folate, vitamin B_{12}, riboflavin deficiency
	Dry scaly skin	Essential fatty acid, biotin deficiency; vitamin A excess or deficiency
	Necklace distribution dermatitis, rough skin	Niacin deficiency
	Acral distribution dermatitis	Zinc deficiency
	Calcinosis	Hypercalcemia
	Acanthosis	Obesity/metabolic syndrome
	Edema	Low albumin, fluid overload
	Hyperpigmentation	Uremia
Nails	Koilonychias (spoon-shaped)	Iron deficiency, also deficiency of riboflavin, vitamin C, and niacin (pellagra)
	Transverse leukonychia (opaque white band)	Protein-energy wasting, zinc deficiency, pellagra (niacin), inadequate calcium
	Haplonychia (soft nails)	Deficiency of vitamins A, B_6, C, D, and inadequate calcium
	Beau's lines (transverse grooves or depression)	Period of severe illness; protein-energy wasting, pellagra
	Pale nail bed	Anemia
Head/face	Moon face	Edematous protein-energy wasting (kwashiorkor); glucocorticoid use
	Bilateral temporal wasting	Protein-energy wasting
	Apathy	Protein-energy wasting, folate deficiency
	Sunken fontanelle	Dehydration, excessive ultrafiltration

(*Continued*)

TABLE 20.9 (*Continued*)
Common Physician Exam Findings/Micronutrient Deficiencies

Site	Physical Examination	Potential Nutrition/Metabolic Status
Mouth	Oral mucocutaneous rash, angular stomatitis, cheilosis	Deficiency of vitamin B complex (riboflavin, niacin, B_6, biotin), iron deficiency
	Bleeding gums	Vitamin C deficiency with dialysis losses
	Cracked lips, dry mucous membranes	Fluid restriction; excess ultrafiltration, insufficient fluid intake in polyuric patient
	Dysgeusia	Common due to medications and uremia
	Excessive thirst	Fluid restriction; excess ultrafiltration, insufficient fluid intake in polyuric patient; high salt intake
	Pale gums	Anemia
	Halitosis or uremic breath	Uremia
Tongue	Atrophic glossitis	Deficiency of iron, riboflavin, B_6, niacin, B_{12}
	Diminished taste	Zinc deficiency
	Pale tongue	Anemia
Eyes	Abnormal vision	Possible side effect of abnormal blood pressure
	Circles under eyes	Dehydration
	Sunken eyes	Dehydration
Hair	Dull, easily pluckable, hypopigmented	Protein-energy wasting
	Lanugo	History of significant weight loss
	Hypopigmented hair	Protein-energy wasting, copper deficiency
	Brittle hair	Zinc deficiency
	Alopecia	Anemia, zinc deficiency, medication side effects
Digestive	Abdominal distention	Constipation
	Ascites (smiling umbilicus)	Hypoalbuminemia; fluid overload; edematous malnutrition
	Abdominal cramping, bloating, pain	Constipation
	Anorexia	Common in late stage CKD, uremia, medications
	Appetite	Dysregulation CKD, increased with glucocorticoid use and post transplantation
	Nausea/vomiting	Uremia, delayed gastric emptying, rapid ultrafiltration, high feeding volumes coinciding with peritoneal dwells
	Early satiety	Common in peritoneal dialysis due to presence of dialysate solution in peritoneum
Bones	Tibial bowing	Rickets, vitamin D deficiency, renal osteodystrophy (ROD)
	Harrison's sulcus	
	Rachitic rosary	
	Rickets	
	Bone widening at ends	
Blood pressure	Hypertension	Intrinsic renal disease, fluid overload
	Hypotension	Possible after dialysis; poor cardiovascular remodeling; rapid ultrafiltration
Temperature	Hypothermia	Protein-energy wasting
Heart rate	Bradycardia	Protein-energy wasting, cardiovascular changes due to hypertension or chronic fluid overload, modulated by medications
	Tachycardia	Beri beri (thiamine deficiency), cardiovascular changes due to hypertension or chronic fluid overload, hypovolemic state

TABLE 20.10
Laboratory Measurements for Patients with Renal disease

Laboratory	Clinical Significance
Serum albumin	Increased: dehydration (false elevation); post receiving blood products Decreased: over-hydration (falsely decreased); chronic protein losses (e.g., nephrotic syndrome), poor intake; infection
Alkaline phosphate	Increased: hyperparathyroidism; renal osteodystrophy; calcium deficiency; liver disease
Blood urea nitrogen (BUN)	Increased: dehydration; decreased GFR; excessive protein intake; GI bleed; inadequate dialysis Decreased: acute low protein intake; over-hydration; malnutrition BUN:Cr ratio: >15: catabolic state, dehydration, or excessive protein intake; <10: intra-renal problem (AKI or CKD) Urea reduction ratio: rapid calculation of urea clearance with HD, usually goal>65%; (PreBUN-Post BUN/PreBUN*100)
Normalized protein catabolic rate (nPCR)	Calculation or urea generation between the end of one HD treatment to the start of the next. Utilized as a marker of nutrition status in maintenance HD population measured as grams protein/kg/day
Serum calcium	Increased: hypervitaminosis D; dehydration; immobility Decreased: hypoparathyroidism; hyperphosphatemia; acidosis; vitamin D deficiency; magnesium deficiency; hypoalbuminemia
Creatinine	Increased: dehydration; decreased GFR; high protein intake Decreased: low protein intake; over-hydration; malnutrition; low muscle mass
Ferritin	Increased: chronic illness; megaloblastic anemia; inflammatory disease Decreased: severe protein deficiency; iron deficiency anemia
Hematocrit	Increased: blood products, dehydration Decreased: chronic illness-decreased erythropoietin production
Hemoglobin	Increased: blood products, dehydration Decreased: chronic illness-decreased production of erythropoietin
Iron	Increased: transfusion; hepatitis Decreased: anemia; chronic bleeding
Lipids: Cholesterol Triglycerides	Increased: nephrotic syndrome; high fat intake; steroids; hypothyroidism; stress, peritoneal dialysis Decreased: malnutrition; malabsorption; hyperthyroidism; liver disease; statin
Magnesium	Increased: renal insufficiency; hypothyroidism, decreased clearance on PD Decreased: malnutrition; hypoparathyroidism; CKD
Sodium	Increased: dehydration; loss of antidiuretic hormone; water loss that has exceeded sodium loss Decreased: over-hydration; vomiting; diarrhea; diuretic therapy; renal tubular disorders; excessive sweating; uremia with acidosis Hyponatremia is rarely due to sodium depletion alone; fluid restriction and fluid removal during dialysis may be needed
Phosphorus	Increased: decreased GFR Decreased: refeeding syndrome; malnutrition; excess phosphate binding therapy; hungry bone syndrome
Potassium	Increased: dehydration; impaired renal function; hemolysis; acidosis; Calcineurin inhibitor; hyporenin-hypoaldosterone Decreased: vomiting; diarrhea; diuretic therapy; renal tubular disorder
Transferrin saturation	Increased: falsely elevated in dehydration Decreased: falsely decreased in over-hydration

Gastrointestinal Findings

Gastroesophageal reflux, gastroparesis, and constipation are common in children with CKD. These can be a consequence of uremia, medications, required fluid restrictions, or dialysis. Gastroesophageal reflux can be especially common in infants and young children on peritoneal dialysis given the limited abdominal space for both food and peritoneal dialysate solutions. Prevention of constipation is also extremely important for maintaining functionality of peritoneal dialysis catheters.

Medications

There are a wide variety of medications used in patients with renal disease. Some medications are used to treat nutrition problems while others impact nutrient intake or utilization. Table 20.11 outlines common medications with nutrition implications.

Nutrition Diagnosis

Common nutrition diagnoses for patients with renal disease include:

- Altered nutrition-related laboratory values (specify)
- Decreased nutrient needs (specify)
- Food and nutrition-related knowledge deficit
- Excessive fluid intake
- Malnutrition (undernutrition)

TABLE 20.11
Common Medications with Nutrition Significance

Medication Type	Use/Side Effects
	Renal Osteodystrophy
Active vitamin D (1-25 dihydroxy vitamin D)	Used to increase Ca absorption and normalize PTH; essential for normal bone mineralization; promotes calcium-phosphorus homeostasis
Phosphate binder	Taken with meals; interferes with iron absorption; can cause constipation. Non-calcium-based phosphate binder powders carry risk of clogging feeding tubes if not flushed well. Diminishing binding capabilities with increasing dosage
Vitamin D_3 (25 OH vitamin D)	Treats vitamin D deficiency, increases calcium with increased absorption
	Anemia Management
Iron supplements	Treats anemia; usually prescribed with erythropoiesis stimulating agent. Can stain teeth or contribute to constipation
Erythropoietin stimulating agent	Prescribed along with iron, B_{12}, and/or folate supplementation
Hypertension management	Diuretics: utilized with urine output; monitor electrolytes abnormalities in sodium and potassium ACE-Inhibitors: may experience slight decreases in GFR leading to decreased potassium excretion
Growth hormone	Used for long-term treatment of growth failure in CKD
Alkali therapy	Citrate/bicarbonate – alkalinizing agent used as a buffer to treat acidosis. May come with sodium or sodium + potassium combinations
	Electrolyte Therapy
Potassium exchange resin	Treats hyperkalemia via sodium exchange. May cause diarrhea and increased sodium absorption
Electrolyte supplementation	A variety of supplementation may be needed to tightly manage abnormalities or replace high losses

Nutrition Intervention

Nutrition Prescription

Macronutrients

Patients with CKD have similar energy requirements to their peers (Chapter 3). If additional co-morbidities require increased energy, energy requirements default to that of the co-morbidity with the higher energy demand.

Protein needs can be increased at later stages of CKD and in dialytic therapies with increased protein losses. Co-morbidities may lead to increased protein demand. Optimization of protein intake to promote growth and attain nutrition goals while avoiding azotemia is a fine line that every clinician should be aware of in the management of CKD. Multidisciplinary discussion of nutrition and growth goals as well as metabolic control is imperative.

Fluid needs are dictated by the etiology of renal disease and level of renal impairment. For example, renal dysplasia is often associated with high levels of water excretion and thus, fluid requirements are increased over normal age-related expectations. Hemodialysis is associated with lower residual renal reserve and urine output, thus fluid needs are decreased to prevent effects of chronic fluid overload such as left ventricular hypertrophy. Fluid goals should focus on euvolemia, with avoidance of hyper or hypo-hydrated states. Output dictates fluid requirements which include but may not be limited to: urine output, respiratory losses, sweat losses, and gastrointestinal losses.

Micronutrients

Fat-soluble vitamins are less well cleared in the setting of renal impairment. Children with CKD have decreased retinol clearances. Increased vitamin A levels are associated with altered bone health and may be identified through unexplained hypercalcemia. Avoidance of both organ meats and exogenous supplementation is recommended. Vitamin D has a significant role in CKD. Both active and inactive forms of supplementation are often required. Vitamin E and K are less well studied in CKD. Current evidence does not support supplementation or targeted restriction of either vitamin E or K as a result of CKD.

Water-soluble vitamins are more likely to be deficient in children due to dialysate losses. Most commonly reported water-soluble vitamins lost through dialysate include: thiamin (B_1), pyridoxine (B_6), folic acid, and vitamin C. Other supplementation of water-soluble vitamins is generally recommended when overall nutrient intake is limited related to poor intake or as a result of other dietary restrictions. Appropriate folate and vitamin B_{12} supplementation can also work in conjunction with anemia management. Vitamin C should be supplemented if levels are low; however, vitamin C is also a precursor to oxalate production and can contribute to kidney stone formation.

Zinc and copper deficiency have been reported in patients with CKD due to dietary restrictions. Deficiencies in binding proteins through proteinuria have also been reported to contribute to zinc and copper deficiencies especially in the setting of uncontrolled nephrotic syndrome. Selenium supplementation is less well studied but has been identified as a potential nutrient of concern given its changes in metabolism with renal impairment. Children on CRRT may have higher losses through the dialysate that require additional supplementation. Iron deficiency is common in children with CKD due to impaired erythropoietin production. Lastly, aluminum is not well excreted with renal disease and associated with toxicity, most frequently as a result of aluminum containing dialysate solutions or aluminum containing phosphate binders.

Primary electrolytes of concern in renal impairment include: sodium, potassium, phosphorus, calcium, and magnesium. Sodium is generally utilized in maintaining volume and blood pressure control. Tight sodium control can be extremely challenging with respect to both social situations and the food environment. Salt substitutes are generally contraindicated as, chemically, they are potassium chloride which may lead to hyperkalemia. Limiting excessive sodium intake remains important even after transplant as it still plays a preventative role in the development of hypertension.

Notably, infants and children with CKD may have significant salt wasting and require supplementation for both water balance and growth.

Potassium is cleared through the kidney, and thus, regulation of appropriate potassium levels is imperative. Dyskalemia is a life-threatening issue for children with CKD. Hyperkalemia is common with CKD, although hypokalemia can occur as well. Similar to sodium, potassium can be challenging to manage as its primary sources are generally healthy foods such as fruits, vegetables, cereals, and milk. Mediterranean and DASH style diets that incorporate more plant-based food sources but also incorporate more potassium may allow higher tolerance of these higher potassium-content foods through decreased absorption and acid production. Potassium levels will determine the allowance in the child with renal disease. Potassium additives are becoming a substantial source of potassium intake in processed foods.

A good understanding of the calcium-parathyroid hormone (PTH)-vitamin D axis is important in the management of phosphorus and calcium in children with CKD. Without activated vitamin D, intestinal absorption of calcium may be poor, signaling increased PTH release causing calcium and phosphorus release from the bone. High phosphorus intake can further increase PTH. Phosphorus and calcium management are important for management of renal osteodystrophy (ROD), growth and prevention of vascular calcifications. Vascular calcifications are a significant risk for cardiovascular morbidity. Dietary phosphorus restriction is extremely difficult in children with CKD due to poor clearance and intake of high phosphorus content foods common in children's diets. Maintenance of phosphorus levels requires dietary control, ROD medication management, and, when necessary, dialysis. Assessment of phosphorus intake is extremely problematic. Phosphorus is not reported on the nutrition labels. Phosphorus is a hidden additive in food and drink products. Additive sources have a high bioavailability. Appropriate calcium and phosphorus serum levels vary with age and reflect the rate of bone formation; levels are higher at younger ages to support bone accrual. After transplantation, phosphorus levels can be difficult to maintain initially due to high rates of phosphaturia and may even require supplementation. Excessive calcium intake can also be a risk factor for vascular calcification and for this point; it is recommended that the total intake from diet and medications be less than 200% of the DRI for age.

Lastly, magnesium clearance can also be decreased in children with CKD. Dietary restrictions are not generally recommended, although sometimes necessary. This is more frequent in children on peritoneal dialysis. Hypomagnesemia is problematic in renal transplant patients due to increased wasting associated with calcineurin inhibitors.

Specific Diagnoses and Effects of Nutrition Intervention

Cardiovascular Disease and Lipid Management

Dietary control of factors that increase hypertension, obesity, and calcifications become very important for mediation of cardiovascular risk. Dyslipidemia is present in children with CKD and occurs more frequently at later stages of CKD as well as after transplant (more so related to obesity). Standard nutrition therapy for dyslipidemia can be attempted (e.g., reduction in total fat and saturated fat and increase in mono- and polyunsaturated fats). However, these children likely already have a multitude of dietary restrictions making this difficult to achieve. Low cholesterol levels have also been reported as a risk factor in cardiovascular health.

Renal Transplantation

Cardiovascular disease and its associated risk factors remain of great concern even in patients with renal transplantation. Obesity, hypertension, and metabolic syndrome are common, and as these issues would further affect the health and longevity of both the transplant and the child, a generally healthy diet (e.g., encouraging a Mediterranean or DASH style diet habits and physical activity) must be emphasized. Use of glucocorticoids in the immunosuppression plan may also contribute to this substantially higher risk of obesity in children with CKD. Adequate hydration after renal transplant

is also very important. Standard food and water safety guidance becomes even more important as these children may be at higher risk for experiencing food-borne illness with immunosuppression.

Acute Kidney Injury

There is limited evidence on nutrition therapy available in children with AKI, with most seen in children requiring CRRT. Lack of nutrition may be a contributing factor to initiation of CRRT, thus a dietitian should be involved in the care of these children. CRRT allows for unrestricted nutrition therapy and results in an excess loss of nutrients (e.g., protein, folate, carnitine, selenium). CRRT is most frequently performed in hemodynamically unstable children; tolerance of enteral nutrition can be difficult and they frequently require parenteral nutrition. The dietitian should understand that stopping CRRT often means transition to an intermittent therapy while awaiting renal function to return. Nutrition therapy for acute intermittent dialytic therapies and non-dialysis AKI often mimic those of chronic management. AKI is dynamic in nature and treatments from a nutrition standpoint need to be dynamic as well, often requiring nutrition reassessment 1–3 times per week.

Nephrotic Syndrome

As the standard medical treatment for NS involves improving and preventing edema, medical nutrition therapy is utilized to support this goal. Thus, the corresponding nutrition therapy focuses on sodium and/or fluid restrictions. Fluid restrictions are often short term. If the child is in remission, fluid intake may be liberalized. Although proteinuria, a hallmark sign of NS, leads to increased protein losses, additional protein supplementation in the setting of NS is not recommended.

Nephrolithiasis

Nutrition can play a key role in prevention and reduction of stone formation. Medical nutrition therapy for most kidney stones focuses on preventing saturation of stone-forming substances. Lemonade therapy can be effective in increasing citrate intake in combination with pharmacological therapy in nephrolithiasis. The standard recommendation for lemonade therapy is 60 mL freshly squeezed lemon juice diluted in 1 L of water. Urinary citrate levels should be re-checked after several months to monitor effectiveness.

Generally speaking, dietary restriction of oxalate is not recommended for the prevention of nephrolithiasis. The exception are patients with identified oxaluria and over-consumption of very-high oxalate foods. Calcium may moderate the absorption of dietary oxalate, and adequate calcium intake is recommended.

Renal Tubular Disorders

In renal tubular acidosis, nutrition therapy may include similar nutrition therapies as seen in nephrolithiasis. Rare disorders like Bartter's syndrome and Gitelman syndrome may require high amounts of electrolyte supplementation including that of sodium, chloride, potassium, and magnesium. In nephrogenic diabetes insipidus, nutrition therapy focuses on prevention of hypernatremia due to impaired water reabsorption in the kidney. Avoidance of excessive intake of solutes (primarily sodium and protein) that may increase water/urine excretion is important. Water supplementation via tube feedings is often necessary due to the high total fluid volumes (150–200 mL/kg per day) required to maintain adequate serum sodium levels. Growth can also be challenging as fluid intake may displace nutrient intake for oral feeders.

Other Renal Dysfunction

There are many other rare disorders of renal impairment (e.g., primary hyperoxaluria, cystinosis, Liddle syndrome, metabolic disorders) that the dietitian should be aware of but are too numerous to review in the context of this chapter. Understanding how these disorders affect the baseline function of the kidney will help the dietitian implement appropriate nutrition interventions to ensure age-appropriate growth and control of metabolic processes affected by renal impairment.

Common Nutrition Interventions

The primary goal of nutrition management is to achieve optimal nutrition, minimize metabolic disorders, and promote growth. Nutrition intervention should include the development of individualized meal plans to meet energy and nutrient needs for the patient, but also provide a palatable and culturally acceptable diet. Educational plans for the patient/family should assure compliance with the diet.

Oral Diet

The standard diet therapy will reflect the restrictions developed from Tables 20.12 and 20.13. Different cultural and social backgrounds may also make providing adequate nutrition complex.

TABLE 20.12
Summary of Nutrition Management for Acute Renal Disease

	AKI (No Renal Replacement Therapy/Conservative Therapy)	AKI (Intermittent Renal Replacement Therapy)	AKI (Continuous Renal Replacement Therapy)
Energy	EER for age (or original disease state)	EER for age (or original disease state)	Ebb phase of critical illness: BMR/age Flow phase of critical illness: 120%–130% EER for age (or original disease state)
Energy composition	Non-ICU: AMDR ICU: 30%–40% lipid, meet minimum protein needs, remainder carbohydrate		Non-ICU: AMDR ICU: 30%–40% lipid, meet minimum protein needs, remainder carbohydrate (account for carbohydrate gain or loss dependent on anticoagulation source and replacement fluid)
Protein	DRI or less per blood urea nitrogen (BUN) monitoring (Do not restrict protein to delay renal replacement therapy initiation)	DRI + 0.2 g/kg (hemodialysis, adjust for frequency of hemodialysis) DRI + 0.4 g/kg (peritoneal dialysis)	≥2.5 g/kg
Sodium	Will vary. Consult with renal/primary team to determine		Typically, no restriction; may need
Potassium	Tightly limit	Limit. (Adjust per levels, consult with renal/primary team to determine)	electrolyte supplementation. Be aware of transition in dialytic modalities
Phosphorus	Tightly limit	Limit	
Fluids	Will vary according to urine output and edema. Consult with renal team to determine		Generally unrestricted unless severe edema. Ultrafiltration rate controls fluid removal and can be titrated
Micronutrients	Tightly limit fat-soluble vitamins	Limit fat-soluble vitamins May need supplementation of water-soluble vitamins	May need supplementation of folate, thiamine, selenium, and carnitine

Source: Adapted from Nelms CL, Juarez M, Warady BA. Renal Disease. In: Corkins MR, Balint J, Bobo E, Plogsted S, Yaworski JA, eds. *The A.S.P.E.N. Pediatric Nutrition Support Core Curriculum*. 2nd ed. Silver Spring, MD: American Society for Parenteral and Enteral Nutrition; 2015:351–385.

Legend: EER, estimated energy requirement; BMR, basal metabolic rate calculated using Schofield Equation; AMDR, acceptable macronutrient distribution range; ICU, intensive care unit; DRI, dietary reference intake.

TABLE 20.13
Summary of Nutrition Management for Chronic Renal Disease

	Nephrotic Syndrome	CKD (Stages 3–5)	CKD (Stage 5D on Hemodialysis)	CKD (Stage 5D on Peritoneal Dialysis)	CKD (Stage 5T)
Energy	EER for age or per clinical status				
Energy Composition	Non-ICU: AMDR ICU: 30%–40% lipid, meet minimum protein needs, remainder carbohydrate				
Protein	DRI – do not need to supplement to replace urinary losses	Stage 3: 100%–140% DRI/kg IBW Stage 4/5: 100%–120% DRI/kg IBW	DRI + 0.1 g/kg IBW	DRI + 0.15-0.3g/kg/ IBW (dependent on age)	DRI + post-operative healing <2 years: 2–3 g/kg 2–13 years: 1.5–2 g/kg 13–18 years: 1.5 g/kg
Sodium	1–3 mEq/kg, varies according to edema or HTN unless sodium wasting				Chronic Disease Risk Reduction Intakes. May vary according to hypertension, edema, or sodium wasting
Potassium	Restriction not needed	May tolerate >3 mEq/kg but will vary according to serum levels and age	1–3 mEq/kg but will vary according to serum levels and age	Generally unrestricted unless low transporter status. Will need to be monitored	Generally unrestricted but dependent on the function of the transplanted kidney and effect of calcineurin inhibitor on serum levels
Phosphorus	Restriction not needed	Limit to 80%–100% DRI to maintain age-appropriate serum levels. Infants and young children may not need as significant a restriction to maintain age-appropriate serum levels			Generally unrestricted and may need supplementation in immediate post-transplant period dependent on bone health prior to transplantation
Fluids	Will vary according to urine output and edema. Consult with renal team to determine	Generally unrestricted	Maintain euvolemia; limit to UOP, insensible losses + UF. UF is generally limited to <13 mL/kg/ hour treatment	Maintain euvolemia; limit to UOP, insensible losses, + UF. Or approximately 1 L X BSA/day if oliguric	Generally, minimum fluid goals are necessary to maintain hydration. May use Holliday Segar method, BSA × 2–2.5 L/day or match urine output
Micronutrients	DRI/age	100% DRI. Supplement water-soluble vitamins if needed	100% DRI. Water-soluble vitamin supplement is recommended		DRI/Age. May need supplementation of magnesium due to calcineurin-related wasting

Source: Adapted from Nelms CL, Juarez M, Warady BA. Renal Disease. In: Corkins MR, Balint J, Bobo E, Plogsted S, Yaworski JA, eds. *The A.S.P.E.N. Pediatric Nutrition Support Core Curriculum*. 2nd ed. Silver Spring, MD: American Society for Parenteral and Enteral Nutrition; 2015:351–385.

Legend: EER, estimated energy requirement; BMR, basal metabolic rate calculated using Schofield Equation; AMDR, acceptable macronutrient distribution range; ICU, intensive care unit; DRI, dietary reference intake; IBW, ideal body weight; UF, ultrafiltration; UOP, urine output; BSA, body surface area; L, liter.

Individualization to each patient's specific needs will determine the best nutrition plan of care. Most common modifications will focus on sodium, potassium, phosphorus, and fluid within a diet order. Conversion from milliequivalents to milligrams or grams may help families and kitchen staff understand and improve implementation of the diet. Institutions may also need more liberalization in hospital versus at home given difficulty in implementation of diet to ensure the child is receiving adequate nutrition to grow while maintaining metabolic control. Specific milligram restriction levels for phosphorus are less frequently discussed due to the inability to track numbers well and are reported as "low-phosphorus" diet restrictions.

Enteral Nutrition

Tube feedings are commonly needed in children with renal disease, especially those with more advanced stages of CKD earlier in life. The nephrology community is very proactive in initiating nutrition support therapy given the increased morbidity and mortality associated with poor growth in this specific disease population. Tube feedings can act as supplements to oral intake or as a sole source of nutrition.

For infants, human milk remains the best due to its low renal solute load. In the setting of fluid restrictions, human milk will require concentration with low renal solute load formulas or modulars to allow for optimal nutrition provision. Tolerance to concentrated products is individualized based on the child's medical history and age. Renal dietitians are often forced to continue to attempt increasing concentrations of formula to improve nutrition while maintaining fluid restrictions. Concentration can be as high as 2 kcal/mL. Caution should always be executed when concentrating formulas for infants and children with gastrointestinal co-morbidities or neonates at risk for necrotizing enterocolitis. There are limited infant and pediatric renal-specific formulas on the market. It is important for the dietitian to realize that "age appropriateness" of formulas is tied to meeting macro- and micronutrient needs based on normal aged healthy infants, children, and adults. Children with renal impairment do not have "normal" macro- and micronutrient needs (e.g., calcium, phosphorus), thus the requirement of age appropriateness does not hold true. To this end, calculation of both macronutrients and micronutrients provided is imperative to understand a child's laboratory values in concert with their intake. Common interventions made when even standard infant or pediatric renal-based formulas are not adequate for individual situations include: dilution of a base formula with additional electrolyte-free modular products (fat, carbohydrate, and/or protein) to supplement nutrition needs or use of a regular age-appropriate product diluted with a very-low renal solute formula to ensure appropriate electrolyte restrictions are met. Other interventions may include techniques such as "decanting" formula with potassium resins or phosphorus binders. These methods require more specific mixing instructions for families and bedside nurses. They are less accurate in identifying true intake of all nutrients (e.g., potassium, phosphorus, iron). Decanting methods can still present difficulty in managing electrolytes appropriately.

Parenteral Nutrition (PN)

Use of PN presents many problems of concern for a child with CKD – especially with regard to fluid and vitamin/mineral needs. As children with CKD often require fluid restriction, maximal concentration of PN may require more fluid than an enterally fed counterpart. Standard vitamin solutions may contain too much vitamin A than can be appropriately cleared by a child with CKD. PN has been used in children receiving maintenance HD as a means to halt protein catabolism related to the act of hemodialysis and protein removal through the hemodialysis filter. This is termed intradialytic PN (IDPN). The goal in this therapy is to bridge the gap in protein losses and prevent additional weight loss from occurring. IDPN has been proven to help prevent hospitalizations for malnutrition induced by inadequate intake.

Supplementation/Vitamins/Minerals

A variety of supplements may be required in children with renal impairment. Renal multivitamins should be given to children receiving dialytic therapies. ROD control requires

supplementation of both active and inactive forms of vitamin D. Carnitine supplementation may be important for children on frequent HD and CRRT. Patients on CRRT requiring PN may require additional folate, vitamin C, and selenium. Electrolyte supplementation is most commonly needed in infants and toddlers where sodium or phosphorus needs are higher. Phosphate and/or magnesium supplementation may be necessary in the initial period after renal transplantation if oral intake cannot maintain adequate serum levels. Monitoring of serum values and physical manifestations of deficiencies are necessary to know when to supplement vitamins, minerals, or electrolytes in this population.

Nutrition Education

Education is an essential piece to medical nutrition therapy for children with renal impairment. It is the responsibility of the dietitian to educate the child and family on how to implement diet modifications at home. Assessment of reading literacy, cooking literacy, participation in governmental food subsidies, the food environment, and school participation are all part of knowing how to approach education for these children and families. Education provided should also involve the child given the fact that renal disease is lifelong. Education focusing on cooking at home using unprocessed foods as much as possible will help with all types of renal diet restrictions to limit food additives. Utilizing seasonings that do not contain sodium (herbs and spices) are important when children are used to eating higher-sodium diets. Label language is also important to review so families understand that despite certain products advertised as "low sodium", they may not be low enough for their child's restriction. Education on potassium restrictions should focus on maintaining a healthy intake of lower potassium containing fruits and vegetables. As our knowledge of plant-based sources of phosphorus and its bioavailability have improved, in addition to avoidance of phosphate additives, education now centers on encouraging more plant-based healthy sources of phosphorus despite their high phosphorus content (e.g., plant-based milks vs. animal-based milks; allowing whole-wheat breads and legumes). Education on fluid restriction should focus on defining a fluid goal and discussing with the family how they will track it on a daily basis and potential barriers that may ensue (e.g., daycare or school settings). Understanding how to work with schools and daycare is also important for a renal dietitian so that a child may continue to receive these services without significant interruption in their day-to-day life. Other fluid restriction-based interventions focus on thirst management by allowing children to suck on hard candies or chew gum, if developmentally appropriate. Providing families with modifications on how to dine out on occasion may also help with compliance and rapport building. In children with CKD, the caregiver burden is substantial and the dietitian should make attempts to ease the nutrition-related disease burden that ensues. Lastly, early and ongoing education surrounding the importance of growth and avoidance of malnutrition is imperative. This can ease discussions regarding more aggressive nutrition support therapy should the child's growth start to falter with advancing CKD.

Coordination of Care

The treatment of renal disease is built with large multidisciplinary teams. Common specialties that a dietitian working with children with renal impairment may interact with on a regular basis can include: social workers, child-life specialists, psychologist, and school specialists. Any member of this team may be helpful in aiding implementation of nutrition interventions. For example, social workers may aide with insurance coverage related to formula, child-life specialists may help with implementation of nutrition interventions or help with education on age-appropriate levels, school specialists may help navigate school-district compliance with diet modifications, and psychologists may help with managing patient and family sources of non-compliance with medical and nutrition interventions. Other specialty referrals that may be important for children with renal impairment can include occupational therapy, physical therapy, home health, and even intensive feeding therapy.

TABLE 20.14
ADIME Summary for Pediatric Renal Diseases

- Assessment
  - Growth assessment
    - Use standard growth charts
    - Use dry weight
    - Height-for-age-adjusted BMI
    - Mid-parental height
    - MUAC
  - Nutrition focused physical exam
  - Nutrient intake
  - Labs
    - Important indicators of nutrition status and need for dietary restrictions
    - See Table 20.10
  - Medications/side effects
    - See Table 20.11
  - Assess for protein-energy wasting (kidney cachexia)
- Diagnosis
- Intervention
  - Nutrition prescription
    - Significant alterations in protein, fluid, electrolyte, and micronutrient needs
    - See Tables 20.12 and 20.13
  - Common nutrition interventions
    - Oral
    - Enteral nutrition
      - Increase formula concentration
      - Consider renal formulas
      - Frequent use of electrolyte-free modular products
      - Decanting with potassium resins or phosphorus binders
    - Parenteral nutrition
      - Concentrate PN to meet fluid restrictions
      - PN multivitamin may contain too much vitamin A
    - Education
      - Following diet modifications at home
    - Laboratory monitoring
      - Essential in this population. See Table 20.10
    - Supplements
      - Use renal multivitamins for patients on dialysis
    - Other specialty referrals
      - Social work
      - Child-life specialist
      - Psychologist
      - School specialists
- Monitoring & evaluation
  - Growth parameters
  - Laboratory monitoring

Nutrition Monitoring and Evaluation

Continued monitoring and evaluation are essential to decreasing morbidity and mortality in patients with renal disease. These children are vulnerable to poor growth, malnutrition, and life-threatening metabolic abnormalities. Continued reassessment of growth, fluid status, vital signs, laboratory values, understanding of diet restrictions/needs, and compliance are necessary critical components to monitor the overall picture of the child's medical and nutrition status.

Growth parameters and frequency of assessment of dietary intake are determined by the child's age and stage of CKD. For dietary assessment, it is recommended that for infants less than 1 year of age, intake should be assessed every 2 months for CKD stage 3b or higher. For children aged 1–3 years, dietary intake should be assessed for every 3 months for CKD stage 3b or higher. While for children over the age of 3, dietary intake should be assessed at a minimum of every 6 months for greater than CKD stage 3b, until CKD5D where intake should be assessed at a minimum of 4-month intervals. Table 20.8 describes recommended anthropometric parameter measurement frequency by age and CKD stage (Table 20.14).

Alterations to the function of the kidney lead to a variety of metabolic and electrolyte changes requiring careful planning and treatment. Careful monitoring of laboratory values is required to determine kidney function, monitor electrolytes, and identify the need for vitamin and mineral supplements. Given the role of the kidneys in excreting fluid, a weight may be necessary in order to access weight change and growth status. The NFPE is especially important in this population due to weight changes caused by fluid status. Nutrient needs of patients with renal disease vary by disease state. The dietitian is an essential part of the multidisciplinary team caring for patients with renal disease.

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21 Care of Children and Youth with Special Health Care Needs

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CONTENTS

The term children and youth with special health care needs (CYSHCN) refers to a heterogeneous group of children who have or are at an increased risk of a wide range of chronic developmental, medical, and behavioral conditions. Approximately 20% of all children in the USA fall under this category. Almost a quarter of CYSHCN have functional limitations and over half are either moderately or severely impacted by their condition. Almost two-thirds of CYSHCN have a complex

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condition such as autism or developmental delays that require a range of interventions. Diagnoses that fall under the umbrella term of CYSHCN include attention-deficit hyperactivity disorder (ADHD), behavioral/conduct disorders, asthma, autism, developmental delay and behavioral problems, cerebral palsy, epilepsy, and rare genetic disorders, among others. Children with chronic organ-specific diagnoses and diseases covered in many of the other chapters in this book are also categorized as CYSHCN. Given the shift from institutionalized care to community care and increased life expectancy of CYSHCN over the last several decades, the majority of pediatric dietitians will work with CYSHCN throughout their careers.

Disease states, disorders, and functionality of CYSHCN vary greatly though commonalities in this group exist. Compared to typically developing peers, CYSHCN have higher reliance on family or non-formal caregivers for health-related care, increased health care and other service utilization and costs, high rates of unmet health care needs, increased missed days of school, and higher rates of emergency department and hospitalization use. While this chapter focuses on the large group of CYSHCN, there is a subset of about 1% of the total population of children, defined as children with medical complexity, who have the highest rates of health-related expenses and needs. Children with medical complexity often rely on alternate forms of nutrition as described in other chapters. Most CYSHCN qualify for additional insurance benefits as well as governmental and education support programs which often provide, and pay for medical nutrition services.

CYSHCN AND NUTRITION CARE

Nutrition and growth impacts almost every aspect of life for CYSHCN. Nutrition care for CYSHCN is often complex. Plans function best when designed at the individual level and meet the unique needs and goals of the family and child. Nutrition interventions and needs for each child evolve over time. This is partly due to the intrinsic nature of growth and development during childhood. For CYSHCN, it is also due to advances in understanding disease, genetics, and new treatments. While there have been few randomized control trials on this topic, it is felt that optimal and timely nutrition interventions help to lower the risk of comorbidities, improve health and well-being, and lower costs for CYSHCN. In 2015, the Academy of Nutrition and Dietetics (The Academy) released a position statement highlighting the unique needs of CYSHCN and emphasized that care for this population should be provided throughout the lifecycle, in a family-centered, community based, culturally component, and multidisciplinary manner.

Common Nutrition Issues

CYSHCN have a wide spectrum of nutrition, growth, and dietary needs. Some CYSHCN require only nutrition screening and growth surveillance with no medical nutrition intervention, while others require nutrition assessments, alternate feeding routes, and ongoing interventions. It is estimated that 50%–90% of CYSHCN have nutrition risk factors and 80% of children with developmental disabilities have some form of feeding problems. CYSHCN can have altered macronutrient and micronutrient needs, atypical body mass composition, feeding problems associated with swallowing, digestion, or metabolism, and sensory issues.

The etiology of nutrition, growth, and feeding issues for an individual child is often multifactorial. A summary of a few commonly encountered medical diagnoses of CYSHCN and their nutrition considerations are presented in Table 21.1. A pediatric dietitian is likely to encounter additional diagnoses including ones discussed elsewhere in this book. Underlying medical/behavioral health diagnoses, comorbidities, medication/treatment side effects, individual intrinsic characteristics of the child including genetic factors, characteristics of the caregivers as well as social environments and support systems all affect the health status of CYSHCN.

TABLE 21.1
Diagnoses and Associated Nutrition Considerations for CYSHCN

Medical Diagnosis	Background Information	Common Nutrition Considerations
Cerebral Palsy	Umbrella term to describe a permanent motor disorder that results from a static neurologic injury and results in varying degrees of functional limitations Diagnosed based on clinical symptoms with supporting brain imaging findings Children have abnormal muscle tone, posture, movements. Comorbidities common; many (but not all) also have cognitive, sensory, communication, feeding, and behavior impairments Incidence: 2–3 in 1,000 live births	Altered metabolic demand, metabolism, body composition, and functional limitations places some children to be at risk for being underweight and others, overweight Accurate anthropometric measurements can be more difficult to obtain due to contractures, physical limitations, and adaptive equipment orthopedic issues such as scoliosis Physical activity and weight-bearing activities may be limited. Risk of low bone density Gastrointestinal issues common especially in children with severe neurologic impairment: pain, constipation, retching, feeding intolerance, and non-oral feeding Medications used for common co-occurring conditions such as epilepsy, swallowing dysfunction, spasticity, and gastrointestinal issues can alter hunger cues, digestion, and nutrient absorption Disease-specific growth charts exist with some evidence that being underweight on these charts predicts risk of morbidity and mortality
Tracheostomy and Ventilator Dependent	Refers to children who rely on respiratory support delivered via artificial airway and mechanical ventilation. Varying diagnoses and underlying pathologies lead to the need for support, including abnormal ventilatory control, airway abnormalities, chronic lung disease, and neuromuscular weakness Tracheostomies placed in 6 in 100,000 children per year and about half require mechanical ventilation (MV) Duration and type of support needed is related to underlying diagnosis; with >50% of MV-dependent children due to bronchopulmonary dysplasia are able to live without MV by 2 years of age	Underlying diagnosis helps predict nutrition issues/needs Metabolic and fluid needs are individualized for each child and often fluctuate based on time on the ventilator, oral/respiratory secretions, and any plans for changes in support, illness, or surgeries Swallowing, oral motor, and feeding issues are common including aspiration, oral hypersensitivity, oral aversion, and abnormal swallow reflex. Need for feeding and speech therapy and enteral nutrition are common, though some children are able to eat orally Respiratory care and treatments including suctioning and cleaning, require a significant amount of caregiver time and monitoring which may impact caregiver's ability to implement nutrition plans

(*Continued*)

TABLE 21.1 (*Continued*)
Diagnoses and Associated Nutrition Considerations for CYSHCN

Medical Diagnosis	Background Information	Common Nutrition Considerations
Neuromuscular Disorders	Group of disorders with pathology in the peripheral nervous system that result in abnormal muscle function and varying degrees of weakness Severity of clinical symptoms, underlying etiology (i.e., specific genetic or metabolic abnormality) and age of presentation depend on the specific disorder. Children can develop difficulties with walking, secretion management, respiratory issues, and spinal curvature. Cognitive function is often normal though oral communication abilities may be altered due to weakness Examples: • Spinal Muscular Atrophy: incidence 1:6,000–1:10,000 live births • Duchenne muscular dystrophy: prevalence 1:5,000 boys • Others: mitochondrial disorders, myotonic dystrophy, congenital myasthenia, Charcot-Marie-Tooth disease	Altered metabolic demand, body composition including muscle mass, and limitations in physical activity intolerance affect nutrition needs Progressive oral motor weakness for some children affects ability to eat Impacts on nutrition and growth of new medications such as gene therapies or biologic medications should be evaluated Medications used to slow progression such as corticosteroids and acetylcholinesterase (ACE) inhibitors in Duchenne muscular dystrophy may impact weight and nutrient needs
Down's Syndrome (Trisomy 21)	Genetic condition associated with an additional copy of information on chromosome 21 Children with Trisomy 21 often have characteristic physical traits (i.e., decreased muscle tone, flattened facial features, etc.), short stature, associated comorbidities and varying degrees of intellectual disability Incidence: 1:700 live births in the USA	Poor suck and oral motor weakness increase risk of malnutrition in infancy Nutrition needs and metabolic demands are impacted by comorbidities which commonly include heart defects, intestinal atresia, thyroid disease, celiac disease, sleep apnea, developmental delays, and behavioral concerns Increased risk of obesity especially in older children, adolescents, and adults – etiology likely multifactorial including decreased energy needs and limited participation in physical activity Guidelines exist for routine laboratory monitoring including yearly evaluation for hypothyroidism and iron deficiency anemia Specialized growth charts exist – can be used as a complement to standard growth charts

(*Continued*)

TABLE 21.1 (*Continued*)
Diagnoses and Associated Nutrition Considerations for CYSHCN

Medical Diagnosis	Background Information	Common Nutrition Considerations
Prader-Willi Syndrome	Genetic condition that results in specific physical features with associated cognitive, neurological, endocrine, and behavioral abnormalities History of reduced fetal activity as well as hypotonia in early infancy, early dental caries, sleep apnea, reflux, scoliosis, global developmental delay, growth hormone deficiency, and obesity are common associated features Weight, growth, and interrelated behavioral issues such as food seeking, hyperphagia, and obsessive-compulsive disorder are predictable and salient features of this condition necessitating multidisciplinary and life-long care Incidence: 1:20,000–1:30,000 live births	Hypotonia and feeding issues make children at risk for malnutrition in infancy and almost all require assistive feeding (special needs feeder bottle or enteral access device) in the first 6 months of life. However, as children age there is a significant risk of obesity Nutrition care should involve behavioral therapies and other strategies to address issues such as food-seeking behavior as well as eating non-food items Energy restriction, weight control, and management of abnormal eating behaviors to prevent obesity improves life span and prevents the development of comorbid conditions such as diabetes mellitus Children can have altered growth, reduced muscle mass, and short stature. Treatment with growth hormone therapy is recommended. Treatment of hypogonadism can promote lean muscle mass
Russell-Silver Syndrome	Congenital disorder that results from several different genetic abnormalities and presents with prominent clinical features. Diagnosed based on the clinical scoring system of these features Clinical features include prenatal (asymmetric) and post-natal growth failure, relative macrocephaly, body asymmetry, bone-age abnormalities, feeding difficulties, hypoglycemia, triangular-shaped face, and prominent forehead. Majority of children have normal intelligence and can have typical educational attainment and fertility later in life Estimated incidence: 1:30,000–100,000 children	Poor weight gain in infancy and asymmetric intrauterine growth restriction is a defining feature. Malnutrition is often seen and is multifactorial. Some children do not feel hunger, while others have esophagitis, oral motor difficulties, delayed gastric emptying, or other gastrointestinal issues. Growth failure, with z-scores <-2, is common Children with this condition have overall low muscle mass. Energy intake and weight should be monitored closely to avoid obesity and comorbid conditions Growth hormone therapy is often used in early childhood to improve body composition. Nutrition deficits should be corrected prior to initiation Some children have hypoglycemia without symptoms that require intervention with complex carbohydrates. Monitor for urinary ketones and avoid fasting Severe feeding issues are common in the first year of life

(*Continued*)

TABLE 21.1 (*Continued*)
Diagnoses and Associated Nutrition Considerations for CYSHCN

Medical Diagnosis	Background Information	Common Nutrition Considerations
Autism Spectrum Disorder	Common developmental disability with a spectrum of disease manifestations. Common deficits and limits of functioning with social interactions, communication, sensory processing difficulties, daily activities, and behavioral issues. Underlying cause is unknown but NOT associated with vaccinations Diagnosed by formalized behavioral and developmental testing usually in early childhood/toddler age. Cognitive impairment occurs in about 75% of children and children typically need life-long care. Often co-occurs with other syndromes or conditions Prevalence: 1:54 children in the USA	Children with autism often have food selectivity issues including food preferences and refusals – while typically developing children have similar behaviors, for children with autism these behaviors persist much longer Nutrition and food issues in children with autism are a wide spectrum. Results of some studies demonstrated that children with autism can have improved diets compared to typically developed peers (theorized due to caregiver involvement in food) while others show worse nutrition and nutrient intake. Discussing with a caregiver will help identify which category a child falls under Alternative restrictive diets and nutrition supplements including gluten-free, casein-free diets have been popularized and familiar to many caregivers. The majority of these therapies do not have any evidence base to support their use. (see Chapter 27) Behavioral medications such as stimulants or antipsychotics that are sometimes used can affect hunger cues and nutrient intake
Sickle cell disease	Genetic condition that results in a hemoglobinopathy with abnormal (sickled) shape of red blood cells. Diagnosed by genetic testing and via the newborn screen in all US states Sickling red blood cells lead to multiorgan pathology including hemolytic anemia and jaundice and can lead to pain crisis and acute chest syndrome. Increased risk of bacterial infections. Mainstay of treatment includes blood transfusions, preventive care, and antibiotics. Bone marrow transplantation and novel gene therapies are also used Prevalence: 1:500 African Americans and 1:1000 Hispanic Americans in the USA, though children of all races and ethnicities are affected	Birth weight is usually normal but poor growth in early childhood is common; theorized that is may be related to increased energy requirements, protein turnover, and in some children, hypophagia Focus on fluid intake and avoiding dehydration to prevent pain crises Nutrient supplementation and monitoring are commonly needed. Children have risk of poor bone development – monitoring of Vitamin D recommended Folic acid supplementation is also routinely used Iron overload is seen in children who require multiple blood transfusions Zinc supplementation can improve growth

(*Continued*)

TABLE 21.1 (*Continued*)
Diagnoses and Associated Nutrition Considerations for CYSHCN

Medical Diagnosis	Background Information	Common Nutrition Considerations
Human Immunodeficiency Virus (HIV)	Viral infection that leads to immunological deficiencies and heightened risk of opportunistic infections with late stages of the disease leading to Acquired Immunodeficiency Syndrome (AIDS) Mainstay treatments are antiretroviral drug therapy (ART) and infection prophylaxis when needed. Symptoms can include diarrhea and swollen lymph nodes In the USA, there has been a significant reduction (now < 1%) in perinatally acquired cases to now only ~ 200 cases a year due to advancement in detection and treatments. Racial disparities are still prevalent with African Americans affected more. However, adolescents represent about a quarter of all new diagnoses	Nutrition concerns are evolving as treatment improves and much is dependent on other factors of the child's social environment and stage of the disease. If malnourished, muscle wasting is more common than in children without HIV In contrast to children in developing countries with higher rates of HIV and underlying malnutrition, children in the USA may not require nutrient supplementation and main nutrition concerns stem from side effects and long-term complications of ART

Social Determinants of Health (SDOH) and CYSHCN

Similar to their typically developing peers, CYSHCN are affected by their environment and SDOH such as poor access to healthy foods, lack of a dental home, housing insecurity, poverty, and unstable home environments. CYSHCN with complex needs have twice the rates of food insecurity compared to children with no special needs. CYSHCN also encounter higher rates of family stressors including caregiver job loss and increased risk of adverse childhood experiences, both which may directly impact their growth. CYSHCN who live in poverty are less likely to receive adequate care coordination services compared to those who live at increased income levels. It is important for the dietitian not to overlook the impact of SDOH on growth and development in these children and to work closely with social workers to help families utilize community and government resources and behavioral health support when needed.

NUTRITION MANAGEMENT FOR CYSHCN

Compared to nutrition assessments for typically developing children, assessments for CYSHCN are often more in depth, time consuming, and nuanced. Table 21.2 presents basic guidelines and considerations for conducting nutrition interviews with CYSHCN. A nutrition plan for CYSHCN often requires adaptation to meet the patient and caregiver's specific needs, goals, and daily schedules. A nutrition care team working with CYSHCN must be able to reassess and modify plans as needed. Acute changes to a child's clinical status such as severe illness or upcoming surgeries may require adjustment to the current nutrition regimen. Modifications may also need to be made when there is progression or regression in functionality or activity levels.

TABLE 21.2
Basic Guidelines for Nutrition Interviews with CYSHCN

Basic Guidelines	Actions/Considerations
Treat child/youth as an individual	• Acknowledge the child's presence • Speak directly to the CYSHCN and their caregivers • Use person-centered language (i.e., their name) instead of disease/disorder focused language • Do not assume a child of any age or developmental ability cannot understand what is being said
Learn about child's baseline functional abilities and means of communication	• Ask instead of making assumptions: Describe a day in your child's life? What does your child do for physical activity? What is your child's personality like? What are important goals for you and your child? Who all cares for and feeds your child? • Consider input from home videos, photos, or stories; families are often eager to share • CYSHCN commonly do not display their top functional ability in clinics, whether due to stress, fear, anxiety, illness, fatigue, or other reasons
Acknowledge the importance of the nutrition team-caregiver-child partnership and the integral role caregivers play in the care of CYSHCN	• Be flexible regarding some of the details of nutrition care plans as long as it continues to be beneficial to the child • Consider different weekend/weekday feeding schedules • Provide educational materials and written plans to meet the language and health literacy needs of the family
Discuss the multidisciplinary nature of nutrition care for CYSHCN	• Recognize it is okay not to have all the answers immediately • Consider specialty input and consultation including a care conference

Nutrition Assessment

Nutrition assessment for CYSHCN has many components including: medical diagnosis, behavioral/developmental diagnosis, anthropometric measurements, physical exam, laboratory data, feeding skills, clinical data, functional abilities, cognitive skills, environmental factors, social factors, and economic resources. Mealtime support, mental health concerns, and level of independence are also included. Nutrition assessment of a CYSHCN can present unique challenges depending on the child's specific diagnosis and healthcare needs.

Nutrition-Focused Physical Examination

Nutrition-focused physical examination (NFPE) is crucial for the assessment of all children. Performing NFPE on a CYSHCN is a particularly critical aspect of assessing their growth and health. Anthropometric measurements must be interpreted in combination with the physical exam, or a dietitian risks assigning an inaccurate diagnosis. For example, diagnosing obesity in a child with inaccurate height measurements due to spinal curvature, or a diagnosis of underweight in a child with excessive fat stores but low muscle mass.

Extremities/Muscle/Bone

Notable physical exam findings might include severe spinal curvature such as scoliosis or kyphosis and contractures. These conditions will decrease the accuracy of height measurements, including many of the alternative height-measurement techniques. There are times when height measurements are not meaningful, and it is important for dietitians to document clearly when accurate and meaningful measurements are impossible to obtain and avoid using any measurements or calculations that do not contribute to an accurate assessment of the child's nutrition status.

CYSHCN who are unable to use specific muscle groups will have notably lower muscle mass in those areas. For example, a child with minimal volitional movement of her legs will usually have minimal lower body muscle mass. If a child has hemiplegic cerebral palsy, the entire side of the body that is affected will have decreased muscle mass compared to the other side of the body. CYSHCN with low muscle mass can still experience malnutrition and muscle wasting, and consistently performing and documenting NFPE is essential to be able to recognize when a child with low muscle mass is experiencing muscle loss. Evaluating for change in functional status is also important for identifying decreased nutrition status in CYSHCN who have baseline low muscle mass.

Children with negligible muscle mass may look proportionate visually but upon palpation, excessive fat stores can become evident. Conducting a thorough examination aids the dietitian in designing a nutrition regimen to avoid accumulation of excess fat stores. Some children with spasticity will accumulate excessive fat stores in their abdomen, but these fat stores often will not extend to their extremities and further energy increases will not benefit muscle mass. Excessive fat stores around the abdomen and trunk can be detrimental to children with decreased muscle mass, decreasing their ability to participate in self-cares and assist with transfers. The ability to breathe comfortably can also decrease in children with severe spinal curvature who gain excessive weight. Equipment such as wheelchairs, positioning devices, and orthotics are adjusted and remade as necessary to accommodate the child's size. There are limitations on how often these alterations and replacements are covered by insurance, and how well the equipment fits into the lifestyle of the child and family. These can be considerations that play a role in decisions around the timing of nutrition interventions.

During NFPE, noting the child's muscle tone lends additional information to the analysis of energy needs, with increased tone perhaps indicating why higher energy intake is not having the anticipated impact on weight or fat stores, or a dramatic decrease in tone after initiation of baclofen indicating a potential need for a decrease in the energy prescription.

Functional Status

In addition to measuring hand grip strength, observing therapies and communicating with the family and multidisciplinary team members such as physical, speech-language, or occupational therapists provides the dietitian with additional objective and subjective information about a CYSHCN's functional and nutrition status.

Oral

Inspecting the face, eyes, nose, mouth, lips, tongue, gums, and teeth is part of NFPE and aids in the identification of deficient hydration and possible deficiencies of iron, water-soluble vitamins, and vitamin A. Dental health needs to be regularly monitored by a dentist comfortable working with CYSHCN, but the dietitian can also identify concerns with poor mouth care and the potential role of mouth pain in decreased oral intake. Gingival hyperplasia can be caused by anti-seizure medications and is not necessarily a sign of poor dental health.

Edema

Typical areas of fluid accumulation vary for CYSHCN depending on their age, mobility, and positioning. A child who uses a wheelchair may have fluid accumulation in the ankles and/or in the perineal/scrotal areas.

Skin

CYSHCN who have very low energy needs may be at risk for essential fatty acid deficiency (EFAD). A focused NFPE for EFAD includes evaluation of hair and skin. Notable findings include: dry, dull, hair that is easily plucked with no pain, and skin that is dry, waxy, oily, scaling, or with crusty plaques on the scalp, lips, and nasolabial folds. Many macro- and micronutrient concerns manifest in the skin and are important signs for a dietitian to identify and address with the multidisciplinary team.

Anthropometrics

The objective measurement of an individual's body remains an important aspect of nutrition assessment. Chapter 1 provides instruction on performing a variety of anthropometric measurements. Choosing the appropriate measurements to obtain can be less straightforward in CYSHCN than in typically developing children. Obtain only measurements that contribute useful information to the child's nutrition assessment. Children who use wheelchairs might require a wheelchair scale or mechanical lift with scale. Measuring tibia length appears to have a meaningful correlation with height in children less than 12 years old. There may not be an accurate or meaningful way to measure the height or length of a child with severe kyphosis and lower extremity contractures. Mid-upper arm circumference (MUAC) is an important measurement to consider, particularly for children whose weight- and height-measurement accuracy is compromised. If a CYSHCN has hemiparesis, measure the unaffected side.

Condition-Specific Growth Charts

The Academy recommends setting the expectation that CYSHCN will grow at their own potential and follow their own growth curve, even if below the age- and gender-appropriate growth curve. The increased use of z-scores to evaluate anthropometric measurements has notably improved the dietitian's ability to monitor changes, particularly for children who are at the far ends of the bell curve. The Academy's Pediatric Nutrition Care Manual proposes that specialty charts can be used as an additional source of information as long as the limitations of each chart are carefully considered. The CDC notes that while specialty growth charts "provide useful growth references", most do not include body mass index (BMI) charts and recommends utilizing the CDC BMI charts in those instances. In general, the use of condition-specific growth charts is not encouraged due to

concerns about their limitations such as small sample sizes, lack of heterogeneity, and unresolved questions of whether altered growth is due to genetic potential or external conditions.

Growth Charts for Children with Achondroplasia

The American Academy of Pediatrics (AAP) suggests using the achondroplasia growth charts for total body length, weight, and occipitofrontal circumference.

Growth Charts for Children with Down's Syndrome

New growth charts for children with Down's syndrome were developed in 2015. These growth charts can be helpful when used alongside the CDC growth charts. The 2015 Down's syndrome growth charts help the dietitian assess how well children are growing compared to their peers, while the CDC growth charts are beneficial in evaluating BMI-for-age z-score to determine if a patient is overweight or obese. When evaluating recommendations regarding the use of these charts, dietitians need to note the date of the recommendation, as many recommendations against the use of Down's syndrome charts were authored in regard to the 1988 growth charts for Down's syndrome.

Growth Charts for Children with Cerebral Palsy

The ideal growth parameters to support optimal health for children with cerebral palsy (CP) are unknown and the use of growth curves specific for CP alone are not recommended. Children with more severe impairment from CP tend to have lower bone density and muscle mass than neurotypical children, and children who do not receive enteral nutrition (EN) can also be shorter and lighter than those children who receive EN. Global variations in anthropometric measurements have been observed to have a positive trend with rates of EN use in that country, and at least some growth deficits in children with CP appear to be due to malnutrition.

The most recent growth charts available for use with children with CP were published in 2011. The use of the CDC growth charts for children with CP appears to result in more children identified as underweight compared to the 2011 CP growth charts. One unique feature of the 2011 CP growth charts is the cut-off line on the weight for age chart that correlates to increased morbidity and mortality. This can be a helpful tool in the nutrition assessment of patients with CP, as measurements of linear growth (and thus BMI) may be difficult to attain. This information about correlation with increased mortality may assist dietitians in conversation with caregivers, if there is resistance to intervention, but physical assessment of these children and comparison to the CDC charts are also necessary components of the nutrition assessment.

NFPE and following The Academy guidance to track CYSHCN as they follow on their own curves are ways a dietitian can avoid the accumulation of excess fat stores in a child with low muscle mass. Some growth charts may be closer to describing optimal growth than others, but all growth charts are a tool for comparing a child's growth with children of the same age and sex to identify the need for further investigation. Clinicians using the WHO or CDC charts with CYSHCN must take into consideration the influences of the child's specific medical condition on their growth potential and goals and use consistent and accurate measurement techniques and to follow change over time.

Obtaining Nutrition History

The Subjective Global Nutrition Assessment (SGNA) questionnaires are appropriate for CYSHCN. Encourage families of children with EN to think of EN as meals and snacks. This is important for many reasons, including enabling tools such as the SGNA questionnaires to feel more applicable and less ostracizing to a family nourishing their child via EN. Modifying questions from the SGNA questionnaire, ask about the child's appetite, frequency of intake (or EN), feeding/eating problems (or problems with the delivery and tolerance of EN), and dietary restrictions.

In addition to the standard nutrition assessment discussed in Chapter 3, additional interview questions should be considered for CYSHCN, including:

- This nutrition plan is different from that of many other children; how are you feeling about it, and are you being supported by other members of your family and social circle?
- Is this nutrition plan working well within the whole family's lifestyle and schedule?
- Do you avoid any foods or food ingredients for the child? (example: casein and gluten for autism spectrum disorder)
- Do you have any questions about the nutrition plan and how it relates to your child's specific underlying disease/disorder pathology? Are there other nutrition interventions or ideas that you have questions about or want to consider?
- Does the child use any assistance with mobility? *If yes*- What assistance, and how often? (might use wheelchair at school but not at home; or when visiting large medical facilities but nowhere else)
- What physical activities or sports does the child participate in? (Do not make assumptions about mobility or activity involvement)
- Are there any upcoming surgeries, changes in medication, or changes in your and your child's quality of life goals?
- Does this nutrition plan allow your child to receive their favorite foods or flavors? (Adjust tube or oral meals as possible to accommodate food preferences)
- How long does a meal last?
- Does the child appear full after the meal or do they run out of time or energy first? (e.g., caregiver or child fatigue, short mealtime allocated at school, etc.)
- How many foods does the child eat? Do they accept only specific brands (rigid sensory preference)?
- Does the child require food items to be ground, chopped, or pureed?
- Have you had any trouble getting the products and supplies you need for your child? (e.g., ordering formula or supplies; using Women, Infants, and Children Program (WIC) payment adds complexity and requires multiple documents and systems to align)

Particularly for CYSHCN who are receiving nutrition with specific recipes or formulations, a thorough assessment can include reviewing: the prescribed diet, recipe and preparation methods, location of meals and snacks, fluid intake, and frequency of product refills. At each visit, briefly consider whether the current overall nutrition plan and feeding route modality remains optimized, to avoid missed opportunities to advance regimens or modalities.

Laboratory Monitoring

Primarily monitor laboratory markers in the same manner as other children receiving nutrition via the same route, whether oral, enteral, parenteral, or a combination. Table 21.3 presents specific laboratory considerations.

Nutrition Diagnosis

CYSHCN can have a wide variety of nutrition diagnoses assigned. Examples of nutrition diagnoses for CYSHCN are in Table 21.4. Children who do not communicate with words or assistive devices may be unable to report symptoms, so dietitians may need to rely on signs when evaluating and diagnosing.

Nutrition Prescription

CYSHCN can have extensive prescribed medication lists. Table 21.5 identifies some commonly used medications which can impact energy and micronutrient needs in this population. It is also

TABLE 21.3
Significance of Specific Laboratory Values for CYSHCN

Lab	Significance in Caring for CYSHCN	Recommendations
Sodium level	Concern if receiving exclusive EN, because of the low sodium content of commercial tube feedings, including micronutrient-dense versions	• Monitor serum and urine sodium levels and maintain urine sodium levels ≥ 25 mEq/L keeping in context the child's medications • Supplement sodium as needed and coordinate with endocrinology if other sodium regulation concerns are present
Vitamin D	Promote healthy bone density for children with CP	Maintain 25-hydroxyvitamin D level > 50 nmol/L (20 ng/mL)
Essential Fatty Acids (EFAs)	CYSHCN may require low volume or off label use of EN formulas, which may not provide adequate essential fatty acids. Goals: 2%–4% of total energy intake from linoleic acid; 0.25%–0.5% from alpha-linolenic acid; age-based Acceptable Macronutrient Distribution Range (AMDR)	• To calculate estimated essential fatty acid needs for a child with very low energy needs, consider both the percent total energy intake method and the AMDR. These can result in a wide range of estimated needs; adequacy can further be evaluated through nutrition-focused physical exam (NFPE) and laboratory measures • Obtain information on EFAs for commercial enteral formulas by requesting directly from the manufacturer • Laboratory measurements to determine if patient has essential fatty acid deficiency
Folate and vitamin B_{12}	• Anti-epilepsy medications can affect folate levels • CYSHCN can have risk factors for vitamin B_{12} deficiency (neutral stomach pH, inadequate intake, inflammatory bowel disease, pancreatic insufficiency, kidney disease) but are not always able to communicate their symptoms	• - Monitor complete blood counts, serum vitamin B_{12}, and serum folate levels; methylmalonic acid and homocysteine levels, if discordant labs; supplement as needed • RBC folate can be elevated with small intestinal bacterial overgrowth (SIBO); vitamin B_{12} can be elevated or depleted with SIBO • Evaluate medications for nutrient deficiency side effects

important to know when a medication may be contributing to gastrointestinal concerns, salivary concerns, or can alter laboratory studies.

Energy

CYSHCN have a wide range of energy needs. Most medical conditions do not have corresponding estimated energy needs equations. In general, calculation of energy needs for CYSHCN requires comparison of their estimated energy intake to their trends in NFPE findings and anthropometric data. If energy estimates are needed for an acute hospitalization and indirect calorimetry is not available, equations for typically developing children are used and titrated as needed over time. If dietitians use condition-specific equations, they should also calculate EER and use clinical judgment in determining an energy prescription.

Protein

There is minimal evidence available regarding the protein needs of CYSHCN. Typically, the DRI for age is used to estimate protein needs (Chapter 3). It is important to consider macronutrient distribution in CYSHCN. Children with extremely low energy needs may require supplementation to meet the protein DRI for age and are then receiving a large proportion of their energy from protein. Children with high energy needs may rely on fat supplements to meet their energy needs, pushing their percentage of intake from protein to be lower.

TABLE 21.4
Examples of Nutrition Care Process and Terminology Problem-Etiology-Signs/Symptoms statements used with CYSHCN

Medical Diagnosis	Common Nutrition Diagnoses	Etiology
Cerebral palsy	Inadequate oral intake	Swallowing difficulty and fatigue with oral intake
Tracheostomy/Ventilator dependence	Inadequate enteral nutrition infusion, Inadequate oral intake	Increased frequency of tube feedings held for pulmonary treatments, inability to consume food orally
Autism spectrum Disorder	Inadequate protein intake Limited food acceptance	Limited food acceptance with sensory processing disorder
Epilepsy	Food-medication interactions	Use of carbohydrate-containing medication
Down's Syndrome	Overweight	Excessive energy intake, decreased activity
Prader-Willi syndrome	Predicted excessive energy intake	Hyperphagia
Russell-Silver syndrome	Inadequate energy intake	Altered in GI function, inadequate oral intake
Human Immunodeficiency Virus (HIV) infection	Altered gastrointestinal function	Related to side effect of prescribed medication
Sickle Cell Disease	Inadequate vitamin D intake	Related to appropriate use of sunscreen and low oral intake

Source: Adapted from Nutrition Diagnostic Terminology. *Nutrition Care Process Terminology (eNCPT)*, 2020 Edition.

Fluid

The Holliday-Segar Method of estimating fluid needs can be used as a starting point for most CYSHCN, though in children with severe neurologic injury this may overestimate fluid needs. History provided by the child and caregiver, and laboratory markers can all be utilized to evaluate hydration adequacy. CYSHCN may have increased fluid losses from a decreased ability to control oral secretions or may have increased stool output, they may have low fluid intake due to reliance on others to assist with drinking or nutrition support therapy, or they may purposely limit fluid intake to minimize the need to find specialized restroom facilities while out of the home.

Micronutrients

Evaluating the child's diet adequacy compared to the DRI tables for age and gender is important for preventing micronutrient deficiencies (Appendix E). CYSHCN can require multiple medications with nutrition impact. When a child is taking a medication with known drug-nutrient interactions, monitor closely and adjust recommended intake as needed.

Nutrition Intervention

CYSHCN, like all children, can require a vast range of nutrition interventions. Low-energy, high-protein, and micronutrient-dense tube feeding formulas are a helpful option for children with low energy needs. Using these formulas can decrease or eliminate the number of additional nutrition supplements needed to meet intake goals. Using a multivitamin that contains higher amounts of phosphorus, or a calcium/vitamin D combination supplement are two additional options for simplifying nutrition regimens for some CYSHCN. Commercial or home blenderized tube feedings are often sought out by both dietitians and families of CYSHCN. EN and parenteral nutrition (PN) are extensively reviewed in Chapters 8 and 9.

TABLE 21.5
Drug-Nutrient Interactions

Nutrition Concern	Drug Class
Inhibit absorption of calcium carbonate; calcium citrate preferred form of supplementation	• Proton Pump Inhibitors (esomeprazole, lansoprazole, omeprazole, pantoprazole)
Can cause weight loss (increase energy needs or decrease appetite)	• Anti-ADHD (amphetamines) • Anticonvulsant (lamotrigine, topiramate, zonisamide)
Can cause weight gain (decrease energy needs or increase appetite); Valproate can decrease vitamin D and carnitine levels (supplementation may be needed)	• Anticonvulsant (gabapentin, valproate) • Antipsychotic (risperidone) • Antispasmodic (baclofen) • Endocrine (Adrenocorticotropic hormone) • Steroids (prednisolone) • Tricyclic antidepressants
Require separation of food, medication, or supplement	• Anti-ADHD (amphetamines) • Antibiotics (doxycycline monohydrate, nitrofurantoin, carbamazepine) • Anticonvulsant (phenytoin sodium extended) • Anti-drooling (glycopyrrolate) • Beta-blockers (atenolol) • Endocrine (levothyroxine) • H2 blockers (ranitidine) • Laxatives (lactulose) • Nutrient meds/supplements (magnesium, iron, zinc, sodium bicarbonate, calcium carbonate, psyllium) • Probiotics (lactobacillus) • Proton Pump Inhibitors (lansoprazole)
Higher than DRI intake of specific nutrients may be required due to metabolism or absorption	• Antibiotics (Doxycycline monohydrate, trimethoprim) • Anticonvulsant (carbamazepine, phenobarbitol, phenytoin sodium extended, valproic acid) • Diuretics (Hydrochlorothiazide) • Endocrine (metformin) • H2 Blockers (famotidine & ranitidine) • Oral Contraceptives • Proton Pump Inhibitors (lansoprazole, omeprazole) • Steroids (prednisolone) • Tricyclic antidepressants
Limit caffeine intake	• Anti-ADHD (amphetamines) • Benzodiazepines (lorazepam, diazepam) • H2 Blockers (famotidine, ranitidine) • Tricyclic antidepressants/anti-drooling (amitriptyline)
Fluid restriction may be indicated	• Oxcarbazepine

Source: Adapted from Pronsky ZM, Crowe SJP, Roberts W. *Food Medication Interactions*. 17th ed. (Elbe D, Epstein S, Ayoob K, eds.). Birchrunville, PA: Food-Medication Interactions; 2012.

Ketogenic Diet for Epilepsy

Children with medication-refractory epilepsy may be initiated on a ketogenic diet as treatment for seizures. The ketogenic diet is a high-fat, adequate protein, low-carbohydrate diet which shifts the metabolism of the body from glucose to fat so the brain can use ketones over carbohydrates as its primary energy.

The classic ketogenic diet is prescribed as a ratio of grams of fat to grams of net carbohydrate and protein combined. A ratio of 3:1 to 4:1 provides 87%–90% of energy as fat. In comparison, a typical diet providing 30% fat would have a ratio of 0.2:1. The ketogenic diet ratio is adjusted to maintain a therapeutic level of ketosis within a goal range that is specific to each patient. Higher ratios are more ketogenic but can also result in increased adverse effects such as constipation, diarrhea, reflux, metabolic acidosis, need for additional micronutrient supplementation, or decreased palatability for children consuming the diet orally.

There are other dietary treatments for epilepsy such as the modified Atkins diet, medium-chain triglyceride diet, and the low glycemic index treatment. Lower ratio or non-ratio-based diets for epilepsy can be just as effective for improved seizure control and may be better tolerated. There is research refuting the efficacy of fluid restriction as part of a ketogenic diet, and fluid restriction is no longer considered an essential part of ketogenic diets. Adequate fluid intake is advised given the higher risk of nephrolithiasis with some ketogenic diets. Adequate energy provision is essential to promote growth.

Ketogenic diets must be closely monitored by a dietitian with expertise in its use and initiation of the diet may require hospitalization for close monitoring and adjustment. Commercial formulas are available in powdered and liquid form in several ratios. Fat, protein, and carbohydrate modulars can be used to adjust the ketogenic ratio for optimal seizure control. Table 21.6 lists commercial

TABLE 21.6
Commercial Ketogenic Formulas and Modulars

Commercial Formula	Brand	Format
KetoCal® 2.5:1 LQ	Nutricia	Liquid
KetoCal® 3:1	Nutricia	Powder
KetoCal® 4:1	Nutricia	Powder
KetoCal® 4:1 LQ Unflavored	Nutricia	Liquid
KetoCal® 4:1 LQ Vanilla	Nutricia	Liquid
Keto Peptide 2.43:1 (food-based)	Functional Formularies®	Liquid
KetoVie® 4:1 Chocolate	Cambrooke™	Liquid
KetoVie® 4:1 Vanilla	Cambrooke™	Liquid
KetoVie® 4:1 Unflavored	Cambrooke™	Liquid
KetoVie® Peptide 4:1	Cambrooke™	Liquid
KetoVie® 3:1 Unflavored	Cambrooke™	Liquid
RCF®	Abbott Nutrition	Powder
*requires additional fat and carbohydrate modulars		
Commercial Modular	**Brand**	**Format**
Liquigen®	Nutricia	Liquid
Polycal™	Nutricia	Powder
MCT oil®	Nestle Health Science	Liquid
Microlipid™	Nestle Health Science	Liquid
Beneprotein®	Nestle Health Science	Powder

Websites for: Nutricia, Nestle, Abbott, https://www.ketovie.com/products/ketovie/, https://www.functionalformularies.com/keto.html, https://www.nestlemedicalhub.com/products/beneprotein; accessed 6/10/21.

ketogenic formulas and frequently used commercial modulars. Particularly with higher ratios, multiple supplements (i.e., multivitamin, sodium, potassium, selenium, folate, magnesium, zinc, vitamin D, carnitine, calcium, and citrate) may be needed to meet the DRIs, maintain normal lab values, and minimize the risk of adverse effects.

Food-based oral meals and snacks utilize high-fat foods such as butter, avocado, fruit- or vegetable-based oils (olive, coconut, canola, etc.), and heavy cream. The KetoDietCalculator is an available tool that can be used to calculate oral or enteral meals and recipes. PN can also be written to meet ketogenic goals and support children requiring this route of nutrition. Medications, particularly liquid formulations, can contain notable amounts of carbohydrate. Therefore, all medications should be switched to the lowest carbohydrate form, which is usually a non-chewable tablet or capsule.

Lab parameters monitored with children receiving ketogenic nutrition can include blood glucose, urine ketones, serum beta-hydroxybutyrate, complete blood count, electrolytes, calcium, magnesium, phosphate, liver and kidney profiles, fasting lipid profile, serum carnitine, zinc, selenium, bone mineral density scan, urinalysis, urine calcium, and urine creatinine. Particular attention should be placed on monitoring for metabolic acidosis and hypoglycemia when feedings for a child on a ketogenic diet are stopped (for procedures, intolerance, etc.).

If micronutrient supplementation is indicated, dose and schedule it purposefully, accounting for the many drug-nutrient interactions common among the extensive medication schedules of some CYSHCN.

Children with progressive diseases might be eating orally and have an enteral access device placed to help facilitate adequate hydration, medication intake, and eventually partial or full nutrition. Children who are making developmental gains over time might transition from full EN to partial or full oral intake. Communicate openly with the child and the family to understand their goals and work together with the multidisciplinary team to formulate a path to best meet the goals and medical needs of the child.

Coordinating with the Multidisciplinary Team

Best practices for delivery of health care for CYSHCN include care delivered in a family-centered, culturally competent, and linguistically appropriate manner by a multidisciplinary team with a focus on enrollment in a pediatric medical home. Dietitians are an integral member of the care team and provide unique skills to optimize health for CYSHCN. It is important for dietitians to be included and encouraged within these team models. Examples of the role that dietitians play, in addition to providing direct patient care, include helping to coordinate nutrition care between multiple care providers, advocating for families and children when care seems disjointed, and identifying nutrition, feeding, and weight goals. Dietitians often will work closely with occupational and speech-language therapists to incorporate texture modifications, pacing, positioning, and behavior modification into nutrition care plans. For children who are seen in several specialty clinics, each with a dedicated dietitian, identification of a primary dietitian is best for streamlined and coordinated care. This primary dietitian should consult with other providers as needed and work closely with the child's medical home. Dietitians for CYSHCN also collaborate closely with school systems/school nurses as well as state and federal agencies such as Women, Infants, and Children (WIC) and Title V programs, dentists, social workers, interpreter services, home-health suppliers, and private and public insurers.

Partnering with CYSHCN and Their Families

It is helpful for dietitians to be aware of some of the unique experiences, rewards, challenges, and stressors associated with caring for CYSHCN. Feeding difficulties and atypical patterns or routes of feeding alter the caregiver-child and family-community relationships. Caregivers, in contrast to providers, view a child's feeding problems in the context of how it impacts and effects the life of

the entire family and not just that of the child. Caregivers of CYSHCN at diagnosis display a range of emotions including disbelief, sadness and loss of identity, and concerns about society pressures on caregivers and families. Many families adapt to having a child with special needs though some continue to have chronic sorrow. Emotional, psychological, and social stressors associated with caregiving for CYSHCN often fluctuate over time.

Caregivers of CYSHCN spend a significant amount of time each week performing hands-on medical care, care coordination, and advocacy activities for their child. Most of these caregiving activities are unreimbursed and under-supported. Caregivers of CYSHCN work to balance the needs of siblings, the family-unit, social pressures, their personal adult relationships, work, and their own health and well-being (including sleep). The current health care system falls short of meeting the needs of families of CYSHCN. Compared to caregivers of typically developing children, families of CYSHCN report significantly increased personal, physical, family, and financial stressors. Caregivers of CYSHCN have higher rates of anxiety, depression, and post-traumatic stress disorder. Despite the additional stressors and responsibilities, many caregivers adjust to the "new normal" of raising a child with special needs, focus on hope, and can comment on positive aspects of raising their child with special needs. The majority of caregivers of CYSHCN create appropriate loving child-caregiver bonds and enjoy discussing their child's accomplishments, abilities, and personality.

Information sharing and education in the dietitian-child-family partnership should be multi-directional. The partnership is influenced by the dynamics of the caregiver-child dyad, individual personalities, experiences, and coping mechanisms of each member. Caregivers of CYSHCN bring valuable viewpoints and first-hand experiences to the table. Although not ideal, the reality of the health care and social/educational systems today is that caregivers of CYSHCN provide the majority of communication between disciplines. Caregivers should be given resources that will help them troubleshoot common problems at home and should always have access to a medical professional competent in assisting them with nutrition issues. Furthermore, children and caregivers should be provided with psychosocial resources that may help with coping with stress.

Nutrition Monitoring and Evaluation

Evaluating the efficacy of nutrition interventions is essential to providing optimal longitudinal care to CYSHCN and relies on establishing intended outcomes for care. The keys to establishing consequential nutrition care indicators are to use appropriate reference standards, define the child's current goals and anticipated outcomes, explain rationale for unmet expectations, determine barriers and supports, and decide on next steps. Determining and documenting meaningful indicators and criteria establishes clear nutrition goals for CYSHCN and all the people and services involved in their care. Frequently used terms for monitoring and evaluating the nutrition care of CYSHCN can include weight change, estimated fluid intake, EN formula concentration, essential fatty acid profile, specific NFPE goals, nutrition skill of supportive individuals, nutrition quality of life, and many more.

TRANSITION OF CARE

An important aspect of the dietitian-caregiver-child partnership is providing longitudinal care and anticipating future needs especially as the child ages into young adulthood. CYSHCN are at increased risk of obesity and malnutrition, poor health outcomes, and the need for modified and assistive feeding. However, in adulthood they may lose many of their financial and government support systems but continue to have high health care and support needs. The dietitian is integral in assisting families as their child transitions into adulthood and can coach families on raising important nutrition-focused concerns. Tasks for the dietitian may include finding a dietitian who typically cares for adults who is also comfortable in caring for young adults with special health care needs, or

providing guidance to family practitioners or adult generalists about an individual's nutrition needs, including frequency of follow-up.

ETHICAL CONSIDERATIONS WHEN WORKING WITH CSHCN

Discordance between Caregivers and the Dietitian

There may be situations in which the nutrition and/or medical team are concerned that the prescribed nutrition care plan is not being followed by the family and this is detrimental to the child. In these situations, it is important to have an open dialog with the family and, when appropriate, the child, about concerns or barriers they have regarding the current nutrition plan. Families present a wide range of concerns when in disagreement with a nutrition plan including concerns that the child is uncomfortable with feeds or that the growth and weight goals are not appropriate for their child. If challenges are identified in caring for a growing child, refer to resources that assist with improved home access such as wheelchair ramps, bathroom remodel, and transfer/lift equipment, especially for children with medical complexity or known life-limiting disease. Referrals for home-health aides, more frequent nutrition check-ins, and focusing on objective findings of feeding issues may improve nutrition plan compliance.

If there is concern for fabricated illness, physical/emotional neglect, or abuse, a referral to child protective services is required. Table 21.7 presents a list of eight questions that a dietitian could ask herself when considering requesting the involvement of child protective services in the nutrition care of a child. It is recommended that all eight criteria be met to qualify for state intervention. For these difficult and often emotional discussions, input from a multidisciplinary team including the child's primary and subspecialty providers, social work, ethics, nursing and therapist teams, and in some cases child advocacy may be helpful.

Growth Attenuation Therapy

Another ethical issue that may arise when working with CYSHCN is growth attenuation therapy, which is a hormone-based therapy to accelerate growth plate closure, requested by some families of children with severe neurologic impairment and functional limitations to limit overall growth. The main reason caregivers request this therapy is to enable them to care for their child as she ages. It is therefore

TABLE 21.7
Proposed Questions Prior to Calling Child Protective Services

1. By refusing to consent are the parents placing their child at significant risk of serious harm?
2. Is the harm imminent, requiring immediate action to prevent it?
3. Is the intervention that has been refused necessary to prevent the serious harm?
4. Is the intervention that has been refused of proven efficacy, and therefore, likely to prevent the harm?
5. Does the intervention that has been refused by the parents not also place the child at significant risk of serious harm, and do its projected benefits outweigh its projected burdens significantly more favorably than the option chosen by the parents?
6. Would any other option prevent serious harm to the child in a way that is less intrusive to parental autonomy and more acceptable to the parents?
7. Can the state intervention be generalized to all other similar situations?
8. Would most parents agree that the state intervention was reasonable?

All eight answers must be a "yes" to justify state interference with caregiver decision making

Source: Reprinted by permission from Springer Nature: Diekema D. Parental refusals of medical treatment: the harm principle as threshold for state intervention. *Theor Med Bioeth*. 2004;25:243–264.

important that the dietitian also work with families to ensure that the child is at a healthy weight, without excessive weight gain or obesity. As with much of the decision making and care plans for CYSHCN, dietitians should be comfortable discussing and reaching out to their colleagues such as endocrinology, ethics, and palliative care for assistance with these situations. It is typical of pediatric institutions to require review of each individual growth attenuation request with input from the ethics committee.

End of Life Care/Alternate Goals of Care

Some CYSHCN have life-limiting conditions with high risk of early mortality and caregivers may choose to pursue alternate goals of care, specifically comfort care. The Academy's Position on Ethical and Legal Issues in Feeding and Hydration states that "registered dietitians should work collaboratively as part of an interprofessional team to make recommendations on providing, withdrawing, or withholding nutrition and hydration in individual cases and serve as active members of institutional ethics committees". Balancing nutrition needs with quality of life may include choosing to continue oral feedings for a child who aspirates, withholding or withdrawing EN or alternate hydration mechanisms. Withholding EN, PN, or hydration at the end of life for children remains a controversial topic given the inability of the child to make autonomous decisions as well as the emotions involved in feeding a child. The AAP notes that forgoing medically administered fluid and nutrition is ethically supportable in situations when the burdens outweigh the benefits to the child. An ethics consultation provides support for families and health care providers when considering forgoing life-sustaining medical treatment. Decisions to withhold nutrition can make some team members uncomfortable, and in most cases, team members should have the option to decline involvement if it violates their personal values.

CYSHCN are a heterogeneous group of children with high rates of nutrition risk factors. While CYSHCN have diverse nutrition care needs, several themes in nutrition care delivery are presented in Table 21.8. Pediatric dietitians will encounter CYSHCN throughout their career. Optimal nutrition care for CYSHCN is flexible, goal directed, individualized, and evidence guided. Open communication and partnerships with multidisciplinary teams and caregivers are best practices for care delivery for this population. The nutrition care and needs of CYSHCN fluctuate and change over time and ethical issues may arise. While working with CYSHCN and their families may be time consuming and challenging, the resilience, diversity, and optimism within this population can create a very rewarding experience for dietitians. Additional resources for further information on nutrition care for CYSHCN is presented in Table 21.9 and the ADIME summary is presented in Table 21.10.

TABLE 21.8
Themes in Nutrition Care Delivery for CYSHCN

Individualized	Nutrition care is focused on optimizing health and well-being for the individual child; care is not compartmentalized based on disease or disorder
Focused on partnerships	Nutrition plans are created and implemented through reciprocal and respectful partnerships between the nutrition team, child, and family/caregivers
Multidisciplinary	Nutrition assessments are multidimensional and require input, communication, and consistency across members of a multidisciplinary team
Enhanced nutrition assessment	Optimal evaluation of nutrition status/weight/growth requires time, thoughtfulness, integration of multiple data points, and a physical exam.
Ongoing monitoring, re-evaluation, and assessment	Nutrition care is not stagnant; plans fluctuate and change over time with adjustments and modifications required with updated information about diseases, disorders, medications, and the individual's clinical/functional status
Advocacy	Nutrition practitioners continuously advocate for the well-being of their patients and ongoing investigation into best practices and evidence-based guidelines for CYSHCN

TABLE 21.9
Resources for Further Information on CYSHCN and Nutrition

Academy of Nutrition and Dietetics: https://www.eatright.org

- Pediatric Care Nutrition Manual – online access
- Nutrition Interventions for Children with Special Health Care Needs, 2010. Washington State Department of Health. https://www.doh.wa.gov/Portals/1/Documents/8100/961-158-CSHCN-NI-en-L.pdf
- Bright Futures 4th Edition American Academy of Pediatrics: Available online: https://brightfutures.aap.org/materials-and-tools/guidelines-and-pocket-guide/Pages/default.aspx
  - Health Promotion Themes: Healthy Nutrition, Healthy Weight, Health for Children and Youth with Special Health Care Needs
- Searchable sources for medical information about specific disease/disorders:
  - Genereviews National Institute of Health: https://www.ncbi.nlm.nih.gov/books/NBK1116/
  - National Organization for Rare Diseases: https://rarediseases.org
  - American Academy of Pediatrics Clinical Disease/Disorder specific Guidelines: https://pediatrics.aappublications.org
- Academy of Nutrition and Diabetes: https://www.andeal.org
- Caring for Children Who Have Severe Neurologic Impairment: A Life with Gracey: by Julie Hauer (Book)
- Nutrition Strategies for Children with Special Health Care Needs (available for purchase and/or download at http://uscucedd.org)
- Nutrition Interventions for Children with Special Health Care Needs (available for download at http://here.doh.wa.gov/materials/nutrition-interventions)
- Caregiver support resources:
  - Inspire: https://www.inspire.com/
  - Oley Foundation: https://oley.org/

TABLE 21.10
ADIME Summary for CYSHCN

Assessment
- Growth assessment
  - Anthropometric measurements may be affected by medical conditions and functional status. Use alternative measurements when indicated
- Nutrition-focused physical exam (NFPE)
  - NFPE findings may be affected by functional status and medical conditions
- Nutrient Intake
  - Consider developmental abilities and feeding skills
- Labs
  - May be altered by diagnosis and medications. See Table 21.3
- Gastrointestinal Findings
- Medications/Side Effects
  - See Table 21.5

Diagnosis
- See Table 21.4

Intervention
- Nutrition Prescription
- Common nutrition interventions
  - Oral
  - Enteral Nutrition
  - Parenteral Nutrition
  - Education
  - Laboratory Monitoring
  - Supplements
  - Other specialty referrals
    - Communicate with caregivers and other specialty providers to coordinate care

Monitoring and Evaluation

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22 Adolescent Medicine

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CONTENTS

Adolescence is a time of significant physical and emotional growth, and the dietary needs and common nutrition challenges for adolescents are different from those of younger children and of adults. Rapid changes in body habitus as a result of pubertal development may cause adolescents to become more sensitive about their appearance, and in some cases to become preoccupied with thoughts of weight and body image. Eating disorders carry a significant burden of morbidity and mortality in the adolescent population. Complications of eating disorders may include amenorrhea, osteopenia, electrolyte disturbances, cardiac arrhythmias, and death. Identifying disordered eating patterns in adolescence is critical to ensure that the adolescent can progress through this developmental stage in a healthy manner and achieve optimal bone density and height, as well as regular menstrual cycles for females. Additionally, many adolescents choose to participate in sports for fitness and recreation, leading to additional nutrition needs and questions regarding optimizing performance and adequate hydration, among others. This chapter will review the pathophysiology and treatment of eating disorders in the adolescent population, as well as discuss specific dietary concerns and recommendations for adolescent athletes.

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EATING DISORDERS

Epidemiology

Eating disorders (EDs) may occur in patients of all genders, racial and ethnic groups, and socioeconomic classes. The prevalence of EDs varies among study populations; however, in the USA, the estimated prevalence of anorexia nervosa is 0.3%, bulimia nervosa is 0.9%, and binge-eating disorder is 1.6%, with a mean age of onset of 12.5 years for all EDs. While the patient population is predominantly female, about 5%–10% of patients with anorexia nervosa and bulimia nervosa are male. Diagnosis of EDs in males may often be delayed due to misperceptions among patients, family members, and healthcare providers as well as differences in presentation between males and females. For example, some male patients with EDs may be more focused on building muscle rather than drive for thinness, as is seen in female patients. There is some evidence to suggest that transgender and non-binary youth have a higher risk of developing an ED. Changes to the diagnostic criteria for EDs may have improved recognition of eating disorders in males. EDs may also occur in patients of any type of body habitus; adolescents with a larger body habitus may be subjected to increased weight stigma through media, peers, and family members, resulting in worsening body image. EDs such as atypical anorexia in patients with a larger body habitus may be overlooked or delayed in diagnosis, but have the potential to result in severe medical complications similar to those found in patients who are severely underweight.

Adolescents with chronic health conditions necessitating strict dietary restrictions or monitoring may be at increased risk for development of EDs. Examples include young people with type 1 diabetes mellitus, celiac disease, and inflammatory bowel disease. In one study of adolescents with type 1 diabetes mellitus, as many as a third of patients who were interviewed reported binge eating, self-induced vomiting, excessive exercise, and manipulating insulin doses for weight loss.

Pathophysiology

In 2013, the release of the fifth edition of the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-5) led to the reorganization and expansion of diagnostic categories of EDs, including several new diagnoses. Major categories of EDs affecting the adolescent population are defined in this section.

Anorexia Nervosa

Anorexia nervosa (AN) is defined as restricted energy intake that is insufficient to meet the individual's energy requirements, resulting in a significantly low body weight for the patient's age, sex, and projected height. AN is also characterized by an intense fear of weight gain and a distorted perception of body weight/shape, with lack of acknowledgment of the low body weight. Subtypes of AN include the restricting subtype, in which weight loss is achieved through restrictive dieting or fasting with or without hyperexercise, and the binge-eating/purging subtype, which is characterized by repeated episodes of binge eating and purging (including self-induced vomiting, laxative use, diuretic use, and/or hyperexercise). Atypical AN means that the patient has not yet lost weight below a critical threshold but shares the same mindset as individuals with AN; they may be normal weight, overweight, or obese.

Bulimia Nervosa

Bulimia nervosa (BN) is characterized by repeated episodes of binge eating, defined as eating an amount of food that is larger than most individuals would consume during a similar period of time, as well as a sense of being "out of control" and unable to limit the overeating during the episode. BN also involves associated inappropriate compensatory behaviors such as self-induced vomiting, fasting, or excessive exercise to prevent weight gain. Misuse of laxatives, diuretics, or other medications and hyperexercise for the purpose of weight loss or preventing weight gain due to binge

eating also constitutes purging behavior. Additionally, for the diagnosis of BN to be applied, the individual's self-image must also be overly influenced by body weight and shape. The binge eating and associated inappropriate compensatory behaviors typically occur at least once a week for 3 months. Subthreshold BN involves a similar presentation as described above, except the behaviors are occurring less frequently than once a week for at least 3 months.

Binge-Eating Disorder

Binge-eating disorder (BED) involves frequent binge-eating episodes (typically at least once per week for 3 months) during which the individual may consume food more quickly than normal, eats until uncomfortably full and/or eats when not feeling hungry, eats alone due to embarrassment or shame, and may feel guilty or disgusted following the binge-eating episode. In order to meet criteria for BED, this behavior must not be accompanied by the inappropriate compensatory behaviors characteristic of BN, or restrictive eating patterns associated with AN.

Avoidant Restrictive Food Intake Disorder

Avoidant Restrictive Food Intake Disorder (ARFID) is a relatively new diagnosis which was introduced with the DSM-5 in 2013, replacing the previous DSM-IV category of "feeding disorder of infancy or early childhood", which was limited to children aged 6 years and younger. ARFID has no such age restriction and may be applied to children, adolescents, or adults. ARFID describes patients who cannot meet their nutrition needs for a wide variety of reasons, without a disturbance in body image. ARFID is defined as an eating or feeding disturbance marked by significant weight loss (which can also entail a failure to gain weight or height along developmentally appropriate growth curves in children). This disturbance may also cause significant interference with daily functioning, including an inability to participate in social activities or eat in normal situations, or problems with relationships as a result of the disturbance in feeding. Three main subtypes of ARFID include: Limited Intake (patients with low overall appetite or lack of interest in eating), Limited Variety (patients with extremely picky eating, food neophobia, and aversions to certain foods based on sensory and/or texture issues), and Aversive (patients whose avoidance or restriction of some or all foods results from a specific anxiety or fear, such as fear of choking or fear of perceived significant abdominal pain). Notably, patients with ARFID may present with more than one of these subtypes simultaneously.

A future revision of DSM-5 may include individuals with underlying ARFID who also develop AN. At this time, the classifications are separate and distinct, but treatment for ARFID with coexistent AN has been found to be slightly different than treatment for ARFID or AN alone. Descriptions of treatment are evolving, with evidence-based research needed to clarify optimal strategies.

Other Specified Feeding and/or Eating Disorder

The label "other specified feeding and/or eating disorder (OSFED)" is applied to patients whose symptoms cause significant distress and/or impairment but do not meet criteria for AN, BN, ARFID, or BED. OSFED includes patients with atypical anorexia nervosa, in which the individual's weight is at or above a normal range despite significant weight loss and otherwise meeting criteria for AN; purging disorder in the absence of binge eating, and binge-eating with or without purging behavior that is of low frequency or limited duration and, therefore, does not meet criteria for a previously described disorder.

Orthorexia

Orthorexia, defined as an obsession with proper or "healthy" eating is not currently recognized as a DSM-5 diagnosis. However, patients and families discuss this label, and it is brought as a concern to the nutrition community. Adolescents or young adults may be overly fixated on the nutrition content of foods and find themselves reducing their intake to only foods they perceive as "healthy", resulting in both physical and psychological health consequences. It is important that dietitians screen for

orthorexia when completing diet recalls and nutrition assessments, as this can quickly slide further into AN if left untreated. The layperson's term of "orthorexia" may be a useful construct to introduce the diagnosis of AN to patients and families since the former term carries less stigma than the latter diagnosis. Explaining to a young person that her overly healthy eating, at any weight, can have unhealthy unintended consequences to her body, and that the dietitian and clinician team will help get back to more optimal nutrition strategies and health may also be useful in partnering with the patient and family for effective care.

SPORTS NUTRITION

Young athletes have higher energy demands due to participation in sports activities, and adolescent diets may contain insufficient energy and nutrients to meet their dietary and hydration needs. Adolescent athletes may attempt to lose weight to enhance athletic performance, switch to a desired weight class, or achieve a particular body physique perceived as favorable in their sport (such as gymnastics or ballet for both genders but traditionally for girls, and for boys, wrestling and lightweight crew). Some athletes may have unrealistic or unhealthy goals for weight loss or gain and may engage in potentially dangerous practices to achieve these goals. In addition, some coaches may have unhealthy weight expectations for athletes that affect the adolescents' perceptions of what their own goals should be. Unhealthy weight loss methods in adolescent athletes include overly rapid weight loss (>1 kg/week), use of laxatives, diet pills, or non-prescribed stimulants, self-induced vomiting, voluntary fluid restriction, and methods of increasing sweat production, such as spending long periods of time in a sauna. These methods may be counterproductive to the athlete's goals of optimizing performance; for example, dehydrated athletes may experience changes in mental status and cognitive ability and worsened endurance with high-intensity exercise. Taken to the extreme, unhealthy eating attitudes and behaviors can be life threatening. Accordingly, high school- and collegiate-athletic associations have specific guidelines for athletes in sports such as wrestling where dramatic weight loss may be prevalent. Such guidelines discourage attempts to utilize these extreme measures by regulating urine specific gravity, minimum percentage body fat, and amount of weight that an athlete may lose preseason.

Healthy methods for weight loss in an adolescent athlete may include gradual loss of no more than 0.5 kg/week, with a well-balanced diet including an intake that meets energy requirements and adequate fluid replacement for activity.

Female Athlete Triad/ Relative Energy Deficiency in Sport

Adolescent athletes may engage in a variety of unhealthy eating behaviors to lose weight. Inadequate energy intake may also result from a lack of information regarding nutrition and amount of energy expended during exercise, or from intentional restriction and disordered eating patterns. Regardless of underlying cause, the term "female athlete triad" describes a medical condition commonly seen in physically active females including a combination of low energy availability, menstrual dysfunction, and low bone mineral density. The name "relative energy deficiency in sport" or RED-S is also recognized to reflect that both male and female patients may be affected by low energy availability. Energy availability is defined as the amount of energy remaining after exercise training for other physiologic functions in a particular day. Low energy availability, whether associated with disordered eating or not, leads to endocrine changes causing menstrual irregularities and hypogonadotropic hypogonadism and can lead to decreased bone mineral density. When originally characterized, the female athlete triad included osteoporosis, amenorrhea, and disordered eating, although the concept has since been expanded to better encompass the consequences of low energy availability among physically active females and males participating in sport. For example, low bone mineral density in patients who do not meet criteria for osteoporosis may still be a significant risk factor for stress fractures in physically active individuals. Viewing the three components of this

syndrome as a spectrum allows for earlier detection of symptoms and intervention before endocrine disruptions worsen.

NUTRITION MANAGEMENT

Nutrition Assessment

Diagnosis of Eating Disorders

Annual wellness visits and pre-participation sports evaluations represent opportunities to screen for disordered eating behavior in the adolescent. The dietitian or clinician should inquire about the patient's eating habits and body image. At these visits, each adolescent's weight and height should be plotted on a growth chart to evaluate achievement of expected weight and height gains. While adolescents are expected to gain weight during puberty, sudden fluctuations of weight (including a significant loss or gain, or failure to gain along expected percentiles for weight and height) should lead a healthcare provider to assess for changes in eating and exercise habits. Reports of menstrual disturbances may also increase suspicion for energy deficiency. New vegetarianism, veganism, pursuit of a "Paleo" or other diet, or other sudden or unexplained changes in eating and exercise habits should trigger evaluation for disordered eating and necessary education to ascertain that these changes are occurring in a safe and health-promoting manner.

If an ED is suspected in an adolescent, an in-depth workup includes a complete nutrition, medical, and psychiatric history, coupled with a thorough physical examination including orthostatic vital signs. Weight should be obtained after voiding, in a hospital gown, and with back facing the scale consistently at each visit, with some patients handling the sharing of numbers gracefully, whereas others use the numbers as a trigger for further restricting or other behaviors. Height should be obtained without shoes using a wall-mounted stadiometer for an accurate measurement. Psychosocial assessment should be obtained after confidentiality has been established, using phrasing that also explains the limits of confidentiality, such as, "Everything we talk about without a caregiver in the room will be kept private or confidential unless you tell me something life threatening or dangerous, in which case I will tell you that we have to discuss this with your caregiver." The HEADDS exam is an acronym to remember key aspects of the psychosocial history (Table 22.1). Table 22.2 outlines useful questions to identify disordered eating. A 24-hour diet recall should be obtained with specific inquiries on any avoided foods and related reasons (food allergies, texture aversion, nutrient concerns). A change in eating habits over time should be noted.

Anthropometric Measurements and Nutrition-Focused Physical Exam

A thorough head-to-toe physical examination should be performed. Features which may be concerning for nutrition insufficiency including EDs on physical examination include:

- Sudden change in growth trajectory (weight and/or height) when plotted on growth chart.
- A decrease in BMI-for-age percentiles and z-scores when plotted on the growth chart. Patient's weight may remain unchanged over time; however, coupled with an increase in height, a significant decrease in BMI-for-age may be noted.
- Abnormal Vital Signs: bradycardia, orthostatic hypotension, hypothermia
  - To measure orthostatic vital signs: measure blood pressure and heart rate after 5 minutes of supine rest, then repeat measurements after 2–3 minutes of standing. Orthostatic hypotension is defined as a drop in diastolic blood pressure of greater than 10 mm Hg or increase in heart rate of >20 beats per minute within 2–3 minutes of standing. Orthostatic hypotension in the setting of a known or suspected ED may indicate that the patient is volume-depleted due to dehydration because of restricted fluid intake or purging.

TABLE 22.1
HEADDS Assessment

Home	• Who lives with the young person? If caregivers not together, how does the patient split time between homes? Who lives in each home? What happens when there is an argument in the home?
Education	• School/grade performance – any recent changes or any dramatic changes in the past? • Grades repeated or skipped? Classes failed? Connection at school/home (peers, teachers, coaches, etc.)? • Suspension, termination, dropping out?
Activities	• On own, with peers, with family (what do you do for fun? Where? When?) • Sports: regular exercise? What type(s)? How stressed is the teen if she misses a workout? • Church/religious connection/attendance, clubs, projects? • Hobbies or other activities? Work? How many hours/week? • In a gang? Carry or own a gun?
Drugs	• Use by peers? Use by young person? (include tobacco, alcohol, marijuana, vaping) • Use by family members? (include tobacco, alcohol, marijuana, vaping) • Amounts, frequency, patterns of use/abuse? • Car use while intoxicated or using? • Source – how does the young person obtain/pay for drugs? • Trouble with caregivers or the law?
Depression/Suicide	• Depression – ever to the point of wishing she did not exist? Ever have thoughts of killing herself? If yes, ever had a plan? What plans? Ever attempt? Which methods? • Sleep disorders (such as induction problems, also early/frequent waking or greatly increased sleep and complaints of increasing fatigue) • Appetite/eating behavior changes • Persistent feelings of "boredom" • Emotional outbursts and highly impulsive behavior • History of withdrawal/isolation • Feelings of hopelessness or helplessness • History of past suicide attempts, depression, psychological counseling • History of suicide attempts in family or peers • Psychosomatic symptomatology • Suicidal ideation (including current and past) • Decreased emotional affect, avoidance of eye contact on interview • Preoccupation with death (clothing, media, music, art)
Sexuality	• Sexual orientation? • Gender identity? • Oral sex, vaginal sex, anal sex? • Number of partners? • History of pregnancy/abortion? • Sexually transmitted infections – knowledge and prevention? Contraception? Frequency of use? • Any history of sexual/physical abuse?

- Pallor or dry skin
- Thinning scalp hair and/or lanugo
- Delayed pubertal development
- Atrophy of breasts
- Scaphoid abdomen; palpable loops of stool from constipation
- Acrocyanosis, peripheral edema
- Signs of self-induced emesis, including abrasion or callus on knuckles (Russell sign), parotid gland enlargement, erosions of dental enamel, particularly on the lingual and occlusal surfaces

TABLE 22.2
Screening Questions for Disordered Eating

- How much of your day is spent on food/body thoughts?
- Are there body areas that truly distress you? If yes, which areas?
- What is the most you have ever weighed? At what height? When was that?
- What is the least you have weighed in the last few years? At what height? When was that?
- What do you think you should weigh?
- What number (weight in pounds or kilograms) feels scarily high? What number feels scarily low?
- For girls, when was your last period? At what weight? With or without any hormones such as birth control pills or progestin?
- What do you do for exercise? How much, how often? What is the level of intensity? How stressed are you if you miss a workout?

Best Questions to Rule IN an Eating Disorder

- Do you worry you have lost control over what you eat?
- Do you make yourself sick when you are uncomfortably full?
- Have you ever had an eating disorder? (undiagnosed or diagnosed)?
- Do you ever eat in secret?

Best Questions to Rule OUT an Eating Disorder

- Does your weight/shape affect how you feel about yourself significantly?
- Are you satisfied with your eating patterns?
- How stressed are you if you miss a workout? (for those who hyperexercise)

- Signs of excess energy intake including increased weight-for-age z-score, elevated blood pressure, hypertension, acanthosis nigricans (skin condition that causes a dark discoloration in the body folds and creases, typically in the armpits, groin, and neck), hepatomegaly, premature puberty

Laboratory Evaluation and Further Testing

A thorough evaluation of a patient with nutrition insufficiency includes laboratory testing to evaluate for possible underlying medical conditions or complications. It is important to note that even patients with severe EDs may still have normal results on laboratory testing, so decisions regarding treatment and monitoring should be made in the context of the overall clinical assessment in the face of potentially benign laboratory results. Initial evaluation may include a complete blood count, a comprehensive metabolic panel (CMP) including serum electrolytes, liver enzymes, blood urea nitrogen, and creatinine, magnesium, calcium, phosphorus, and glucose levels, thyroid-stimulating hormone concentration, and urinalysis. Erythrocyte sedimentation rate can be a useful screen for starvation versus an inflammatory process; with the former, values tend to be very low (<3 mm/hour). If the diagnosis is uncertain, other studies for medical causes of malnutrition may be important as indicated by the clinical presentation, such as serologic testing for celiac disease, inflammatory markers for possible inflammatory bowel disease, or other laboratory evaluation as indicated. Patients with amenorrhea should also have a urine pregnancy test, serum follicle-stimulating hormone (FSH) and luteinizing hormone (LH) levels, and prolactin. Low FSH and LH levels are common in starvation, whereas LH:FSH in a 3:1 ratio can be indicative of polycystic ovarian syndrome (PCOS) (See Chapter 24), and markedly elevated levels may indicate ovarian failure. Patients with amenorrhea for more than 6 months should also be considered for bone density assessment using dual energy X-ray absorptiometry (DEXA).

Based on the nutrition assessment and physical examination of the patient, additional testing for specific vitamin deficiencies, such as for vitamin B_{12}, vitamin D, iron, and zinc, may also be ordered.

All patients with suspected EDs should undergo an electrocardiogram (EKG) to assess heart rhythm and length of the corrected QT interval (QT), as prolonged QTc is a serious risk factor for ventricular arrhythmia and death.

Nutrition Diagnosis

Common nutrition diagnoses for patients with EDs include:

- Inadequate energy intake
- Increased energy expenditure
- Malnutrition (undernutrition)
- Altered nutrition-related laboratory values (specify)
- Disordered eating pattern

Nutrition Intervention

Nutrition Prescription

During starvation, patients may initially be hypometabolic. They then experience rapid hypermetabolism as refeeding begins, typically requiring 120%–150% of predicted energy needs using standard equations. Energy needs must be met without excessive protein intake; therefore, fat and carbohydrate recommendations are higher than typical. Energy needs should be frequently monitored and increased as weight restoration occurs. Increased needs may persist for some time after weight restoration is complete. It may be appropriate to share energy goals with caregivers during family-based treatment, though use caution with discussing "calories" with patients. The goal is to remove the focus from numbers.

Treatment Options

Most patients with EDs can complete the majority of treatment in the outpatient setting. The overall goal of treatment is to restore the patient to a healthy weight for growth and development, as well as to help the patient improve her body image, sense of self, and relationship with food and exercise. Inpatient treatment may be indicated for patients who present with signs of severe dehydration, electrolyte abnormalities such as hypokalemia, hyponatremia, or hypophosphatemia, abnormal EKG (such as bradycardia or prolonged QTc), acute refusal of nutrition or hydration, or failure of prior outpatient treatment. Patients with psychiatric co-morbidities presenting an imminent threat to safety, such as suicidal ideation or plan, should also be hospitalized.

Inpatient Stabilization

The goals of medical stabilization in a patient with ED include both weight gain and the avoidance of refeeding syndrome (see related section). The patient must be closely monitored for signs of refeeding syndrome while slowly increasing energy intake for weight gain of approximately 0.9–1.4 kg/week. Targeted weight gain will be less in partial-hospitalization programs (0.5–0.9 kg/week) and outpatient programs (0.2–0.5 kg/week). The patient should be encouraged to eat by mouth as much as possible.

Nasogastric (NG) tube feedings may be necessary in some cases if the patient is not able to consume the appropriate amount of food by mouth. Potential benefits of NG feeding include faster medical stabilization and improved weight gain.

Parenteral nutrition is typically not recommended, as this method of nutrition is costlier and associated with higher risk of medical complications, especially when manipulated by patients wishing to avoid weight gain.

Family-Based Treatment (FBT)

FBT is an intensive outpatient treatment program, wherein caregivers play an active role in helping to restore their child's weight before slowly transitioning control over eating back to the patient, until the adolescent is able to maintain age-appropriate weight gain on her own without unhealthy eating behaviors. FBT has become an established component of the treatment of AN and BN and has been demonstrated to lead to positive outcomes in terms of both weight restoration and psychological factors. In the initial phase of the treatment, the patient's caregiver will take responsibility for choosing, planning, and preparing meals and snacks for the patient, and over time the patient will progress to later phases of the treatment and gradually regain responsibility for making food choices.

Cognitive Behavioral Therapy and Dialectical Behavioral Therapy

Cognitive behavioral therapy (CBT) also has been shown to be effective for many EDs, particularly BN and BED. CBT helps patients identify and modify unhelpful cognitive distortions in order to improve emotional regulation. CBT is also an established treatment approach for many other psychiatric conditions, including anxiety and depression. In the context of ED treatment, the goal of CBT is the reestablishment of regular eating patterns; patients also learn to question and reframe the distorted thoughts which can lead to guilt, shame, and worsened self-image. Dialectical behavioral therapy (DBT) involves behavioral modification combined with insight; from the patient's perspective, if I experience trigger "A", I can utilize skills "B" and "C" to handle that stress. The core skills of DBT include mindfulness, interpersonal effectiveness, emotional regulation, and distress tolerance.

Day-Treatment or Partial-Hospitalization Programs

Treatment in a partial-hospitalization program (PHP) may be appropriate for patients with ED who do not need inpatient care or 24-hour supervision but require a higher level of care than outpatient therapy. This type of program typically entails 5–10 hours/day of group activities, therapy sessions, supervised mealtimes, and other activities with a multidisciplinary staff. Intensive outpatient programs (IOPs) involve 1–3 hours, 1–5 days a week, of skills-building group work designed to help patients utilize more effective emotional regulation skills rather than abnormal eating attitudes and behaviors as a means of coping.

Residential Treatment

Patients who are medically stable but require a high level of care for treatment of their ED may benefit from a residential treatment program. Examples of patients who may require residential treatment include those who are extremely resistant to engaging in an outpatient or day-treatment setting, do not have a supportive family environment, or those who have previously attempted outpatient or day-treatment programs without success. The length of residential treatment may range from days to months; during the stay, the patient will receive 24-hour supervision with group- and individual-therapy sessions and nutrition counseling.

Refeeding Syndrome

Refeeding syndrome describes the electrolyte changes, fluid imbalances, and altered homeostasis that can occur in malnourished patients when nutrition rehabilitation is initiated. The incidence of refeeding syndrome among patients with EDs who are admitted to the intensive care unit is up to 10%, with severe consequences including delirium, seizures, rhabdomyolysis, cardiac arrhythmia, acute respiratory failure, and death. The most commonly reported finding in refeeding syndrome is hypophosphatemia, which can be used in some cases as a surrogate marker for refeeding syndrome. Studies of patients with BMI < 15.1 kg/m^2 have identified hypophosphatemia in up to 27% within the first week of nutrition rehabilitation. Patients with severe hypophosphatemia have a significantly increased risk of mortality. Other electrolyte disturbances commonly seen in refeeding syndrome include hypokalemia, hypomagnesemia, hyperglycemia, and thiamine deficiency.

Risk factors for refeeding syndrome include patients with chronic malnutrition (including prolonged fasting, oncologic patients), chronic diuretic use, inflammatory bowel disease, significant vomiting or diarrhea, acute weight loss of greater than 10% of body weight in 1–2 months, and patients with underlying complex health needs (Tables 22.3 and 22.4).

Pathophysiology

In refeeding syndrome, total body depletion of phosphorus stores during catabolic starvation combined with increased cellular influx of phosphorus when anabolic feeding commences results in congestive heart failure, peripheral edema, and liver congestion with elevated liver enzymes. The initial high glucose load accompanying a rapid increase in caloric intake stimulates insulin secretion, which triggers the cellular uptake of phosphorus, potassium, glucose, and magnesium. As the body makes adenosine triphosphate (ATP) within the first 12–72 hours after refeeding, body phosphorus stores are depleted, with no further ATP able to be made. Rapid refeeding without adequate phosphorus can rapidly increase afterload in patients with myocardial wasting. Hypophosphatemia occurs due to a switch from gluconeogenesis (during starvation) to glycogen production by the liver and production of ATP at the cellular level. The newly anabolic state can also lead to thiamine deficiency.

TABLE 22.3
Criteria for Identifying Pediatric Patients at Risk of Refeeding Syndrome (1 month to 18 years)

	Mild Risk: 3 Risk Criteria Needed	Moderate Risk: 2 Risk Criteria Needed	Significant Risk: 1 Risk Criterion Needed
Weight-for-length z-score (1–24 months) or BMI-for-age z-score (2–18 years)	−1 to −1.9 that is a change from baseline	−2 to −2.9 that is a change from baseline	≤ −3 that is a change from baseline
Weight loss	<75% of norm for expected weight gain	<50% of norm for expected weight gain	<25% of norm for expected weight gain
Energy intake	3–5 consecutive days of protein or energy intake <75% of estimated need	5–7 consecutive days of protein or energy intake <75% of estimated need	>7 consecutive days of protein or energy intake <75% of estimated need
Abnormal serum values before feeding (potassium, phosphorus, magnesium)	Decreased to 25% below lower limit of normal	25%–50% below lower limit of normal	25%–50% below lower limit of normal
Higher-risk co-morbidities (includes eating disorders, food insecurity, malabsorptive states)	Mild disease	Moderate disease	Severe disease
Loss of subcutaneous fat	Evidence of mild loss or MUAC z-score of −1 to −1.9	Evidence of moderate loss or MUAC z-score of −2 to −2.9	Evidence of severe loss or MUAC z-score of ≤ −3
Loss of muscle mass		Evidence of mild or moderate loss or MUAC z-score of −2 to −2.9	Evidence of severe loss or MUAC z-score of ≤ −3

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MUAC, mid-upper arm circumference.

TABLE 22.4
Criteria for Identifying Adult Patients at Risk of Refeeding Syndrome (≥18 years)

	Moderate Risk: 2 Risk Criteria Needed	Significant Risk: 1 Risk Criteria Needed
BMI (kg/m^2)	16–18.5	<16
Weight loss	5% in 1 month	7.5% in 3 months of >10% in 6 months
Energy intake	None or negligible oral intake for 5–6 days or <75% of estimated energy needs for >7 days during an acute illness or injury or <75% of estimated energy needs for >1 month	None or negligible oral intake for >7 days or <50% of estimated energy needs for >5 days during an acute illness or injury or <50% of estimated energy needs for >1 month
Abnormal serum values before feeding (potassium, phosphorus, magnesium)	Minimally low levels or normal current levels and recent low levels necessitating minimal or single-dose supplementation	Moderately/significantly low levels or minimally low or normal current levels and recent low levels necessitating significant or multiple-dose supplementation
Loss of subcutaneous fat	Evidence of moderate loss	Evidence of severe loss
Loss of muscle mass	Evidence of mild or moderate loss	Evidence of severe loss
Higher-risk co-morbidities (includes eating disorders, food insecurity, malabsorptive states)	Moderate disease	Severe disease

Source: Reprinted from Silva JS, Seres DS, Sabino K, et al. ASPEN consensus recommendations for refeeding syndrome. *Nutrition in Clinical Practice*, April 2020; 35:178–195, Copyright 2020 American Society for Parenteral and Enteral Nutrition, with permission from Wiley.

Treatment of Refeeding Syndrome

In patients with severe malnutrition, initial refeeding has traditionally proceeded slowly, starting at 50% of estimated energy needs, or 1,500 kcal/day for girls, 1,750 for boys. More recently, children, adolescents and young adults have been started at higher amounts, of 2,200–2,500 kcal successfully, with phosphorus supplements preventively given for the initial 5 days. Energy intake should be increased by approximately 250 kcal/day to ensure weight gain of 0.2 kg/day while inpatient. During the initial refeeding process, the patient should be closely monitored with frequent collection of vital signs, strict monitoring of intake and output, daily physical examination, and close measurement of kidney function and electrolytes including phosphorus, magnesium, potassium, and sodium, and glucose. Electrolyte disturbances should be corrected as they arise during refeeding. Fluid intake and output as well as renal function should be closely monitored. Oral potassium may be used with hypokalemia, with a complete metabolic panel, magnesium, and phosphorus checked daily until these results are normal.

Thiamine 100–300 mg can be administered orally, or 50–100 mg intravenously for up to 3 days, with increased doses for patients with confirmed thiamine deficiency. If energy needs are not expected to be consistently met orally, a multivitamin can be useful. In addition, adolescents and young adults require 1,200–1,500 mg of calcium for optimal bone health.

Common Nutrition Interventions

The registered dietitian is an integral part of the healthcare team and is qualified to provide medical nutrition therapy to normalize eating patterns and nutrition status. Advanced training or experience is preferred to effectively work with this patient population. The primary goal of nutrition intervention for EDs is weight restoration via adequate energy and fat intake. Secondary goals include

increasing food acceptance and diversity of food groups, ability to eat in social situations, and/or decreasing anxiety around fear foods.

Dietitians must be aware of gastrointestinal complications in malnourished patients. Patients may have delayed gastric emptying, reduced gastric and pancreatic secretion, and complaints of constipation, abdominal distention, heartburn, and early satiety. Discussion with the patient on expectations and normalizing symptoms while working through the meal plan is imperative. Patients will also have reduced hunger cues. It is important for the dietitian to educate how to navigate this to ensure adequate intake until metabolism normalizes.

There are no specific methods for outpatient intervention recommended in the literature. Any meal plan that ensures adequate energy, protein, carbohydrate, and fat intake is appropriate. Patient education on nutrient needs is an integral part of treatment. However, when the child or adolescent is in a malnourished state, she likely will not have the capability to comprehend and understand the education provided. Thus, it is important to restore weight as early as possible. Current research does show that Family-Based Therapy is effective for individuals under the age of 18 years. The dietitian should help support caregivers in understanding the appropriate intake for their child or adolescent by providing nutrition education as well as examples of meals and snacks that meet each patient's energy needs. Long-term education can then be provided to patients as they are able to reclaim meal planning on their own further along in treatment.

All meal plans should include three meals per day and two or three snacks. Common meal plan patterns include either the exchange system, macronutrient inclusion at all meals, or basic education on the USDA MyPlate model for food group inclusion. Different patterns may work for different patients and in different settings (outpatient vs. residential). Meal timing and consistency is of utmost importance with any meal plan. The dietitian should also monitor laboratory values and provide recommendations for appropriate supplementation. Attention to bone health in this age group is essential. Self-monitoring and documenting intake can be a helpful tool for some patients and a stress-inducing tool for others. It is often used in residential treatment with frequent dietitian and therapy supervision. It may not be appropriate in the outpatient setting where the goal is to reduce over-focus on food itself.

The dietitian must not initiate treatment as the sole provider. Eating disorder treatment requires a multidisciplinary approach including medical providers and mental health specialists.

Nutrition Monitoring and Evaluation

Frequent monitoring and evaluation of patients with ED is essential during treatment. Nutrition reassessment should include serial anthropometric measurements and diet recall. Meal plans should be adjusted to continually meet weight gain goals (Table 22.5).

Expected Course and Prognosis for Youth with Eating Disorders

The course of illness for adolescents with EDs varies widely across research studies, depending on the patient population studied, length of follow-up, and how recovery is defined. Adolescents tend to recover more successfully than adults with EDs with a recovery rate among adolescents of about 70%. Significant factors contributing to increased likelihood of positive treatment outcome include a higher percentage of median body weight for age at initial presentation, as well as shorter duration of symptoms prior to presentation. In a study of adolescents who were treated for AN in the outpatient setting, about a third of patients were found to be in remission at the 12-month follow-up time point; 4 years later, less than 10% of these patients were found to have relapsed. Relapse rates may be higher for BN, BED, and purging disorder in adolescents, and about 25% of BN patients will be characterized as having chronic disease. Patients should be monitored both for signs of remission of ED and for other possible psychiatric co-morbidities, as high levels of depressive symptoms have also been

TABLE 22.5
ADIME Summary for Adolescent Medicine

- Assessment
  - Growth assessment
  - Nutrition-focused physical exam
  - Nutrient Intake
  - Labs
  - Gastrointestinal Findings
  - Medications/Side Effects
- Diagnosis
- Intervention
  - Nutrition Prescription
    - 120%–150% of standard predictive equations
  - Common nutrition interventions
    - Monitor for refeeding syndrome
    - Oral
      - Individualized meal plan
      - 3 meals and 2–3 snacks per day
    - Enteral Nutrition
    - Education
    - Laboratory Monitoring
      - Micronutrient labs as indicated
      - Monitor for refeeding syndrome for patients at risk
    - Supplements
    - Other specialty referrals
      - Treatment must include medical providers and mental health specialists
- Monitoring and Evaluation

reported in this population and suicide rates are also increased among patients with EDs. In children and adolescents, early recognition and engagement with a team of care providers, including a medical specialist, therapist, and dietitian, can make the difference between wellness and illness.

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23 Inborn Errors of Metabolism

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CONTENTS

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Inborn Errors of Metabolism (IEMs) are genetic disorders where deficiency of an enzyme or transport protein results in a block in the synthesis or breakdown of carbohydrates, proteins, or fats. These can result in devastating illness which may lead to significant morbidity and mortality if not detected early and treated promptly. Most IEMs are inherited in an autosomal-recessive manner and are rare. Clinical presentation can be mild to severe and age of presentation can be "early" or "late" onset, depending on whether enzyme activity is partially or completely blocked. IEMs may be diagnosed pre-symptomatically through newborn screening (NBS), prenatal testing, or family studies. Symptomatic presentation can happen during a catabolizing illness or situation where there is an energy deficit during childhood or adulthood including during the newborn period before results of the NBS are known.

PATHOPHYSIOLOGY AND PRESENTATION

The pathophysiology of IEMs can be a result of one or more of the following:

- The accumulation to toxic levels of substrates prior to the enzymatic block
- The accumulation of toxic intermediates from alternative metabolic pathways in the biochemical reaction
- Defects in energy production
- Deficiency of the products

In the neonate, the early clinical features of acute metabolic decompensation are almost always non-specific; they include looking "unwell", lethargy, feeding problems, vomiting, abnormal breathing, hypotonia, and seizures. IEMs presenting after the neonatal period present with recurrent vomiting and lethargy with or without typical patterns of organ dysfunction or focal neurological signs. Appropriate diagnostic and therapeutic measures must be initiated as soon as possible to avoid long-term damage.

Newborn Screening, Diagnosis, and Initiation of Treatment

The use of automated tandem mass spectrometry for NBS for IEMs has been adopted in most of the states in the US and Western countries. This method is fast and precise and allows screening for

many IEMs on a single blood spot. A total of 30–40 metabolites are measured in the blood sample (collected 24–72 hours after birth) to screen for various amino acid disorders, organic acidemias, and fatty acid oxidation (FAO) defects. Infants who have an abnormal NBS as well as those who are "late diagnosed" symptomatically are referred to a medical specialist for confirmation of the diagnosis and initiation of treatment. The medical specialists trained in clinical and biochemical genetics work in major medical centers along with dietitians experienced in treating patients with IEMs. A listing of the medical centers with contact information of the dietitians in the USA and in Canada is made available by Genetic Metabolic Dietitians International (GMDI). Diagnostic work up of an IEM is disorder specific but generally includes measurement of plasma amino acids, plasma acylcarnitine and carnitine profile, plasma ammonia, lactate, and urine organic acids. Once a diagnosis is established, treatment is initiated using one or more of the following strategies:

- Restriction of substrate: e.g., phenylalanine in phenylketonuria (PKU)
- Enhancement of residual enzyme activity by co-factor/coenzyme supplementation: e.g., use of tetrahydrobiopterine (BH4) in PKU
- Supplementation of a deficient product: e.g., supplementation with citrulline in ornithine transcarbamoylase (OTC) deficiency
- Utilization of alternate pathways for conjugation of a toxic metabolite: e.g., use of ammonia scavengers in urea cycle disorders (UCD) and carnitine in FAO defects

NUTRITION MANAGEMENT

The goals of nutrition interventions in IEMs are:

- Meet nutrient demands for growth, development, and health maintenance
- Provide interventions to achieve optimal nutrition status, metabolic stability, and reduce risk of secondary complications
- Provide nutrient supplementation or other treatment modalities to improve outcomes
- Monitor dietary intake and laboratory studies to adjust the nutrition prescription and care plan during both acute and chronic care

Nutrition Assessment

Anthropometric Measurements

Growth can be affected due to metabolic abnormalities which cause food aversions, reduced appetite, feeding difficulties, and affect nutrition requirements. Use of free amino acid-based medical foods in certain IEMs is known to increase energy and protein requirements. Obesity can be present due to excess energy consumption or reduced mobility. Disorder-specific growth charts are not available in IEMs; therefore, standard growth charts are used (Chapter 1).

Dietary and Laboratory Assessment

Diets for IEMs can be restricted in one or more essential nutrients or food groups. Medical foods are prescribed in many IEMs and these help in overcoming many of the deficiencies of an otherwise restricted diet. Compliance with medical foods can be difficult, especially in adolescence. Supplemental vitamins and minerals are frequently prescribed.

Dietary assessment should include frequent review of diet records including medical-food consumption and tolerance, tolerance to tube feeding in patients receiving enteral nutrition, gastrointestinal function, access to food/related supplies, and analysis of all macro- and micronutrient intake using appropriate software (e.g., MetabolicPro by GMDI). Biochemical assessments are focused on the restricted nutrients and levels of accumulated metabolites to evaluate the efficacy of dietary and medical interventions. These tests are done in addition to routine assessments of protein, vitamin,

and mineral status, hematological, kidney, liver, and endocrine tests that have a bearing on the growth and health status of the individual.

Social and Family Assessment

Knowledge, beliefs, and attitudes surrounding nutrition, educational level, and financial/employment status affect adherence to dietary recommendations. IEMs are complex disorders, and the management of IEMs can affect emotional health, relationships, and family life. Ongoing assessment of family needs, dynamics, and responsibility sharing between members is necessary. If indicated, a referral to social work can be placed to ensure the patient and family are receiving the available resources.

Nutrition Diagnosis

Common nutrition diagnoses utilized for patients with IEMs include:

- Impaired nutrient utilization
- Altered nutrition-related laboratory values

These diagnoses should be used along with individualized problems determined in the nutrition assessment.

Nutrition Intervention

The nutrition prescription and intervention are dependent on the IEM. See the diagnosis-specific sections below for more details. Common nutrition interventions utilized for all patients with IEMs include nutrition education and other specialty referrals.

Nutrition Education

Diets for IEMs can be complex and require micromanagement of one or more nutrients. This requires timely and ongoing education of caregivers and patients for good dietary compliance and optimum outcomes. Nutrition education needs to be tailored to the age, developmental stage, cognitive abilities, and social and educational background of the patient and family. Disease-specific education materials by several patient support organizations and medical-food companies are available and can be found on the website for GMDI. Table 23.1 also has some examples.

Other Specialty Referrals

Individuals with IEMs can have normal development but many are at risk for mild to severe developmental delay. They can have cognitive, motor, and emotional/psychiatric disability and need timely referrals to other disciplines. Feeding, occupational, physical, and behavioral therapies are commonly needed. Many children need individualized education plans (IEPs) and 504-plan accommodations in school. Communication with school food services to facilitate special meal plans that are also nutritious is essential.

Nutrition Monitoring and Evaluation

Nutrition monitoring and evaluation are essential components in the care of patients with IEMs. Patients with IEMs require routine monitoring of nutrient intake and laboratory values. The nutrition intervention will be adjusted frequently to meet the changing dietary needs of children as they grow and in response to laboratory values. Patients with IEMs will require lifelong follow-up with a provider and a dietitian in a tertiary care center specializing in IEMs.

The following sections describe the nutrition care of patients with the most common IEMs. See Table 23.1 for a list of common IEMs and the associated enzyme defect and dietary interventions.

TABLE 23.1
Enzyme Defect, Dietary Intervention, Medications, and Monitoring in Inborn Errors of metabolism

Disorder	Website for More Information	Enzyme Defect	Dietary Intervention	Medications	Monitoring & Evaluation
Phenylketonuria (PKU)	Pkunews.org https://gmdi.org/Members/-Clinical-Practice-Tools/Nutrition-Guidelines	Phenylalanine hydroxylase (PAH)	Phenylalanine-free medical foods Phenylalanine-restricted/low-protein diet	Avoid aspartame Synthetic BH4, Palanzyq®: for improving phenylalanine tolerance/diet liberalization	Blood phenylalanine and tyrosine levels Growth, developmental, neurocognitive, psychology assessment
Classical Galactosemia	www.galactosemia.org	Galactose-1-phosphate uridyl transferase (GALT)	Soy-based or casein hydrolysate formulas and galactose-free diet in infants. Children and adults: Avoid all dairy products and dairy components/ingredients. All fruits and vegetables allowed	Avoid medications containing lactose	RBC Galactose-1-phosphate (gal-1-P), 25-OH vitamin D, bone mineral density screening Growth, developmental, speech, educational assessment Pre-puberty: Endocrine evaluation for females
Fatty acid oxidation defects	https://www.fodsupport.org/medical/ https://gmdi.org/Members/-Clinical-Practice-Tools/Nutrition-Guidelines	Multiple enzymes See Figure 23.3	Avoid fasting. Medium-Chain Acyl CoA Dehydrogenase Deficiency: avoid medium chain triglyceride (MCT) containing formulas Long-chain Fatty Acid Oxidation Disorders: limit dietary fat, use predominantly MCT-based formulas	Long-chain Fatty Acid Oxidation Disorders: MCT oil or triheptanoin Carnitine: as needed to maintain normal levels	Acycarnitine profile, plasma carnitine, essential fatty acids including docosahexanoic acid, Creatine phosphokinase (CPK) Echocardiogram where indicated. Ophthalmology exam in Long-chain 3-hydroxyacyl-CoA dehydrogenase deficiency/ Trifunctional Protein Deficiency

(*Continued*)

TABLE 23.1 (*Continued*)
Enzyme Defect, Dietary Intervention, Medications, and Monitoring in Inborn Errors of metabolism

Disorder	Website for More Information	Enzyme Defect	Dietary Intervention	Medications	Monitoring & Evaluation
Urea cycle disorders	http://www.nucdf.org/support.htm	Multiple enzymes See Figure 23.4	Essential amino acid-based medical food Low-protein diet	Sodium benzoate Sodium or phenylbutyrate, citrulline for ornithine transcarbamoylase deficiency, Carbamoyl phosphate synthetase deficiency. Arginine for Argininosuccinic acid synthetase deficiency and argininosuccinic acid lyase deficiency	Plasma ammonia, amino acids, protein nutrition status, growth, developmental, neurocognitive assessment
Glycogen storage disease (GSD) type 1 a/b	https://agsdus.org/	GSD Ia: Glucose-6-phosphatase GSD Ib: Glucose-6-phosphatase translocase	Frequent feedings (every 2–4 hours including overnight feedings) Sucrose-, fructose-, galactose-free formulas and food Uncooked cornstarch/Glycosade®	Allopurinol for gout Angiotensin-converting enzyme (ACE) inhibitors or angiotensin-receptor blockers (ARB) for microalbuminuria and proteinuria GSD Ib: Vitamin E, Granulocyte colony-stimulating factor (GCSF) for neutropenia Avoid medications containing lactose, sucrose, sorbitol Avoid Lactated Ringers, glucagon	Blood glucose, lactate, uric acid, lipid panel, complete blood count with differential, coagulation studies, urine micro albumin/creatinine 25-OH vitamin D Iron/total iron binding capacity (TIBC)/ferritin Imaging studies of liver/abdomen. Growth, BMI, feeding evaluation
Maple syrup urine disease (MSUD)	https://msud-support.org/ https://gmdi.org/Members/-Clinical-Practice-Tools/Nutrition-Guidelines	Branched-chain α-ketoacid dehydrogenase complex (BCKD complex)	Leucine-, isoleucine-, valine-free medical food Low-protein diet to restrict the intake of above amino acids corresponding to leucine tolerance	Isoleucine and valine supplementation as necessary to maintain metabolic control	Plasma leucine, isoleucine, valine Biochemical and clinical signs of isoleucine deficiency Growth, developmental, neurocognitive assessment

(*Continued*)

TABLE 23.1 (*Continued*)
Enzyme Defect, Dietary Intervention, Medications, and Monitoring in Inborn Errors of metabolism

Disorder	Website for More Information	Enzyme Defect	Dietary Intervention	Medications	Monitoring & Evaluation
			Organic Acidemias		
Glutaric acidemia type 1 (GA 1)	https://www.oaanews.org/oa-disorders.html	Glutaryl-CoA dehydrogenase (GCDH)	Lysine- and tryptophan-free medical food Low-protein diet to restrict the intake of lysine	Carnitine supplementation to prevent deficiency Arginine per discretion of the clinician	Plasma amino acids (to detect dietary deficiency), carnitine. Growth, developmental, neurocognitive assessment
Isovaleric acidemia (IVA)	https://www.oaanews.org/oa-disorders.html	Isovaleryl Co-A dehydrogenase (IVD)	Leucine-free medical food Low-protein diet to restrict the intake of leucine	Carnitine/ glycine per the discretion of the clinician	Plasma amino acids, carnitine Growth, developmental, neurocognitive assessment
Methylmalonic acidemia (MMA)	https://www.oaanews.org/oa-disorders.html	Methylmalonyl-CoA mutase, cobalamin biosynthesis defects	Valine-, methionine-, isoleucine-, threonine-restricted medical food. Low-protein diet to restrict the above amino acids corresponding to valine tolerance	Carnitine. Bicitra or Polycitra for renal tubular acidosis Metronidazole (to reduce enteral propionate and ammonia production) Carbaglu® as an adjunctive treatment for hyperammonemia Hydroxy B_{12} in cobalamin biosynthesis defects	Plasma amino acids, methylmalonic acid and carnitine Complete blood count with differential, kidney function tests Growth, developmental, neurocognitive assessment
Propionic acidemia (PA)	https://www.oaanews.org/oa-disorders.html	Propionyl-CoA carboxylase (PCC)	Same as in MMA	Carnitine Bicitra or Polycitra Carbaglu	Plasma amino acids, carnitine Growth, developmental, neurocognitive assessment Cardiac evaluation: echocardiogram, electrocardiogram

PHENYLKETONURIA

PKU was one of the first neurogenetic disorders identified, the first successfully treated IEM, and the disorder that was instrumental for the introduction of NBS in the USA and elsewhere. PKU results from a defect in the function of the enzyme phenylalanine hydroxylase (PAH) which catalyzes the conversion of phenylalanine (PHE) to tyrosine (TYR) (Figure 23.1).

TYR is necessary for synthesis of proteins, catecholamines, melanin, and thyroid hormones. Conversion to TYR is the major metabolic pathway of PHE. When PAH is nonfunctional, PHE accumulates in the blood and other body tissues and gets converted to phenylpyruvic acid and phenylketones. If untreated, PKU results in intellectual disability, seizures, and tremors, as well as other neurocognitive and behavioral problems. PAH requires the coenzyme BH4, and a defect in the synthesis or recycling of BH4 results in a very rare and "atypical" form of PKU that has different neurological manifestations and treatment.

More than 600 mutations in the PAH gene have been identified resulting in varying residual activity and blood PHE levels. PKU is classified based on blood PHE levels at diagnosis into:

- **Severe (Classic) PKU**: blood/plasma PHE concentration >1,200 μmol/L (>20 mg/dL)
- **Moderate PKU**: blood/plasma PHE concentration 900–1,200 μmol/L (15–20 mg/dL)
- **Mild PKU**: blood/plasma PHE concentration 600–900 μmol/L (10–15 mg/dL)
- **Mild Hyperphenylalaninemia (HPA)**: PHE concentrations 360–600 μmol/L
- **Benign Mild HPA**: PHE concentrations 120–360 μmol/L, which typically does not require treatment

The incidence of PKU is approximately 1:10,000–1:15,000 newborns and is more common among Northern Europeans. Infants with NBS results consistent with PKU are referred to a metabolic clinic for confirmatory testing using plasma amino acids. PKU is diagnosed if PHE concentration is persistently above 120 μmol/L and TYR is low or low normal, in an individual with an otherwise

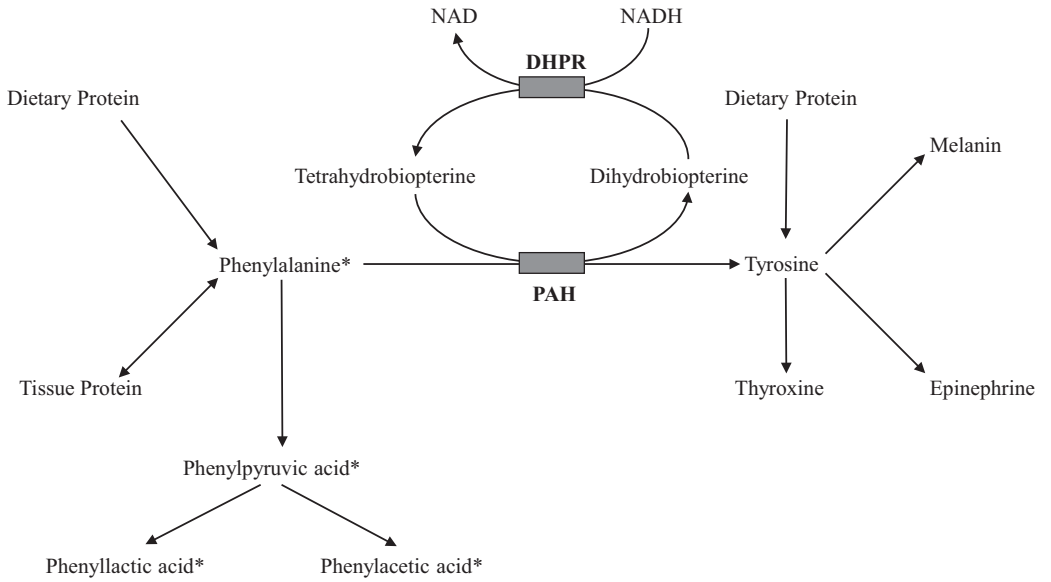

FIGURE 23.1 Metabolism of phenylalanine. PAH, phenylalanine hydroxylase; DHPR, dihydropterine reductase.

*** accumulated metabolites in phenylketonuria**

normal amino acid profile. BH4 deficiency is ruled out by measuring urine pterins and blood dihydropteridine reductase activity in all individuals with elevated PHE and PHE:TYR ratio.

Dietary Intervention at Diagnosis

Blood PHE levels must be brought in the treatment range of 120–360 μmol/L by implementing a PHE-restricted diet as soon as possible after diagnosis (before 2 weeks of age). This is done initially through feeding of PHE-free medical food, provision of adequate energy for anabolism, and daily monitoring blood of PHE levels. Since PHE is an essential amino acid, it must be reintroduced in the diet based on the recommended dietary allowance (RDA) (see PKU toolkit under resources and guidelines for PKU) through addition of human milk or infant formula to the medical food as soon as the blood PHE level drops to the treatment range with further adjustments based on blood PHE levels. Enteral nutrition must be implemented if oral intake is not possible. PHE-free parenteral nutrition mixtures are available and must be ordered from specialty pharmacies when parenteral nutrition is necessary.

Clinical Signs and Symptoms

Failure or delay in treatment can cause irreparable neurological damage resulting in intellectual disability, developmental delay, seizures, and behavioral problems. Untreated adults and children with PKU can present with signs of skin and hair pigment dilution, skin rash, eczema, psoriasis, and a musty odor.

Nutrition Management

Goals of medical nutrition therapy in PKU are to maintain blood PHE between 120 and 360 μmol/L throughout the lifespan; maintain blood TYR in the normal range; and promote normal growth, development, and well-being.

Medical Food

Dietary management of PKU requires utilization of medical food (metabolic formula) devoid of PHE to meet protein and energy needs, provide micronutrients missing from diet, and in the implementation of a low-protein diet to restrict the intake of PHE. Prescription of medical food and dietary PHE allowance is based on individual PHE tolerance. An individual with classical PKU may derive as much as 80% of protein needs from the medical food and only 20% natural protein from foods due to limited ability to metabolize PHE. An individual with mild PKU on the other hand is likely to have a bigger allowance of dietary protein and hence need less of the medical food. The protein in medical foods is present as free amino acids which are rapidly digested and absorbed and result in lower nitrogen retention than intact proteins of higher biological value. Hence, the protein requirement in patients with PKU is 20%–50% above the RDA. The amount of medical food prescribed is based on the difference between the total protein recommendation and the intact protein allowance. For best utilization, consumption of medical food should be divided in multiple doses daily.

The PKU Diet

Fruits and vegetables are included due to their low protein content. Grains are allowed in limited quantity, while meats, nuts, legumes, dairy, eggs, and vegetarian protein alternatives are completely restricted from diet. Specialty foods low in PHE (pastas, breads, baking mixes made from wheat, potato, or tapioca starch) are available from several manufacturers and provide satiety and variety to the PKU diets but the cost may be prohibitive to many families. Foods with pure sugar and fat contain no PHE and are considered “free” foods. The dietary PHE allowed is prescribed as mg/day

or number of PHE "exchanges" per day (one PHE exchange equals amount of food that provides 15 mg PHE or approximately 0.4 g vegetable protein). GMDI provides information for obtaining PKU Food Lists, software programs, and specialty foods for making the dietary management a bit easier. A simplified-protein diet that allows ad lib intake of most fruits and vegetables is being utilized by many clinics, particularly for those with mild PKU.

Diet during Illness

Increased energy needs and catabolism during illness can cause elevation in blood PHE levels with temporary behavior changes but without long-term consequences. This should be minimized by treating the underlying illness, meeting protein and energy needs, and preventing dehydration. Closer monitoring of blood PHE levels and a reduction in dietary PHE intake is often recommended during illness.

Nutrition Assessment

Apart from total protein, PHE, and TYR, the DRI for nutrients are not different from that recommended for the general population. Growth and nutrition health in children with PKU is expected to be normal with good compliance of dietary recommendations and consumption of medical foods. While many medical foods are formulated to meet DRIs for vitamins, essential fatty acids (EFA), and minerals including trace minerals, some are lacking in these nutrients and supplementation is necessary. Dietary assessment should ensure the DRIs are met for all nutrients.

Obesity can be an issue with excessive energy intake from protein-free sugary and fatty foods. Close monitoring of anthropometric measurements is an important part of nutrition management. Biochemical monitoring should include frequent monitoring of blood PHE levels to maintain blood PHE levels in the treatment range of 120–360 μmol/L throughout life. TYR levels should be maintained in the normal range and supplementation is recommended as needed. Periodic measurements of other parameters of protein status, complete blood count, EFA, vitamins D and B_{12}, folate, iron, and trace mineral status are recommended. Evaluation of bone density is recommended for concern of osteopenia and fractures which was previously reported at higher frequency among children with PKU.

All patients with PKU should avoid medications and foods with aspartame as they contribute PHE to the diet and can cause elevation in blood PHE levels.

Medications

Synthetic sapropterin is an oral drug used as adjunct therapy for PKU. Sapropterin is shown to improve dietary tolerance of PHE and reduce dependence on medical food in some patients, typically those with some residual enzyme activity. It also has been shown to reduce fluctuation in blood PHE levels, which has been positively correlated with improved outcomes.

Palynziq® is an injectable enzyme (phenylalanine lyase [PAL]) that does not rely on a patient's enzyme activity. It was approved by the FDA in the USA for patients over the age of 18 years and with uncontrolled PHE levels greater than 600 μmol/L. PAL action reduces blood PHE levels through its conversion to cinnamic acid and ammonia in the gut. In the clinical trial, 66% of adults had PHE levels ≤ 360 μmol/L at 2 years.

Large Neutral Amino Acids Transporters

Large neutral amino acids (LNAA) are known to inhibit the passage of blood PHE into the brain through competition for carrier sites at the blood brain barrier. Supplementation with LNAA has been described as effective in improving neurocognitive function in individuals with PKU, without significantly lowering blood PHE. Use of LNAA is not recommended in young children and women of childbearing age.

Expected Clinical Course

Individuals with PKU can have a normal clinical course and healthy life when compliant with dietary recommendations and blood PHE levels in treatment range. Cognitive outcome is inversely correlated with blood PHE levels with the strongest association found between critical periods of development (<6 years of age) and blood PHE levels exceeding 400 μmol/L. Poor executive function, anxiety, depression, and agoraphobia are commonly seen in patients who are off the diet or are in poor metabolic control.

Maternal PKU

High maternal blood PHE is a teratogen and offspring of women untreated for PKU are at very high risk for having low birth weight, microcephaly, intellectual disability, and congenital heart disease (maternal PKU syndrome). A PHE-restricted diet to maintain blood PHE levels between 120 and 360 μmol/L is recommended before conception and throughout pregnancy to prevent this syndrome.

GALACTOSEMIA

To be used for energy, galactose needs to be converted to glucose via the Leloir pathway in the liver (Figure 23.2). Defects in three different enzymes: galactose-1-phosphate uridyl transferase (GALT), galactokinase, and galactose epimerase (GALE) can occur in this pathway that can result in galactosemia. Of these, GALT deficiency is the most common and has significant genotype-phenotype correlation based on residual enzyme activity.

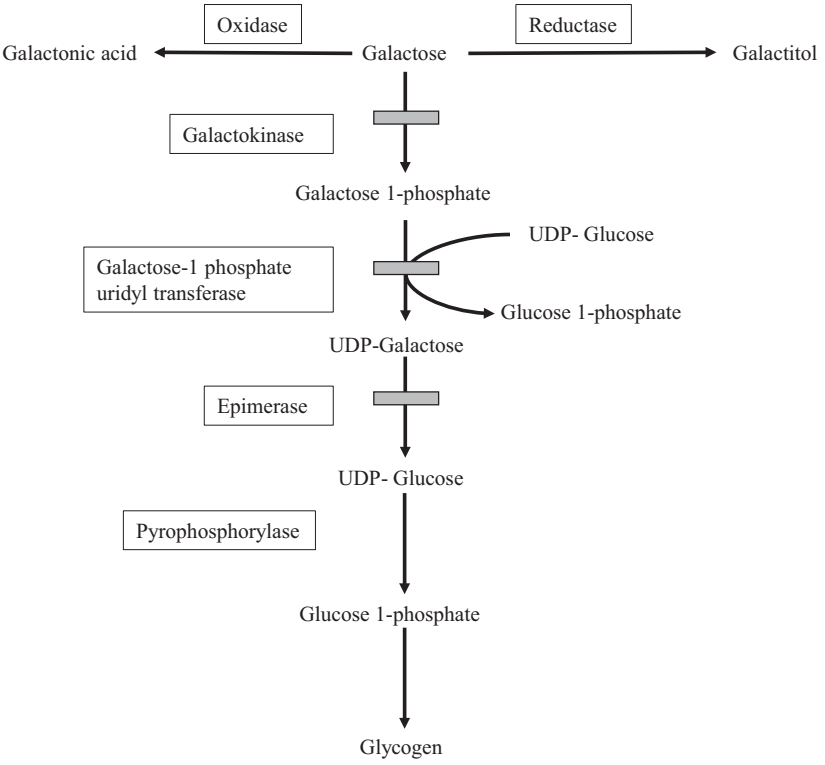

FIGURE 23.2 Galactose metabolism and enzyme blocks (indicated by gray bars) that lead to galactosemia.

GALT deficiency can present as:

- Classic galactosemia (CG) where enzyme activity is absent or barely detectable due to pathogenic mutations on both alleles
- Clinical variant galactosemia where enzyme activity is close to or above 1% of control values but probably never >10%–15% with pathogenic mutation on one or both alleles
- Duarte galactosemia resulting in residual enzyme activity of 14%–25% due to one pathogenic classical mutation that severely impairs GALT activity and another mutation that is partially impaired

Among the GALT defects, classic galactosemia has the most long-term complications. GALT deficiency is reported to occur in 1 in 10,000 to 30,000 live births. NBS for galactosemia is based on measurement of total galactose with testing for GALT enzyme and common DNA mutations either through parallel or as second tier testing. GALT activity maybe falsely normal after erythrocyte transfusion and maybe falsely reduced when the filter paper card used for NBS is exposed to high temperature during transit in summer months. Confirmatory testing is done by measurement of galactose-1-phosphate (Gal-1-P), quantitative GALT assay on erythrocytes, and further genetic testing if needed. Testing for kinase and epimerase deficiency is done with persistently elevated galactose levels, normal GALT, and absence of common GALT mutations.

Clinical Signs and Symptoms

Neonates with classic galactosemia develop life-threatening complications including feeding problems, malnutrition, hypoglycemia, hepatocellular damage, bleeding diathesis, jaundice, and bilateral cataracts (secondary to galactitol accumulation in the lens) within days of ingesting lactose from human milk or lactose-containing formula. The disease progresses rapidly, and if lactose is not removed from diet, it leads to liver failure, *E. coli* sepsis, and death. Symptoms and severity of GALE galactosemia type depend on whether the enzyme deficiency is confined to certain types of blood cells (peripheral) or is present in all tissues (generalized). Peripheral GALE deficiency is usually benign and asymptomatic whereas generalized GALE deficiency presents like and needs similar dietary intervention to classic galactosemia.

Dietary Interventions at Diagnosis

Infants with a diagnosis or suspected diagnosis of galactosemia should be immediately placed on a soy-based formula, a casein hydrolysate formula, or an elemental formula to reduce galactose intake and toxicity. Initiation of dietary treatment should not be postponed until diagnostic confirmation is obtained.

Nutrition Management

Lifelong galactose-restricted diet is recommended in classic galactosemia and patients with erythrocyte GALT activity below 10% of normal. This is achieved by elimination of galactose from the diet. Hence, foods to avoid include human milk, all milk-based foods and beverages, organ meats, meat by-products, fermented soy products, and soy sauce. Food- and medication-label reading is important to avoid all dairy products, lactose, casein, whey, etc. The international guidelines for management of classical galactosemia recommend allowing any amount and type of fruits, vegetables, legumes, unfermented soy-based products, aged/mature cheeses (with galactose content of <25 mg/100 g), and the food additives sodium or calcium caseinate. Calcium and vitamin D should be supplemented following age-specific recommendations for general population. There

is no consensus regarding needing lifelong dietary treatment for patients with galactosemia with 10%–15% GALT activity. Galactose restriction is not recommended in Duarte galactosemia.

Nutrition Assessment

Growth can be affected in classical galactosemia and needs regular assessment. Comprehensive dietary evaluation should ensure the patient is meeting the DRI for all nutrients, particularly calcium and vitamin D. Biochemical follow-up includes measurement of erythrocyte Gal-1-P levels every 3 months in the first year and then yearly until an individual baseline has been established. Erythrocyte Gal-1-P levels <4 mg/dL indicate good dietary compliance, but this may be difficult to reach in childhood due to endogenous galactose production. Measurement of plasma total 25-OH-vitamin D levels is recommended annually with bone mineral density screening from 8 to 10 years.

Children with classical galactosemia need speech and language, neurological, cognitive, and psychosocial assessments. Girls with classical galactosemia should have endocrine evaluation if they fail to develop secondary sex characteristics or have irregular menses.

Medications

Lactose is frequently used as a filler in many prescription and non-prescription medications. This is likely to be in small enough amounts to not cause any significant or measurable rise in blood Gal-1-P levels. If a substitute medication that does not contain lactose is not available, it may be used at the discretion of the physician after the initial crisis.

Expected Clinical Course

Despite adequate treatment from an early age, children with classic galactosemia are at high risk for developmental delays, speech problems (termed childhood apraxia of speech and dysarthria), and abnormalities of motor function. Almost all females with classic galactosemia manifest hypergonadatrophic hypogonadism or premature ovarian failure. Studies have shown that these complications do not correlate with any biochemical variables (erythrocyte Gal-1-P level) or age at treatment initiation. Restriction of milk in the mother's diet of infants who were treated with lactose-free formula at birth did not improve the developmental outcome of these infants in comparison to their older siblings with galactosemia. Individuals with clinical variant galactosemia are not known to develop long-term complications including premature ovarian failure.

FATTY ACID OXIDATION DISORDERS

Fatty acid oxidation disorders (FAOD) are caused by a block in the mitochondrial β-oxidation pathway or the carnitine transport shuttle. They lead to deficient energy production and can have a severe infantile onset or late onset depending on the type of the disorder and severity of enzyme defect. Estimated collective incidence is 1/5,000–10,000 live births. Medium-chain acyl CoA dehydrogenase deficiency (MCADD) is the most common FAOD that occurs in ~1/15,000 births in the USA.

FAO provides as much as 80% of energy for heart and liver function. In the liver, the oxidation of fatty acids fuels the synthesis of ketone bodies which are utilized as an alternative energy source by extrahepatic organs, particularly the brain. Glucose is the preferred energy source in cells and glucose derived from glycogen is used during short-term fasting. During periods of prolonged fasting, febrile illness, or increased muscular activity, fatty acids are mobilized to meet the increased energy demands. The physiologically available fatty acids are mostly the C16 and C18 (long-chain) fatty acids and their oxidation requires entry into the mitochondrial matrix using enzymes of the carnitine shuttle (Figure 23.3, steps 1–3). Once inside the mitochondria, β-oxidation of the fatty acids occurs in a repeating cycle using the four enzyme complexes (Figure 23.3, steps 4–7), each

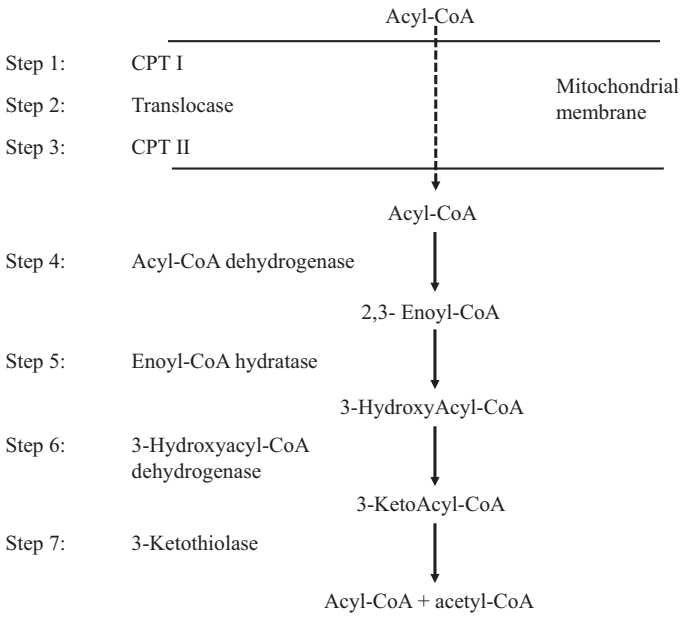

FIGURE 23.3 Simplified schematic of fatty acid β oxidation. CoA=coenzyme A; CPT-1, -2=carnitine-palmitoyl transferase-1, -2.

CPT I, translocase, CPT II are involved in the transfer of fatty acids across the mitochondrial membrane. The rest of the reactions occur within the mitochondrial matrix via β oxidation.

"spiral" of the cycle releasing one molecule of acetyl-CoA and leaving a fatty acyl CoA two carbons shorter for recycling through further β-oxidation. Acetyl-CoA can then enter the citric acid (CA) cycle and/or serve as the precursor for ketone production. The reducing equivalents reduced nicotinamide adenine dinucleotide (NADH) and dihydroflavine adenine dinucleotide ($FADH_2$) produced from β-oxidation and the CA cycle enter the electron transport chain for adenosine triphosphate (ATP) production.

The enzymes of β-oxidation pathway are specific to the structure and chain length of fatty acids and a block or defect in the enzyme activity results in accumulation of the substrate (acylcarnitine compounds) prior to the enzymatic block, carnitine depletion, and the metabolic sequelae of hypoketotic hypoglycemia often associated with metabolic acidosis. If there is insufficient carnitine available to exchange for the CoA moiety and help transport the accumulated intermediates out of the mitochondria, CoA may become a limiting factor and other catabolic pathways which utilize CoA may be unable to function to produce energy.

Clinical Signs and Symptoms

FAOD leads to deficient energy production and produces three variable clinical presentations in all ages. Typically, the most severe life-threatening presentations occur within a few hours of fasting in infants, but in adults may require up to 48 hours of fasting. The neonatal-onset type, where newborns will develop a profound cardiomyopathy, hypoketotic hypoglycemia, and liver dysfunction within the first few days or weeks of life, is often fatal. The infantile-onset type will present in infancy or childhood with intermittent episodes of lethargy and vomiting associated with intercurrent illnesses and lead to hepatic dysfunction, hypoketotic hypoglycemia, and encephalopathy or sudden death. The later- (or adolescent- or adult-) onset myopathic type presents with episodes of muscle weakness, myalgias, rhabdomyolysis, and risk of renal damage.

FAOD can be effectively diagnosed through NBS via mass spectrometry with each defect producing a unique acylcarnitine profile. Confirmatory diagnosis is done with additional biochemical tests (plasma carnitine and acylcarnitine profile and urine organic acids) and genetic testing. While pre-symptomatic diagnosis is possible with NBS, some newborns can present with symptoms of severe hypoglycemia, unexplained liver disease, myopathy, or cardiomyopathy before NBS results get reported. As with other metabolic disorders, NBS can miss some milder cases which may present later in life during an intercurrent illness or catabolic stress.

Nutrition Management

For understanding the nutrition management, it is helpful to classify the FAOD into two sub-types: medium-chain defects, e.g., medium-chain acyl Co-A dehydrogenase deficiency or MCADD; and long-chain defects, e.g., very-long-chain acyl Co-A dehydrogenase deficiency or VLCADD, long-chain 3 hydroxyacyl CoA dehydrogenase deficiency or LCHADD, trifunctional protein (TFP) deficiency which includes LCHADD and carnitine-palmitoyl transferase-1 and 2 (CPT1 and CPT2) deficiency. Following are important aspects of nutrition management in the above disorders.

Avoiding Fasting

The main goal of nutrition management in all patients with FAOD is to avoid fasting and prevent hypoglycemia by eating high-carbohydrate meals frequently. This is particularly important in infants and young children who have limited glycogen stores. Feeding interval should not exceed 4 hours in infants < 4 months; an additional hour can be added for each month between 5 and 12 months. Provision of adequate energy and frequent feeding should be initiated in infants suspected of having a FAOD prior to confirmation of diagnosis. A bedtime snack with complex carbohydrates is recommended to meet the fasting guidelines in children and adults. For those with a severe phenotype who do not tolerate extended fasting times, overnight enteral nutrition should be considered when a bedtime snack is not sufficient. More frequent feeding including midnight feeding and monitoring is recommended during illness due to increased energy needs and risk of hypoglycemia, especially in children.

Fat Content and Diet Composition

Ninety-five percent of dietary fat is long-chain fat. For patients with medium-chain FAOD, restricting dietary fat is not necessary. Nursing or routine infant formulas without medium-chain triglycerides (MCT) or with minimal MCT are safe for infants with medium-chain FAOD. Premature infant formulas and human-milk fortifiers contain large amount of MCT and should be used with caution. A heart-healthy diet is recommended in children and adults.

For long-chain FAOD (VLCADD, LCHADD, TFP deficiency, CPT1 and CPT2 deficiency), restricting fat intake is shown to decrease the accumulation of potentially toxic acylcarnitine compounds. In addition, supplementation with MCT which do not require carnitine for entry into the mitochondria provides an alternate energy source downstream of the enzymatic block. In VLCADD, neonates who develop clinical symptoms prior to diagnosis, human milk or standard infant formula should be discontinued and a low long-chain fat, high-MCT medical formula should be instituted. In asymptomatic infants with positive NBS and confirmatory testing for a severe or moderate phenotype, a combination of nursing and MCT-supplemented formula may be possible. Infants remaining asymptomatic with confirmatory testing suggesting a milder form of VLCADD may tolerate nursing ad lib without supplemental MCT.

For the long term, the suggested diet composition for the healthy individual with VLCADD varies with age and severity of the disorder. Those with a mild phenotype may not require any modification in dietary fat composition. Restricting dietary fat to provide 10% of energy and providing MCT to provide 10%–20% energy is beneficial in LCHADD and TFP deficiency in improving clinical outcomes.

Energy and protein requirements are not typically higher than general guidelines (Chapter 3). Minimally, protein requirements need to meet the DRI for age. Excess energy intake that leads to obesity should be avoided.

In individuals with severe form of FAOD disorders (LCHADD, TFP deficiency, severe form of VLCADD) dietary fat is strictly limited and sources of MCT are added to meet total fat and energy needs. This raises the concern of EFA deficiency. Biochemical EFA deficiency has been diagnosed in treated patients with above disorders. Providing 4% of energy as linoleic acid and 0.6% as α linolenic acid is recommended and this may necessitate the addition of soybean, corn, walnut, and/or flaxseed oil to the diet. Docosahexanoic acid (DHA) has a role in normal retinal and brain function. Addition of preformed DHA (60 mg/day in infants and toddlers; 100 mg/day in adults) helps in normalizing red blood cell DHA levels and may slow progression of pigmentary retinopathy and/or peripheral neuropathy in LCHADD and TFP deficiency.

Individuals on low-fat diets are at risk for fat-soluble vitamin deficiency. Riboflavin and niacin are important coenzymes in the FAOD pathway. Individuals with FAOD should meet the DRIs for all vitamins and minerals and if unable to meet them through diet, supplementation should be considered.

Carnitine is important for transporting long-chain fatty acids into the mitochondria and to enhance excretion of toxic intermediates as carnitine conjugates. Carnitine is synthesized in the liver from lysine and methionine. Carnitine deficiency due to a defect in synthesis is not known. Deficiency can occur in severe malnutrition and malabsorption. Supplementing with carnitine is controversial and may be done when plasma levels are low and to prevent a deficiency.

Nutrition during Acute Illness

The goal of nutrition management during acute illness is to minimize FAO by avoiding fasting and providing adequate non-fat energy either orally or parenterally using intravenous dextrose with electrolytes at appropriate levels (see Table 23.2). Close monitoring is needed during illness with fever, nausea, vomiting, reduced food intake, or poor food tolerance as well as when nil per os (NPO) for medical procedures to prevent a metabolic crisis. Patients are provided with an emergency letter by their genetics clinic to guide medical management in the above situations.

Nutrition Assessment

Obesity maybe present due to excess carbohydrate consumption out of concern for hypoglycemia. Dietary assessment should ensure DRIs for EFA and fat-soluble vitamins are met. Physical exam should look for signs of skin findings, growth failure due to EFA deficiency, and muscle tone and strength due to carnitine deficiency. Risk of pigmentary retinopathy in LCHADD and peripheral neuropathy in TFP deficiency needs referrals to ophthalmology and neurology, respectively.

New Therapies

Use of triheptanoin as an effective therapy was approved in 2019 for the treatment of long-chain FAOD. Triheptanoin is an odd medium-chain triglyceride (7-carbon length) which when oxidized produces two acetyl-CoA as well as a propionyl-CoA. Propionyl-CoA becomes a source of energy by providing intermediates for the CA cycle. Use of triheptanoin has shown improved exercise endurance and reduction in major clinical events secondary to hypoglycemia, cardiomyopathy, and rhabdomyolysis in children and adults with long-chain FAOD.

Medications

MCT intake has been associated with nausea and gastric distress, especially when first introduced. This can be minimized by starting with small doses and increasing the dose as tolerated. Carnitine supplementation has been associated with abdominal discomfort, diarrhea, and body odor.

TABLE 23.2
Nutrition Intervention During Acute Illness

Disorder	Intervention	Monitoring
Fatty acid oxidation defects (FAOD)	• Avoid prolonged fasting • Start immediately: Intravenous (IV) 10% dextrose with 0.45 normal saline at 1.5×the maintenance IV fluid rate. If CPK elevated, adjust fluids to 2×maintenance to prevent renal tubular damage. Electrolytes are added to prevent hypokalemia • Intravenous lipid emulsion (ILE) is contraindicated. Medications such as Propofol containing long-chain fatty acids are best avoided unless used at low dose for a short time • Start enteral feeds with appropriate formula (MCT-free or minimal MCT containing in MCADD, predominantly MCT containing in LCFAOD)	Check Blood glucose Lactate CMP, CBC with differential CPK in LCFAOD Urine dipstick for hemoglobin (if positive suggests the presence of urinary myoglobin) Electrocardiogram and Echocardiogram when indicated based on the underlying condition
Maple syrup urine disease (MSUD)	• Stop natural protein intake for 24–48 hours • Reduce leucine intake by 50%–100% for up to 24–72 hours • Provide 100%–150% of usual energy intake • Aggressive nutrition support to provide non-protein energy with IV 10% dextrose with 0.45 normal saline with age-appropriate GIR and ILE to promote anabolism and reverse catabolism • BCAA (leucine, isoleucine, valine)-free medical food if oral/enteral intake is tolerated or by parenteral nutrition PN if not tolerated • Provide hydration at 1.5×maintenance with 0.45 normal saline and electrolytes • Reintroduce natural protein when leucine levels reach upper level of treatment range and/or after 24–72 hours at 50%–100% of patient's pre-illness while monitoring plasma BCAA levels and when leucine is in normal treatment range (<200 µmol/L in children <5 years, <300 µmol/L in >5 years) • Supplement with isoleucine and valine for persistently elevated leucine levels	CMP, CBC with differential, plasma amino acids Urine Ketones Amylase, lipase, phosphorus, magnesium, and serum osmolality Hourly: check Glasgow coma scale and evaluate mental status
Urea cycle disorders	• Stop all protein intake (for 24–48 hours). Same protocol as above for IV dextrose, intravenous lipid emulsion, electrolytes, and hydration • Ammonia-scavenging drugs: ammunol (IV) including Na phenylbutyrate, Na benzoate and IV arginine, oral Na phenylbutyrate or Ravicti, Na benzoate • Oral citrulline for OTC, CPS deficiency • Oral arginine base for ASS, ASA deficiency • Reintroduce natural protein and medical food (essential amino acids) within 48 hours at total protein intake of 0.5 g/kg and titrate upwards to patient's pre-illness prescription while monitoring ammonia levels	Ammonia, CMP, CBC with differential Plasma amino acids (glutamine citrulline, arginine)

(*Continued*)

TABLE 23.2 (*Continued*)
Nutrition Intervention During Acute Illness

Disorder	Intervention	Monitoring
Organic acidemia(s)	• Stop all protein intake. Same protocol as above for IV dextrose, ILE, electrolytes, and hydration • L carnitine at 100–200 mg/kg orally or via IV • Metronidazole for hyperammonemia • Carbaglu- for hyperammonemia • Reintroduce natural protein and appropriate medical food within 48 hours and titrate upwards to patient's pre-illness prescription	Ammonia, lactate, CMP, CBC with differential Carnitine level if not evaluated
Glycogen storage disease type 1 (a & b)	• IV 10% dextrose with 0.45 saline at age-appropriate GIR to maintain blood glucose levels. Electrolytes added as indicated • Do not give lactated Ringers solution • Do not give glucagon • Reintroduce uncooked cornstarch and enteral feeds/food as clinical status/tolerance improves	Blood glucose monitoring every 1–2 hours until stable with target glucose: 80–120 mg/dL. CMP, CBC with differential, lactate, triglycerides, uric acid

Note: Above protocols should be implemented along with normal clinical/biochemical work up and intervention for the concurrent illness.
Examples of emergency protocols available at:
https://www.newenglandconsortium.org/acute-illness
FAOD: http://www.faodsupport.org
Organic acidemia (some available under links to specific disorders): https://www.oaanews.org/oa-disorders.html
British Inherited Metabolic Diseases Group: https://bimdg.org.uk/site/guidelines.asp
Protocol for surgeries/medical procedures requiring anesthesia/fasting: Overnight admission for initiating of 10% IV dextrose infusion with electrolytes at maintenance fluid rate is preferred. This should be continued during and after the procedure until the patient is able to consume normal nutrition orally with continued monitoring of blood glucose levels and clinical status. If overnight admission is not possible, patient can be given clear liquids with carbohydrates until 2 hours before the procedure with IV dextrose as above begun at the initiation of anesthesia. Patients with GSD I however need IV dextrose once oral intake is stopped for surgeries or medical procedures.
ASA, argininosuccinic acid lyase; ASS, argininosuccinic acid synthetase; BCAA, branched-chain amino acids CBC: complete blood count; CMP, comprehensive metabolic panel; CPK, creatine phosphokinase; , CPS, Carbamoyl phosphate synthetase; GIR, glucose infusion rate; LCFAOD, Long-chain fatty acid oxidation defects; MCADD, Medium-Chain Acyl CoA Dehydrogenase Deficiency; MCT: medium chain triglycerides; OTC, ornithine transcarbamoylase

UREA CYCLE DISORDERS

The purpose of the urea cycle is to convert the ammonia arising from ingested protein and endogenous protein turnover to urea in the liver. Six different enzymes and two transport proteins are required for the completion of the urea cycle (Figure 23.4). Deficiency in any of the six enzymes can result in the buildup of ammonia to toxic levels causing neurologic damage. Deficiencies in transport proteins, citrin, and ornithine translocase cause metabolic disorders that are clinically different from the classic UCD. Except for OTC deficiency, all enzyme defects in the urea cycle are inherited in an autosomal-recessive manner. OTC deficiency is inherited as an X-linked dominant trait and is usually lethal in males. Hyperammonemia is a common biochemical feature of all UCDs with the proximal enzyme defects (e.g., Carbamoylphosphate synthetase I [CPS I], argininosuccinate synthetase [ASS]) generally having a more severe presentation than distal defects (e.g., argininosuccinic acid lyase [ASL], arginase [ARG]).

The incidence of UCDs is 1 in 35,000 live births. OTC deficiency is the most common UCD while N-acetyl glutamate synthetase (NAGS) and ARG deficiency are least common. UCDs can present at all ages from a few days after birth to late adulthood. The severity and onset of symptoms are dependent on the extent of residual enzyme activity and which enzyme in the urea cycle is affected. The buildup of the immediate substrate(s) and the absence of the product for each of the urea cycle enzymatic reaction create a distinct biochemical profile for the corresponding UCD. NBS helps in early diagnosis but neonates with severe UCDs can present before results of NBS are known. Prompt diagnosis and specific treatment are imperative to prevent mortality and reduce morbidity and cognitive impairment.

Clinical Signs and Symptoms

Newborn infants appear normal at birth and may be asymptomatic in the first 24–48 hours but then become lethargic, irritable, feed poorly, and vomit. These symptoms can progress rapidly

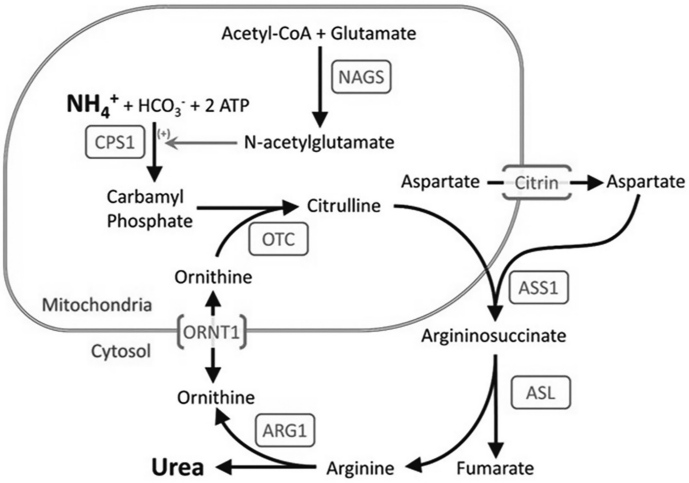

FIGURE 23.4 The urea cycle. (Figure 1 from Ah Mew N, Simpson KL, Gropman AL, et al. Urea Cycle Disorders Overview. 2003 [Updated 22 June 2017]. In: Adam MP, Ardinger HH, Pagon RA, et al., editors. *GeneReviews®* [Internet]. Seattle (WA): University of Washington, Seattle; 1993–2021. Available from: https://www.ncbi.nlm.nih.gov/books/NBK1217/.)

Six catalytic enzyme: N-acetyl glutamate synthetase (NAGS), Carbamoylphosphate synthetase I (CPS1), Ornithine transcarbamylase (OTC), Argininosuccinic acid synthetase (ASS1), Argininosuccinic acid lyase (ASL), Arginase (ARG1). Two amino acid transporters: Ornithine translocase (ORNT1), Citrin (aspartate/glutamate carrier).

resulting in a hyperammonemic crisis, seizures, coma, and death if not treated immediately. Hyperammonemia is the hallmark of UCDs with peak ammonia concentrations >500 µmol/L in most neonatal patients at presentation. Individuals with partial enzyme activity may not be diagnosed with a UCD until faced with a high protein load, growth spurt, puberty, menarche, a catabolizing illness, or surgery. Infants and children diagnosed late can present with malnutrition, chronic neurological symptoms, and episodic encephalopathy with lethargy, ataxia, and seizures. Adolescents and adults can present with chronic neurological or psychiatric problems, episodes of disorientation, or lethargy. Late-onset diagnosis is particularly common in female carriers of OTC deficiency.

The pathophysiology of UCDs is attributed to the toxic accumulation of ammonia and glutamine in the brain causing astrocyte swelling, brain edema, and neuronal dysfunction. Medical interventions to treat UCDs employ a protein-restricted diet and include use of ammonia scavengers such as sodium benzoate and sodium or glycerol phenylbutyrate and individual amino acids (citrulline in CPS and OTC deficiency; arginine in ASS and ASL deficiency) for continuation of the urea cycle. Hemodialysis, intravenous ammonia scavengers (sodium benzoate plus sodium acetate, i.e., Ammunol) and intravenous arginine are used when indicated to resolve an acute hyperammonemic crisis. Liver transplantation successfully cures the hyperammonemia in UCDs. It is recommended in patients with severe disease that is difficult to manage.

Expected Clinical Course

Long-term prognosis is strongly influenced by the duration of coma at diagnosis and peak ammonia levels. Patients who have survived hyperammonemic episodes have varying neurological outcomes including intellectual disability, developmental delay, seizure disorders, and cortical blindness. They continue to be at risk of developing hyperammonemia and metabolic crises triggered by physiological stress throughout life despite treatment with medications and protein restriction. Patients with UCDs who are diagnosed late have some residual enzyme activity and can have normal neurological outcomes, although some degree of cognitive disability and psychiatric problems are frequently seen even in these patients.

Nutrition Management

Treatment of Hyperammonemic Crisis

It is crucial to stop all protein intake immediately and prevent catabolism by promoting and maintaining anabolism in any patient with acute hyperammonemia, including newly diagnosed patients. Energy intake should be approximately 120% of age-adjusted requirements, to promote anabolism. In most patients, oral feeding will not be feasible during the acute phase because of impaired consciousness and vomiting. Ten-percent dextrose infusion (with appropriate electrolytes) should immediately be started intravenously via a peripheral venous line with plans for a central venous line in the severely ill patient to help maximize energy intake. If hyperglycemia occurs, intravenous insulin should be given. Administration of injectable lipid emulsions (1–2 g/kg per day) provides additional energy and helps with anabolism. The re-introduction of protein, either enterally as medical food for UCDs or parenterally as standard amino acids, must not be delayed for more than 24–48 hours. Protein should be introduced at 50% of DRI or pre-illness protein prescription and titrated upwards while using ammonia-scavenging drugs and monitoring plasma ammonia levels.

Long-Term Nutrition Management

The goal of nutrition therapy in UCDs is to maintain stable metabolic control and promote normal growth and development through a nutritionally complete, low-protein diet. Adequate protein and energy supply can be based on the FAO/WHO/UNU 2007 Safe Levels of Protein

TABLE 23.3
Protein Recommendations for Patients with Urea Cycle Disorders

Age (years)	Safe Level of Protein Intake (g/day) – Males	Safe Level of Protein Intake (g/day) – Females
0.5	10.2	9.4
1	11.6	10.8
1.5	11.8	11.1
2	11.9	11.4
3	13.1	12.7
4–6	17.1	16.2
7–10	25.9	26.2
11–14	40.5	41.0
15–18	57.9	47.4

Source: Adapted from: Joint FAO/WHO/UNU Expert Consultation on Protein and Amino Acid Requirements in Human Nutrition (2002: Geneva, Switzerland) Protein and amino acid requirements in human nutrition: report of a joint FAO/WHO/UNU expert consultation. (WHO technical report series; no. 935).

Intake (Table 23.3). Over-restriction of protein may compromise growth and well-being and can cause metabolic instability. Medical foods used in UCDs contain only essential amino acids (EAA) and do not contain the non-EAA to reduce nitrogen burden. Medical foods are an important source of energy, vitamins, and minerals in patients with UCDs. About 40%–50% of protein allowance is provided by the medical food and the remaining protein is provided as vegetables, fruits, and grains. However, optimal ratio and protein intake must be determined by individual titration. The daily protein is divided equally between three to four meals, and a late-night snack shortens the overnight fast. Medical foods are given with meals for maximum utilization.

Arginine becomes an essential amino acid in all UCD except ARG deficiency. Arginine supplementation prevents deficiency and helps in the continuation of the urea cycle for nitrogen excretion. Citrulline is a precursor of arginine and is used in CPS and OTC deficiency. Enteral feeding may be necessary as oral intake/ability maybe affected and is particularly helpful during illness and for administering medications.

Sick-Day Diet

A sick-day diet is recommended during illness or physical trauma and consists of an individualized prescription with reduced or no protein while maintaining or increasing fluid and energy intake with glucose polymers. If there is no prompt improvement, the patient should be transferred to a metabolic center or closest medical facility.

Nutrition Assessment

Nutrition assessment should include assessment of growth and head circumference, inspection for thin sparse hair or hair loss, skin rashes, and other signs of protein/vitamin deficiency. Trichorrhexis nodosa is a hair-shaft abnormality typically seen in ASL deficiency. Growth can be affected due to poor food intake, food aversion, frequent metabolic decompensations, and reduced protein intake due to fear of getting sick. The low-protein diet places UCD patients at risk of iron, zinc, copper, calcium, and vitamin B_{12} deficiencies. Regular nutrition reassessment is important to review the nutrition adequacy of the diet based on age and growth, and to assess adherence to medical food, vitamin supplements, and mineral supplements.

Laboratory Monitoring

Plasma ammonia, amino acids, and electrolytes should be assessed on a regular basis. Plasma amino acids should be measured 2 to 4 hours after a feeding. Rising plasma glutamine may indicate impending hyperammonemia. Glutamine levels under 1,000 μmol/L are considered tolerable. Phenylbutyrate therapy causes low branched-chain amino acid (BCAA) levels. Plasma arginine should be maintained in the high-normal range and all EAAs and BCAAs should be in the normal ranges. Other blood assays include determination of vitamins, minerals, and trace elements. Plasma carnitine status should be monitored for risk of secondary carnitine deficiency related to the conjugation of nitrogen scavenger medications with carnitine.

GLYCOGEN STORAGE DISORDERS

Glycogen storage disorders (GSD) are a group of over 12 different disorders that affect the synthesis or breakdown of glycogen for energy. They have a wide spectrum of clinical presentation and overall frequency of 1 in 20,000–25,000 births. Dietary therapy is the most critical and effective in GSD I (glucose 6-phosphatase deficiency/Von Gierke disease) and will be described here.

Glucose 6-phosphatase (G6Pase) is required for the final step of glycogenolysis and gluconeogenesis to cleave glucose from glucose 6-phosphate (Figure 23.5). Glucose 6-phosphate is formed from the breakdown of glycogen and from fructose and galactose. In the absence of G6Pase, hypoglycemia is the primary consequence of GSD I with secondary consequences of lactic acidosis, hyperlipidemia, and hyperuricemia. GSD I has two sub-types: GSD Ia results from deficiency of G6Pase and GSD Ib results from deficiency of the enzyme translocase that transports G6Pase across the endoplasmic reticulum.

The incidence of GSD I in the overall population is 1 in 100,000 with diagnosis of GSD Ia in 80% and GSD Ib in 20% cases. GSD I is typically diagnosed around the age of 3–4 months, when infants start to sleep through the night and feed less frequently. Affected infants develop hypoglycemia, which can lead to seizures and coma. Blood glucose (BG) levels can be 40 mg/dL or even lower at diagnosis. Early diagnosis reduces the risk of prolonged hypoglycemia which can cause growth and developmental delay, cerebral damage, and even death. Diagnosis is suspected based on clinical presentation and laboratory results. Definitive diagnosis is based on enzyme and genetic studies.

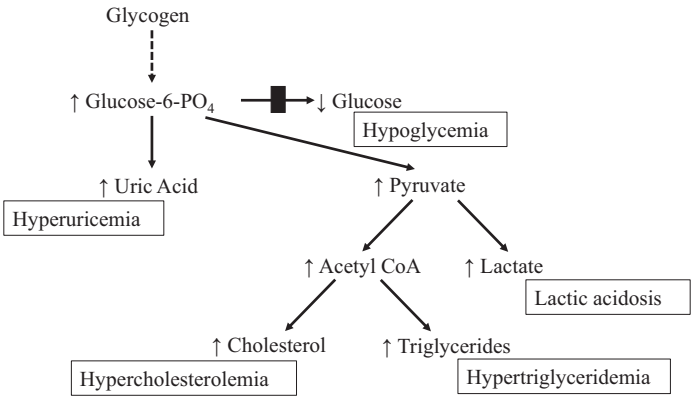

FIGURE 23.5 Simplified schematic of metabolic consequences of G6Pase deficiency.

G6Pase indicated by black block.

Clinical Signs and Symptoms

Children with GSD I may present with hepatomegaly and a protruding abdomen due to excess glycogen and fat deposits noted on a routine physical examination. They have poor growth, thin arms and legs, and excess adipose tissue in the cheeks giving them a doll-like face. The kidneys may also be enlarged.

Expected Clinical Course

Children with GSD I generally have delayed puberty. Beginning in young to mid-adulthood, affected individuals may develop osteoporosis, gout, kidney disease, and pulmonary hypertension. Females with this condition may have polycystic ovaries. Hematological abnormalities include a bleeding diathesis due to impaired platelet function and/or a von Willebrand–like platelet defect. In GSD Ib, there is the additional finding of neutropenia and impaired neutrophil function which can cause frequent bacterial infections and in some cases gastrointestinal symptoms like Crohn's disease or ulcerative colitis. Hepatic adenomas with risk of bleeding and becoming cancerous are serious complications of both GSD Ia and Ib.

Nutrition Management

Infancy

Infants should be given sucrose- and lactose-free formula (to remove fructose and galactose from diet) or an elemental formula that has a higher percentage of carbohydrates and fed every 2–3 hours or on demand around the clock. This necessitates waking up the infant frequently overnight for feedings. Continuous tube feeding or feeding of glucose polymers is frequently implemented overnight to provide glucose at a rate similar to that of normal hepatic release of glucose. The rate is approximately 8 mg glucose/kg per minute in young children and 6 mg/kg per minute in older children.

Once nutrition therapy is implemented, close monitoring of BG levels and other laboratory parameters must continue as the child grows and nutrition needs change. Asymptomatic low BG levels result in suboptimal control, which inhibits normal growth, development, and overall metabolic control. The aim should be to keep BG ≥ 70 mg/dL and to avoid rapid glucose fluxes. Feeding pump failures and clogged or disconnected feeding tubes can result in prolonged fasting, hypoglycemia, and death. Safety precautions such as pump-failure and bed-wetting alarms, dual or vibrating alarm clocks are highly recommended to avoid severe hypoglycemia and tragic outcomes. To avoid hypoglycemia, feeding the infant (~30 minutes) before tapering and discontinuing the tube feeding in the morning is recommended.

Solid foods are introduced according to normal pediatric feeding guidelines and can include all foods except those containing sucrose, fructose, and lactose. Uncooked cornstarch (UCCS) is invaluable in the treatment of this condition as it is gradually digested by amylase and provides a consistent source of glucose to the bloodstream as digestion occurs. UCCS is gradually introduced by age 1 year. Since amylase may or may not be fully present until 2 years of age, early introduction of UCCS may cause symptoms of bloating, gas, and changes in stool consistency which may be transient. Starting with a small dose of UCCS and gradually increasing the dose to the goal may help improve tolerance. A trial of pancreatic enzymes can be used to relieve the symptoms associated with UCCS use.

Long-Term Dietary Management

General dietary guidelines for the treatment of GSD I include small, frequent feedings (every 3–4 hours) high in complex carbohydrates with avoidance of the following: sucrose, galactose, fructose, high-fructose corn syrup, honey, maple syrup, molasses, agave nectar, and sorbitol. The

diet should contain ~60% of energy from complex carbohydrates (including energy from UCCS), ~10%–15% of energy from lean sources of protein and 25%–30% of energy from healthy fats. The carbohydrates in the diet should be divided between all the meals and snacks and timed to exercise and activity levels. A complete multivitamin is recommended to meet the DRI for micronutrients (Chapter 3). Vitamin E supplementation (600 mg/day in pre-pubertal patients and 900 mg/day in adults) is recommended in GSD Ib for its effectiveness in reducing the frequency of infection and improving neutropenia.

Uncooked Cornstarch

One gram of UCCS provides 0.9 g glucose (Table 23.4). Previous guidelines of dosing UCCS based on body weight (1.6 g/kg ideal body weight every 3–4 hours for young children, and 1.7–2.5 g/kg every 4–5 hours for older children, adolescents, and adults) has been shown to result in over-treatment causing hyperinsulinism and rebound hypoglycemia. It is now recommended that UCCS therapy be individualized based on glucose needs determined by hepatic glucose production rate and that smaller doses be given but more frequently, every 3–4 hours round the clock. The introduction of extended-release cornstarch made from waxy maize (Glycosade®) over the last decade is benefitting some individuals with GSD I by extending the time between overnight feedings.

Nutrition Assessment

Nutrition assessment should focus on growth, appetite, energy level, and maintenance of BG levels. Obesity is seen across all age groups in GSD I due to excess energy intake and consuming large amount of UCCS to maintain normoglycemia. Overall diet quality can be poor due to dietary restrictions and UCCS therapy that can cause satiety and poor food intake. Frequent review of diet records, compliance with nutrition supplements, the timing of meals, snacks, and cornstarch intake; sleeping patterns, signs and symptoms of hypoglycemia, gastrointestinal issues, and psychosocial adjustment to the diet are important components of nutrition assessment.

Medical and Surgical Interventions

Medications used for secondary complications of GSD I include medications such as acetylcholinesterase (ACE) inhibitors to protect kidney function, urinary alkalinizers (citrate) to prevent kidney stones, xanthine oxidase inhibitors for gout, and granulocyte colony-stimulating factor (G-CSF) for

TABLE 23.4
Uncooked Cornstarch Therapy in Glycogen Storage Disease

1. Cornstarch should be weighed using a scale for accurate dosing.
2. Argo or Kingsford brands of cornstarch in the USA are shown to be the most effective for maintaining blood glucose levels and preferred for their taste. Other brands should be used with caution. Randomly switching between brands is not recommended.
3. Cornstarch should be mixed just before consumption.
4. Cornstarch cannot be administered via continuous tube feeding as it clogs up the feeding tube.
5. Heat and acidity make cornstarch less effective and hence the beverage used for mixing should be non-acidic and cold or at room temperature. It can be mixed with water or a sucrose/fructose/lactose-free formula or beverage in the ratio of 1 g cornstarch mixed with 2–3 mL liquid.
6. Except for breakfast, cornstarch should be administered ~30–60 minutes after a meal so as to allow adequate food intake. Taking cornstarch early in the morning or upon rising before breakfast helps overcome morning hypoglycemia and swings in glucose levels.
7. Cornstarch should be stored in an airtight container at room temperature in a non-humid environment. Buying and storing in bulk quantities is not recommended.

neutropenia (in GSD Ib). Hyperlipidemia associated with GSD I is not considered to be a cardiovascular risk factor, but lipid-lowering drugs are sometimes used.

Liver transplant is recommended in GSD I when adenomas are large and numerous and have a high risk of becoming cancerous. Transplantation is curative for the hypoglycemia and most other complications of GSD I except for neutropenia in GSD Ib. Renal dialysis and transplant is required in some patients for advanced kidney failure.

Laboratory Monitoring

Home BG monitoring is crucial to maintain good metabolic control in GSD I and for adjusting diet and UCCS therapy for changing needs based on growth and activity level. BG levels should be checked early morning, before each cornstarch dose, before and after exercise, and during illness. The BG and diet log should be shared with the dietitian frequently. The utility of continuous glucose monitoring (CGM) in improving metabolic control is being increasingly recognized in GSD and highly recommended. CGM allows remote data sharing with the healthcare team and is helpful in

TABLE 23.5
ADIME Summary for Inborn Errors of Metabolism

- Assessment
  - Growth assessment
    - Monitor for malnutrition and obesity
  - Nutrition focused physical exam
    - Look for signs of macronutrient and micronutrient deficiencies that are common for the patient's inborn error of metabolism (IEM)
  - Nutrient Intake
    - Medical foods
    - Use nutrient analysis software
  - Laboratory studies
    - Restricted nutrients
    - Accumulated metabolites
  - Gastrointestinal Findings
  - Medications/Side Effects
- Diagnosis
- Intervention
  - Nutrition Prescription
    - Macronutrient and micronutrient prescription may be altered by IEM
  - Common nutrition interventions
    - Oral
    - Enteral Nutrition
    - Parenteral Nutrition
    - Education
      - Diet for IEM
    - Laboratory Monitoring
    - Supplements
    - Other specialty referrals
      - Consider feeding, occupational, physical, or behavior therapy
      - Communication with school and other caregivers
- Monitoring and Evaluation
  - Nutrient intake
  - Laboratory values
  - Growth

making dietary adjustments between clinic visits by looking at trends of glucose levels over several days.

Blood lactate, uric acid, triglycerides, cholesterol, LDL, and HDL should be monitored at clinic visits and as needed. Imaging studies for adenomas and bone age/density are very important.

Other Specialty Referrals

GSD I is a multisystem disorder and needs many sub-specialties (hepatology, nephrology, endocrinology, hematology, developmental specialist) for management. Most relevant referrals for managing nutrition are for feeding and psychological evaluations and should occur early on to prevent long-term problems that can be seen in a chronic disease that requires intense dietary intervention.

IEMs are rare genetic disorders that are managed at specialized genetic centers. The dietitian plays a critical role in the management of patients with IEM. The dietitian educates patients about the specific substrates to avoid in the diet and foods to include in the diet. Nutrition reassessment is necessary to ensure the patient is meeting her macronutrient and micronutrient needs as her diet changes throughout life (Table 23.5).

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24 Endocrine Disorders

Lisa Spence, PhD, RD; Nana Adwoa Gletsu Miller, PhD; and Tamara S. Hannon, MD, MS

CONTENTS

Endocrine hormones are chemical signals that exert effects on tissue and organs throughout the body. Hormones play a critical role in the regulation of physiological homeostasis and are involved in growth and development, appetite regulation, metabolism, sexual and reproductive function, sleep, and mental health. Endocrine diseases result from abnormal levels of endocrine hormones or abnormalities in the signaling response. Diabetes mellitus, which occurs when insulin is not produced or when insulin signaling is impaired, is a common endocrine disease in children. Diabetes mellitus include type 1 diabetes, type 2 diabetes, and prediabetes. Related diseases include cystic fibrosis-related diabetes and steroid-induced hyperglycemia. Diabetes insipidus results from a disorder in the production or action of vasopressin. Youth with gender dysphoria may have higher rates of overweight and obesity. Growth hormone deficiency in children can lead to short stature, but in most cases the cause of short stature is constitutional, secondary to genetics or to nutrition, as well as to complications of non-endocrine diseases. Nutrition is an important consideration for clinical management of endocrine diseases as diet may play a role in the etiology of the disease or diet may modify the response to therapy. Moreover, nutrition status may be used as a criterion for diagnosis of the disease or to evaluate its progression. The objective of this chapter is to describe the pathophysiology, medical management, and medical nutrition therapy of common pediatric endocrine disorders.

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DIABETES MELLITUS

Diabetes mellitus is a cluster of diseases with the common symptom of high blood glucose concentration, termed hyperglycemia. In the pediatric population, type 1 diabetes is most common (1.93/1,000 children), followed by prediabetes (1.6/1,000 children), and type 2 diabetes (0.46/1,000 children), and the incidence of all the disorders is on the rise.

Type 1 diabetes (T1D) is primarily an autoimmune disease, thought to be genetic or viral in origin, which leads to a destruction of the pancreatic β cells resulting in a deficiency in insulin production. Individuals affected by T1D present with signs and symptoms including polyuria, fatigue, polydipsia, nocturia, weight loss, ketosis, dehydration, and ultimately diabetic ketoacidosis. Insulin therapy is the cornerstone of treatment for T1D, and the dosing regimen and glycemic targets can be individualized during therapy. Successful management of T1D is associated with lower risk of long-term microvascular (nephropathy, retinopathy, neuropathy) and macrovascular complications (cardiac function) that are manifestations of hyperglycemia.

While insulin therapy is important for prevention of hyperglycemia, a common and much-feared complication is hypoglycemia. Symptoms of hypoglycemia include with hunger, shakiness, perspiration, dizziness, lightheadedness, sleepiness, and confusion. To reduce the risk of hypoglycemia, guidelines recommend a practice of frequent monitoring of blood glucose. To mitigate the debilitating impacts of both hypo- and hyperglycemia, it is essential that treatment of T1D in children involves providing diabetes self-management education to the child and family, with support from a healthcare team of pediatric endocrinologists, dietitians, nurses, pharmacists, social workers, and psychologists for coping with issues associated with biology, mental health, family dynamics, as well as with the school and community.

The development of type 2 diabetes (T2D) in youth, in the late 20th century, is unprecedented; previously this disease was associated with mid-to-late adulthood. Driving the emergence of T2D in youth is the epidemic of obesity in children. Unlike T1D, insulin resistance resulting from obesity is the predominant pathophysiologic hallmark of T2D. If insulin secretion cannot compensate for the defect in insulin action, a deficiency in insulin production develops, leading to hyperglycemia. Thus beta-cell dysfunction occurs in T2D – like in T1D. In fact, beta-cell dysfunction is apparent even in the prediabetes stage of T2D development, when glucose levels are elevated (≥100 mg/dL or 5.6 mmol/L) but does not meet the threshold for diagnosis of T2D (i.e., blood glucose of 126 mg/dL or 7.0 mmol/L). Poor diet, visceral obesity, sedentary lifestyle, poor sleep, minority race and ethnicity, and genetic susceptibility also factor into the etiology of T2D, each through associations with insulin resistance and beta-cell dysfunction. As with adults, youth with prediabetes or T2D often do not have symptoms. The American Diabetes Association (ADA) recommends screening youth for T2D if they have risk factors such as obesity, family history of T2D, or acanthosis nigricans.

When prediabetes or T2D is diagnosed, the first line of treatment includes medical nutrition therapy, lifestyle management, and metformin. Treatment can progress to include insulin for those with more severe hyperglycemia or metabolic decompensation. Successful prevention, and also treatment of T2D, in children and adolescents requires lifestyle modification to facilitate weight loss via improvements in diet and physical activity. When therapy is unsuccessful, complications of youth-onset T2D develop rapidly including nephropathy, retinopathy, and vascular injury.

DIABETES INSIPIDUS

Diabetes insipidus is rare in children but can occur due to a genetic abnormality or secondary to hypothalamic or pituitary tumors or following neurosurgery. Unlike diabetes mellitus, blood glucose concentrations are normal in diabetes insipidus. Rather, common symptoms for both conditions are frequent urination (polyuria) and constant thirst (polydipsia). In the case of diabetes

insipidus, the urine is dilute and odorless while for diabetes mellitus, the urine is concentrated with glucose. The etiology of diabetes insipidus involves disruption of hormonal regulation of water balance, most often due to abnormal production or function of vasopressin. Vasopressin (also called anti-diuretic hormone) is made in the hypothalamus and its function is to increase fluid balance by reducing the excretion of water from the kidney. Thus, a main complication of diabetes insipidus is dehydration that results from water loss through excessive urination. Treatment of diabetes insipidus aims to address the primary cause, whether a tumor or hormonal. Treatment also focuses on drinking sufficient water to avoid dehydration.

STEROID-INDUCED HYPERGLYCEMIA

Steroid medications, particularly glucocorticoids, are a standard treatment for inflammation that accompanies a wide variety of illnesses including autoimmune diseases (e.g., rheumatoid arthritis, lupus, and ulcerative colitis), cancers, and respiratory diseases. Hyperglycemia is common side effect of glucocorticoid use, occurring in ~30% of users. Glucocorticoids can also exacerbate hyperglycemia in ~20% of individuals with established diabetes. The mechanism of glucocorticoid-induced hyperglycemia is insulin resistance in the muscle and liver, as well as beta-cell dysfunction. Older age is a risk factor for insulin resistance and beta-cell dysfunction, thus steroid-induced diabetes is rare in the pediatric population. However, steroid-induced hyperglycemia complicates the course of underlying infections and cancers, making it important to monitor and treat the hyperglycemia that occurs as a side effect during steroid treatment. For children who are using steroids over the long term or for those using steroids during acute treatment in the hospital setting, hyperglycemia should be managed to lessen risk of infections. Management of glucocorticoid-induced hyperglycemia follows similar guidelines as those for T2D.

CYSTIC FIBROSIS-RELATED DIABETES

A genetic disorder that causes damage to the lungs and digestive system, cystic fibrosis affects mucus production causing airway and digestive secretions to be sticky and thick (Chapter 19). A thick, sticky mucus blocks pancreatic ducts and the production of insulin, resulting in diabetes in about 20% of adolescents with the disease. Given that the etiology of cystic fibrosis-related diabetes (CFRD) is insulin deficiency, treatment of the disease involves insulin regimens, similar to that for T1D. As the risk of infections is high for patients with cystic fibrosis, an additional benefit of insulin therapy is the reduction of hyperglycemia thus lessening the risk of bacterial growth. As for T1D, patients managed with insulin therapy deal with a risk of hypoglycemia, which can be mitigated through providing diabetes self-management education.

POLYCYSTIC OVARY SYNDROME

Polycystic ovary syndrome (PCOS) is the most common endocrine system disorder in women of reproductive age. It is characterized by irregular menstruation, polycystic ovaries, and hyperandrogenism. There is a high prevalence of insulin resistance and obesity. Patients with PCOS are at increased risk of T2D, hyperlipidemia, and coronary heart disease.

SHORT STATURE

Short stature in a child is defined as a height that is two standard deviations below the mean (z scores ≤ -2), or below the 2.3rd percentile using stature-for-age growth charts. Short stature may be caused by an endocrine disorder, but in the vast majority of cases, the etiology of short stature is genetic. Medical and nutrition conditions also contribute to a child's growth and ultimate stature.

Deficiency in growth hormone signaling is an endocrine disorder that affects 1:4,000–1:10,000 children. Without the action of growth hormone, longitudinal growth of the bones is slow or flat and the child will not follow growth curves from age 2 onwards. Other signs and symptoms of growth hormone deficiency are abnormal levels of insulin-like growth factor and insulin-like growth factor binding protein (both which are stimulated by growth hormone), as well as overweight and delayed puberty. In cases when deficiency of growth hormone is established as the cause of short stature, and if the condition is treated early, providing growth hormone by injection is effective treatment, enabling children to reach normal height. During treatment, frequent monitoring by the medical team is important to manage side effects (e.g., headache, fluid retention, muscle and joint ache, slippage of hip bones). Evaluation during treatment is also important since many cases do not respond to growth hormone therapy.

TRANSGENDER HEALTH

Transgender and gender-diverse youth, estimated at 0.7% of the adolescent population, have a gender identity that is different from the sex assigned at birth. Experts believe that many factors including biological traits, developmental influences, and environmental conditions contribute to the development of transgender identities. Adolescents who identify as transgender suffer from depression and anxiety (also termed gender dysphoria) at higher rates compared to cisgender counterparts, leading to eating disorders, self-harm, and suicide. However, the high risk of mental illness among transgender youth is due to negative experiences such as discrimination and stigma, rather than to an inherent mental disorder. To ensure well-being of youth who identify as transgender, the American Association for Pediatrics recommends a gender-affirmative model of care that is developmentally appropriate and oriented toward understanding and appreciating the youth's gender experience. The care model integrates medical and surgical interventions, along with mental health and social services to provide resources and supports for the child, caregivers, and families.

NUTRITION MANAGEMENT

The American Diabetes Association (ADA) *Standards of Medical Care in Diabetes* for children and adolescents recommends individualized medical nutrition therapy (MNT) for children and adolescents with T1D delivered by a dietitian. MNT includes comprehensive nutrition assessment and education at diagnosis and quarterly and annual follow-up to assess energy and nutrition intake in relation to weight status, blood glucose, and glycated hemoglobin (HbA1c), cardiovascular risk factors, along with considering food preferences over time.

The ADA recommends that youth with prediabetes and T2D follow a lifestyle management plan focused on healthy eating patterns that emphasize consumption of nutrient-dense, high-quality foods and decreased consumption of energy-dense, nutrient-poor foods. Emphasis should be placed on decreasing intake of processed foods and increasing intake of whole and less-processed foods including vegetables, fruits, lean sources of protein, whole grains, and healthy sources of fat. Concentrated sweets, particularly juices and sweetened beverages, should be occasional treats or eliminated as much as possible as they can contribute to hyperglycemia. Youth and their families should receive diabetes self-management education and support that is specific to their needs and culturally appropriate. Long-term weight management for children and adolescents with prediabetes and type 2 diabetes should be included in the lifestyle management plan. The pediatric patient and the family meet with the dietitian to assess the family's individualized needs and monitor glycemic control. Along with assessing blood glucose history and HbA1c levels it is important to regularly screen for other common diabetes-related conditions as cardiovascular disease, nutrient deficiencies, or eating disorders.

The overall goals of MNT for children and adolescents with type 1, type 2, or prediabetes are to:

- Provide adequate nutrition to maintain normal growth and development based on the child's appetite, food preferences, and family lifestyle
- Maintain near-normal blood glucose levels and reduce/prevent the risks of acute and chronic diabetes complications
- Achieve optimal serum lipid levels
- Preserve social psychological well-being
- Improve overall health through optimal nutrition
- Provide a level of information that meets the interest and ability of the family
- Provide information on current research to help the family make appropriate nutrition decisions

Nutrition Assessment

Nutrition assessment should include a food/nutrition-related history, anthropometric measurements, biochemical data, other medical tests, and procedures (Chapter 3). The patient's usual food intake assessment will help determine if the child is meeting nutrient and food-group recommendations and to help understand timing and setting of meals, along with eating behavior which are important for making dietary recommendations. The patient's personal, medical, family, and social history are also important to assess, which should include physical activity habits, insulin/medication use, and other health conditions/co-morbidities (hypertension, dyslipidemia, nephropathy), all of which impact the plans for therapy. Biochemical data, medical tests, and procedures in patients are numerous and can include hemoglobin A1c, lipid profile, microalbuminuria, thyroid-stimulating hormone levels, and urinary ketones.

For patients with diabetes insipidus, the nutrition assessment should also include evaluation of daily fluid intake and bowel and bladder habits. Particular attention will need to be made to the degree of polyuria and polydipsia. The polydipsia may be intense or uncontrollable causing craving for ice, plain water, or ice water. Anorexia may occur with a preference of water over food which results in weight loss, poor growth, and other nutrition problems. Symptoms can occur differently in each child with common features being more thirst than normal, more urination, dehydration, and weight loss. Labs to note are blood tests and urinalysis with focus on serum potassium and calcium and urinary levels of glucose.

Nutrition Diagnosis

Common nutrition diagnoses for patients with endocrine disorders include:

- Altered nutrition-related laboratory values (specify)
- Overweight, pediatric
- Obese, pediatric
- Excessive growth rate
- Unintended weight loss
- Food and nutrition-related knowledge deficit
- Limited adherence to nutrition-related recommendations
- Inconsistent carbohydrate intake
- Intake of types of carbohydrates inconsistent with needs (specify)

Nutrition Intervention

Nutrition Prescription for Patients with Diabetes

Energy requirements should be based on usual intake and level of physical activity for both T1D and T2D to maintain a normal growth and development pattern and slow the rate of weight gain or

promote weight loss in overweight or obese children (Chapter 3, Chapter 25). As a general guide, carbohydrate intake should approximate 45%–55% of energy (sucrose intake up to 10% total energy), fat intake at <35% of energy (saturated fat <10%), and protein intake at 15%–20% of energy.

Carbohydrates in foods and beverages have the greatest impact on blood glucose levels with both the amount and type of carbohydrate important to consider. Patients are often consuming a typical Western diet thus will need to reduce carbohydrate intake to meet the 45%–55% of energy goal. Carbohydrate goals for each meal should be prescribed to help reach this target. Whole grains, legumes, fruits, vegetables, milk, and yogurt as key carbohydrate sources should be encouraged daily to provide adequate dietary fiber and essential vitamins and minerals in the diets of children and adolescents. The percentage of energy ingested from carbohydrate will vary and is individualized based on nutrition assessment (energy needs, usual eating habits, preferences, activity levels) and treatment goals (blood glucose and lipid goals) of the patient. The meal plan should coordinate carbohydrate intake (carbohydrate counting) with insulin dosing using a general rule of approximately 1 unit of rapid-acting insulin needed for every 4–15 g of carbohydrate based on pubertal stage, body mass index (BMI), and physical activity level.

Protein intake should be sufficient to support adequate growth and development with no evidence that children or adolescents with diabetes need higher or lower protein intakes than the recommended dietary allowance. Consumption of high-quality protein from meat, poultry, fish, eggs, milk, cheese, and soy should be encouraged.

Healthy fat intake should be promoted for sufficient optimization of growth and development. Vitamins and minerals are also necessary for normal growth and development. While there is no evidence that children and adolescents with diabetes need additional supplementation of vitamins and minerals, the dietitian should monitor the diet to ensure no food groups are restricted or eliminated and that the diet is sufficiently varied to avoid nutrient deficiencies.

Common Nutrition Interventions for Patients with Diabetes

The nutrition intervention will provide goals to normalize blood glucose, blood pressure, lipids, promote healthy weight and growth, and prevent complications of diabetes based on the patient's DRIs. Nutrition recommendations should promote healthy eating and an approach with meal planning that encourages family members and other support persons to follow the same lifestyle recommendations as the child/adolescent with diabetes. Nutrition education/counseling should be continual with follow-up every 6 months to 1 year as the child grows and develops and the family gains experience in nutrition management of diabetes.

For T1D, the intervention should integrate the intensive insulin therapy and needs to be considered in relationship to the child's growth, food intake, periods of illness, times of stress, and activity changes. For T2D, any pharmacologic therapy needs to be considered in conjunction with the food/nutrition assessment specifically for carbohydrate intake at meals/snacks.

Common Nutrition Interventions for Patients with Diabetes Insipidus

The therapeutic goals are primarily to reduce polyuria and decrease thirst, so the child is able to grow adequately and maintain a normal life style. Dietary management includes drinking enough liquid to prevent dehydration and a diet with low sodium, low protein, and high energy providing a high energy:solute ratio. Restricting daily oral sodium intake to 1 mEq/kg and protein intake to 2 g/kg is recommended. It is more important to restrict salt than proteins, which are essential for growth.

Common Nutrition Interventions for Patients with Steroid-Induced Hyperglycemia

The dietary management of drug-induced hyperglycemia should consider the overall treatment goals which are to decrease serum glucose to a target range that prevents acute complications of hyperglycemia such as dehydration, and electrolyte imbalances and to prevent long-term sequelae of diabetes. Because this condition can resemble T2D, the lifestyle management of promoting regular

physical activity and ensuring a healthy diet can be recommended. The dietitian should consider the underlying condition in which the medication is being used and the length of use should be considered. Glucocorticoids inhibit appetite suppression leading to increased weight gain and insulin resistance which will need to be addressed through nutrition intervention.

Common Nutrition Interventions for Patients with Cystic Fibrosis-Related Diabetes

In CFRD, MNT is essential to maintain good nutrition status to mitigate the negative impacts on growth, while normalizing blood glucose levels. The diet should be high in energy, protein, fat, and salt, although specific dietary recommendations should reflect the needs of the individual (Chapter 19). The daily recommended energy intake can be accomplished through dietary intake, nutrition counseling, behavioral interventions, and nutrition supplements (oral or enteral nutrition) as needed. Total daily intake of carbohydrates should generally not be restricted but should be high-quality, nutrient-dense sources, particularly in individuals who are underweight or struggling to meet nutrition goals. High-quality, nutrient-dense carbohydrates should be consumed, while concentrated sweets and low-nutrient quality carbohydrates consumed sparingly.

In patients with CFRD, almost any consumption of carbohydrates should be covered with rapid-acting insulin to mimic endogenous insulin production, and carbohydrate counting should be used to help patients determine the amount of rapid-acting insulin to take with meals and snacks. When possible, all patients should strive to eat a balanced diet from varied sources to achieve macro- and micronutrient needs with daily multivitamin supplements being recommended to ensure adequate intakes. Pancreatic enzyme replacement therapy should be provided at mealtimes.

Common Nutrition Interventions for Patients with Polycystic Ovary Syndrome

The nutritional management of PCOS should focus on weight management using a fiber-rich diet from whole grains, legumes, vegetables, and fruits with an emphasis on carbohydrates with a low-glycemic index.

Common Nutrition Interventions for Patients with Short Stature

The dietitian needs to understand the cause of the short stature and any hormone treatment being used, to determine nutrition recommendations for children. Growth hormone deficiency needs to be distinguished from the malnutrition that occurs with undernutrition or chronic disease. Growth hormone deficiency is associated with a lack of linear growth despite adequate nutrition and generally normal weight for length/height. In the case of patients treated with growth hormone, nutrition status should be closely monitored to improve growth status response and prevent nutrition deficiencies.

The dietitian should review diagnosed nutrition problems based on nutrition signs and symptoms which may include impaired nutrient utilization and altered nutrition-related laboratory values. Weight and growth should be monitored as nutrition therapy will depend on these measurements. Special emphasis should be placed on energy and protein, with high-energy, high-protein nutrition therapy, if warranted. Special emphasis should also be placed on iron intake. Patients should be encouraged to follow a nutritious, balanced meal plan.

Special Considerations for Transgender Patients

Transgender populations require dietary considerations, but there is a significant gap in research and consequently in nutrition care guidelines. Research is needed to identify and guide practices for estimating nutrient and energy needs and applying the nutrition care process. Dietary considerations should be both clinical and psychosocial with specific attention to hormonal therapy and surgical reassignment. In adolescents, treatment may also include suppression of puberty which requires particular attention to nutrition needs.

Clinical changes can include weight gain, changes in body composition, altered lipid profiles, and changes in bone composition as well as other metabolic factors. The dietitian needs to be aware

of specific measures and laboratory values including body weight, lean and fat mass, blood lipids, hemoglobin, hematocrit, and creatinine. There is increased risk of cardiovascular disease, hypertension, obesity, and T2D in this population and thus dietary considerations for these risks need to be considered. Psychological impact includes an increased risk of disordered eating behaviors, unhealthy weight-control behaviors, weight misperception, and body dissatisfaction with behaviors such as vomiting, diet pill use, and laxative abuse.

Nutrition intervention and counseling provided by dietitians have been effective in improving overall diet quality, improvements in behaviors related to binge eating, and metabolic improvements. But more understanding is needed on the impact of diet on mitigating known effects of hormonal therapies, the psychosocial concerns of transgender individuals related to food intake and behaviors, and best nutrition practices by the dietitian.

Nutrition Monitoring and Evaluation

Nutrition monitoring and evaluation should include tracking of food intake, medication, metabolic control (serum glucose and lipids, and blood pressure), anthropometric measurements, and physical activity. Blood glucose self-monitoring results are effective for evaluating the achievement of MNT goals and for determining if adjustments in foods and meals will be sufficient to achieve blood glucose goals or if medication adjustments need to be combined with MNT. Routine charting of a patient's height, weight, and BMI is important for monitoring their growth pattern. Age-specific

TABLE 24.1
ADIME Summary for Type 1 Diabetes and Type 2 Diabetes

- Assessment
  - Growth assessment
  - Nutrition-focused physical exam
  - Nutrient Intake
    - Portion sizes, food choices, dining out
    - Socioeconomic factors affecting food choices
  - Labs
    - Glucose/endocrine profile
    - Fasting glucose
    - Hemoglobin A1c
    - Capillary plasma glucose (preprandial and postprandial)
    - Glucose tolerance test
    - Lipid profile
    - Urine profile
    - Microalbuminuria
  - Gastrointestinal findings
  - Medications/side effects
    - Assess medications that will affect blood glucose including insulin, glucocorticoids, chemotherapeutic agents
- Diagnosis
- Intervention
  - Nutrition prescription
  - Common nutrition interventions
    - Oral
    - Education
    - Laboratory monitoring
- Monitoring and evaluation
    - Anthropometric measurements
    - Laboratory values

development and appropriate self-management should be monitored to ensure that as the patient grows and develops that responsibilities for diabetes management are optimally handled with patient and family (self-monitoring blood glucose, diet, and exercise) (Table 24.1).

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25 Obesity and Lipid Disorders

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CONTENTS

Pediatric obesity is a significant public health concern with the most recent data from 2017–2018 National Health and Nutrition Examination Survey (NHANES) showing a prevalence of 19.3% and severe obesity as high as 6% among youth in the USA. The rates of obesity are higher among adolescents 12–19 years old at 21.2%. Obesity disproportionately affects minorities with rates as high as 25.6% in Hispanic youth, 26.9% in Mexican-American youth, and 24.2% among non-Hispanic Black youth. The increasing rate of pediatric obesity over the past three decades is especially

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concerning because adolescent obesity leads to adult obesity. Children with obesity are five times more likely to have obesity as adults than children without obesity. Additionally, obesity is a chronic and progressive disease; as children develop obesity, they also acquire co-morbidities that track into adulthood including adverse cardiovascular outcomes, hypertension (HTN), diabetes, dyslipidemia, non-alcoholic fatty liver disease (NAFLD), and depression.

PATHOPHYSIOLOGY

Obesity is a chronic disease with many causes. Although it is true that an imbalance of energy intake and energy expenditure largely contributes to obesity, it is important to remember that the disease is complicated by other factors.

Increased Energy Consumption

Pediatric obesity is caused by abnormal eating behaviors. These behaviors may be in part due to abnormalities in hypothalamic homeostasis, which regulates energy balance in our bodies. It is thought that body weight is refractory to short-term increases or decreases in weight, and the body actively regulates its adiposity, making weight loss difficult. Additionally, there is a high expression of genes in the central nervous system and neuronal circuits involved in reward-based decision making, learning, and memory. This pathophysiology can cause patients to always be feeling hungry, thinking about eating their next meal while currently eating one, sneaking foods, or eating large portions of food. Studies have shown that abnormal eating behavior is caused by signaling in areas of the brain which are associated with motivation, desire, and craving for food, and are more activated in obese subjects compared to lean subjects.

Decreased Energy Expenditure

Children and adolescents with obesity may have decreased physical activity due to developmental gross-motor delay, musculoskeletal pain, poor cardiovascular fitness, safety concerns of leaving their home for exercise, depression, and as a result of co-morbidities of obesity such as orthopedic issues or worsened asthma. Patients may also participate in sedentary behaviors such as watching television or using technological devices for many hours each day.

Psychosocial

There are many psychological and social concerns that contribute to obesity. Some of these social issues or mental health concerns may contribute to obesity, and obesity may contribute to some social complications or mental health conditions. Many children and adolescents with obesity may experience teasing and bullying from a young age. Children and adolescents with obesity may feel stigmatized by family members, friends, or healthcare providers making them feel ashamed of their weight. This can have a significant negative effect on their quality of life. Shaming behaviors may cause individuals to have poor dietary consumption, develop eating disorders, and have obesity that continues to progress.

Unfortunately, obesity disproportionately affects those who are disadvantaged and do not have adequate resources to assist with establishing a healthy lifestyle. Patients may live in an unsafe neighborhood and cannot exercise outside or have access to safe parks/playgrounds. Food insecurity also plays a role as children and adolescents who do not have consistent access to food can develop abnormal eating patterns such as restrictive food intake and then binge eating when there is finally access to foods. Youth with obesity have higher rates of mental health concerns such as depression, anxiety, attention-deficit disorder, and eating disorders. Furthermore, research shows that obesity is correlated with the number of Adverse Childhood Events (ACEs) that children experience. Children

with one ACE were 1.5 times more likely to have severe obesity than those with no ACEs. The odds of children with six ACEs having severe obesity were four times that of those with no ACEs. Thus, there are numerous psychosocial factors that can contribute to and worsen obesity.

Genetics

Genetics can also play a significant role in one's predisposition to become obese. Studies show inheritance influences anywhere from 30% to 90% of body mass index (BMI) phenotype. There are about 140 genetic chromosomal regions that have been identified as related to obesity, but only a few have been found to have a large effect on BMI. Only 7% of children have mutations in single genes that control for leptin-melanocortin signaling pathway, which can result in severe, early-onset obesity. These patients experience early-onset severe obesity in the first year of life accompanied by developmental delay.

Hormones

Endocrine disorders, such as hypothyroidism, growth hormone deficiency, or Cushing's syndrome, account for <1% of childhood obesity and are usually seen with poor linear growth and/or short stature. It has been shown that hormonal abnormalities, involving ghrelin, cortisol, and leptin, resulting from poor sleep, also contribute to obesity. Furthermore, lack of sleep contributes to obesity with either too few hours or poor quality due to obstructive sleep apnea.

Early-Life Risk Factors

Several factors in a child's birth history or early medical history may increase a child's risk of developing obesity. These include maternal diabetes mellitus, maternal smoking, gestational weight gain, and rapid infant growth. These risk factors, in addition to those described above, all contribute to this complex and multifactorial disease.

Weight Stigma

When working with patients with obesity, weight stigmatization should not be tolerated from anyone, including caregivers and clinicians. It used to be thought that shaming patients about their weight would motivate them to make behavioral changes, but instead stigma contributes to binge eating, social isolation, avoidance of healthcare services, decreases in physical activity, and increases in weight gain. It has been shown that patients with obesity have poor quality of life; quality of life scores in children/adolescents with severe obesity were worse than age-matched children with cancer. Negative weight-based stereotypes toward children with overweight start as young as age 3.

Healthcare workers, including physicians, nurses, dietitians, psychologists, and medical trainees self-report bias and prejudice toward patients with obesity. Thus, there is a high likelihood before you even see patients with overweight or obesity, that they have already experienced weight stigmatization from family, friends, peers, teachers, and healthcare providers. It should be emphasized with counseling and education that it is important to listen to the patient, believe what they say, and validate how difficult lifestyle modification can be. Additionally, it is important to recognize and acknowledge the multifactorial causes of obesity, so that the individual does not feel at fault for her condition. Using sensitive and appropriate language and neutral words like weight, BMI, unhealthy weight is much preferred to stigmatizing words like obese, fat, or weight problem. Obesity is a medical term that currently should only be used for documentation in the medical record. In addition to being cognizant of the terms being used, it is important to structure sentences in a sensitive manner. Overweight should be spoken of in the same way as other diseases, so instead of saying someone "is" overweight or obese, it's important to say they "have" overweight or obesity, just as

one might say "she has cancer". The addition of "morbid" is also unnecessary and stigmatizing, as one would not say "morbid cancer", for instance. Furthermore, discussions using motivational interviewing help patients feel like they are an active member of their healthcare team, working together for a solution.

TREATMENT OF OBESITY

Lifestyle Modification

Research studies use a standardized measure of BMI with a *z*-score. This helps compare results among children with different age and sex over time as they grow. It is believed that a BMI *z*-score reduction of 0.15–0.25 is associated with improvements in cardiovascular measures and metabolic risk factors. Additionally, an expert panel determined that BMI *z*-score reduction of 0.2 in pediatrics is clinically significant and comparable to weight loss of 5%. However, for some patients, meeting set goals with changes in dietary intake or physical activity and/or maintaining BMI and not demonstrating an increase in BMI, at the very least, may still be considered significant clinical improvement.

It is important to note that early reduction and improvement in BMI predicts better outcomes. Delaying treatment has been found to produce inferior results. Patients who decreased their BMI by 3% after 1 month of obesity treatment were five times more likely to experience success of a 5% decrease in BMI at 1 year than those who did not. Additionally, 85% of patients who did not achieve success at 1 month with reduction in BMI also did not achieve success at 1 year.

The first line of treatment for obesity consists of Lifestyle-Modification Therapy (LMT) and counseling. In 2017, the United States Preventative Services Task Force (USPSTF) published a statement that comprehensive, intensive, behavioral interventions for 26 contact hours over 6 months with children and adolescents 6 years and older who have obesity can result in improvements in weight status for up to 12 months. There is inadequate evidence regarding effectiveness of less-intensive interventions. Counseling sessions varied but included counseling for both caregiver and child as well as individual sessions, information on healthy eating, safe exercising, reading food labels, limiting access to tempting foods and screen time, goal setting, self-monitoring, rewards, problem solving, and supervised physical activity sessions. The behavioral interventions evaluated rarely took place in primary care settings but usually at a tertiary care center with a multidisciplinary team of pediatricians, exercise physiologists, physical therapists, dietitians, psychologists, social workers, and behavioral specialists.

Pharmacotherapy

In some instances, when patients do not have success with LMT alone, the next stage of treatment can be added, which is pharmacotherapy. Medication in addition to LMT can be considered when patients are ≥ 6 years old and BMI is 95th percentile with weight-related co-morbidities or BMI is 1.2 times the 95th percentile irrespective of co-morbidities. Currently, three anti-obesity medications are approved by the FDA for adolescents. The medications are orlistat, phentermine, and liraglutide (Table 25.1). Other medications such as topiramate, metformin, and exenatide have been evaluated for treatment of pediatric obesity and have been shown to help reduce BMI by 3%–4% beyond LMT. However, prescribing these medications to pediatric patients is considered off-label since there is no FDA-labeled indication for obesity. While using any of the FDA-approved medications in patients who are younger than the specified age is also considered off-label, recent clinical recommendations suggest that these medications can be responsibly used in pediatric patients within the context of a specialized setting with trained medical providers.

TABLE 25.1
Anti-Obesity Medications for the Pediatric Population

Medication Name	Mechanism(s) of Weight Loss	FDA Approval	Placebo-Subtracted % Body Weight Loss	Effects on Complications, Co-morbidities and Risk Factors	Side Effects
Orlistat	Gastric/pancreatic lipase inhibition; inhibits absorption of fat by 30%	≥12 years with obesity	3%	Decreases LDL-C and incidence of T2DM in adults	Fatty/oily stools, decrease in absorption of fat-soluble vitamins
Phentermine	Norepinephrine-reuptake inhibitor	≥16 years with obesity	4%–5%	Limited Data	Increased HR and BP, ischemic events, insomnia, and dry mouth
Liraglutide	GLP-1 receptor agonist, central effect on hypothalamus and slowing of gastric motility; produces CNS effect of satiety	≥10 years with T2DM; ≥12 years with obesity	5%–6%	Decrease in BP, glucose levels, HbA1c, insulin levels, CRP, and PAI-1 in adults; no evidence of improvement of risk factors in pediatrics	Increased HR, nausea, vomiting, diarrhea, hypoglycemia, constipation, headache, fatigue, dizziness, abdominal pain

Legend: BP, blood pressure; CNS, central nervous system; CRP, C-reactive protein; HR: GLP-1, glucagon-like peptide-1; HR, Heart rate; HbA1c, hemoglobin A1c; T2DM, Type 2 diabetes mellitus; PAI-1, plasminogen activator inhibitor-1.

Metabolic and Bariatric Surgery

When a combination of LMT and pharmacotherapy has not resulted in significant reduction in BMI, the next step in management of pediatric obesity is metabolic and bariatric surgery (MBS). Children ≥10 years with a BMI 1.2 times the 95th percentile with weight-related co-morbidities or BMI 1.4 times the 95th percentile irrespective of co-morbidities are typically eligible for surgery. Prospective studies among adolescents with severe obesity have shown 30%–40% BMI reduction in 1–3 years post-surgery and a sustained BMI reduction of 30% at 5–8 years post-surgery. Adolescents also have improvements in co-morbidities of obesity with studies showing 95% remission of type 2 diabetes mellitus (T2DM), 66% resolution of dyslipidemia, and 74% remission of HTN.

Roux-en-Y gastric bypass surgery is the gold standard for surgical management of severe obesity (Figure 25.1). This is done by laparoscopic surgery. During the procedure, there is creation of a small proximal gastric pouch to the jejunum of the small intestine. Thus, the remaining stomach and proximal small bowel are excluded from enteral content. On the other hand, the vertical sleeve gastrectomy is currently the most common bariatric operation in the USA and results in removal of 80% of the stomach, which produces a gastric sleeve of approximately 60–100 mL (Figure 25.2). The pylorus and distal antrum remain and gastric filling and emptying are preserved. This results in post-prandial satiety while avoiding dumping syndrome.

Nutritional complications are less common with vertical sleeve gastrectomy than Roux-en-Y gastric bypass surgery. There can be a deficiency of iron and vitamin B_{12} due to the decreased production of intrinsic factor from loss of the gastric fundus. There is a small risk of anemia with iron and folate deficiency, but this can be treated with vitamin supplementation and close monitoring. There is also a risk of bone mineral density loss post-surgery, which can be helped with vitamin supplementation as well. Of note, vitamin D deficiency is a common preoperative finding among

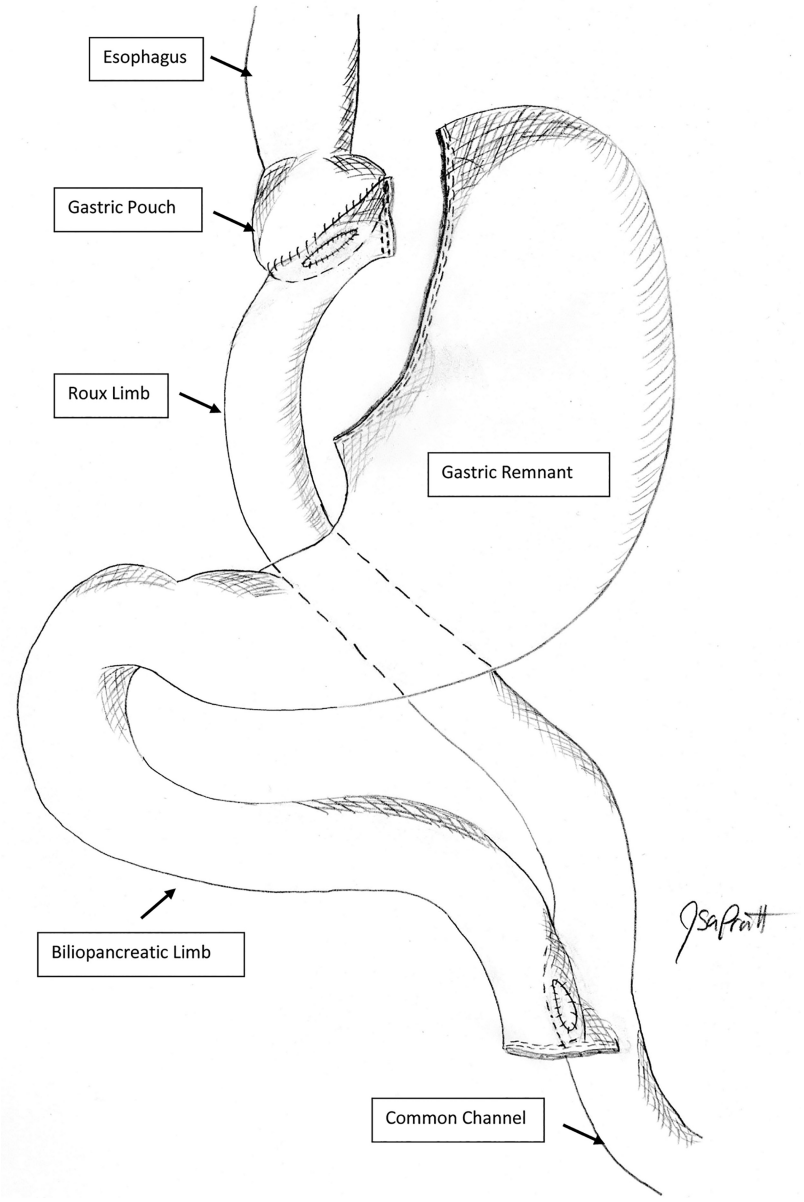

FIGURE 25.1 Roux-en-Y gastric bypass surgery. (Reprinted from Steinhart A, Tsao D, Pratt JSA. Pediatric Metabolic and Bariatric Surgery. *Surg Clin North Am*. 2021;101:199–212, with permission from Elsevier.)

adolescents with obesity, and this deficiency does not change with surgery. Vitamin D supplementation is recommended both pre- and post-surgery.

Contraindications to bariatric surgery include a medically correctable cause of obesity, ongoing substance abuse within the preceding year, medical, psychiatric, psychosocial, or cognitive conditions that prevent adherence to post-operative dietary and medication regimens, or current/planned pregnancy within 12–18 months of the procedure.

The American Academy of Pediatrics (AAP) has recently published guidelines on adolescent MBS that state that patients with severe obesity are unlikely to achieve clinically significant and sustained weight reduction in lifestyle-based weight management programs. When comparing

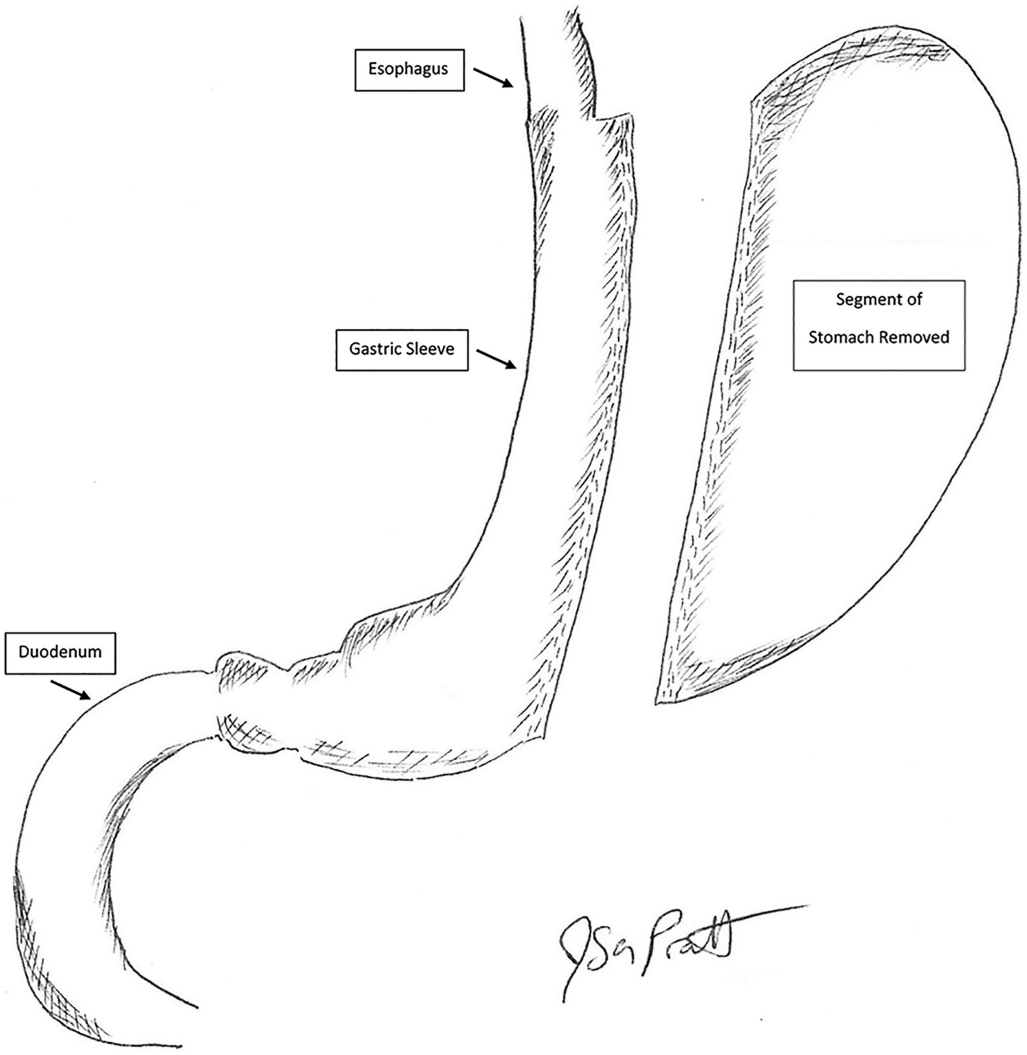

FIGURE 25.2 Gastric sleeve surgery. (Reprinted from Steinhart A, Tsao D, Pratt JSA. Pediatric Metabolic and Bariatric Surgery. *Surg Clin North Am*. 2021;101:199–212, with permission from Elsevier.)

adolescents with higher range of BMI enrolled in a lifestyle-modification program to adolescents with lower range of BMI, the adolescents with the lower BMI range at time of surgery had a higher chance of obtaining non-obese status when compared to those of high BMI range. Delaying surgery may result in patients continuing to increase their BMI and developing co-morbidities of obesity.

CO-MORBIDITIES OF OBESITY

Pediatric obesity is associated with many co-morbidities (see Table 25.2). Many of these co-morbidities are thought to develop from an increased inflammatory state of a body with obesity. Consequently, increased extracellular levels of free fatty acids and cytokines as well as intracellular non-adipose tissue lipids and ectopic adipose tissue within the visceral compartments can lead to the development of diseases such as HTN, T2DM, NAFLD, dyslipidemia, and osteoarthritis (Table 25.2). The initial management and treatment of all of these co-morbidities is LMT.

TABLE 25.2
Co-morbidities of Obesity

Co-morbidity	Screening	Clinical Signs/Symptoms	Management & Treatment in Addition to LMT	Complications from Co-morbidity
Depression	Validated questionnaires (PHQ-9)	Flat affect, anxiety, body dissatisfaction, excess eating, fatigue, difficulty sleeping, history of abuse	Referral to mental health counselor; Medication therapy with SSRI	Eating disorder, self-harm behavior, suicide
Type 2 diabetes mellitus	Fasting glucose or Hemoglobin A1c for patients ≥ 10 years with risk factors	May not have symptoms of polydipsia and polyuria; acanthosis nigricans	Prediabetes: HbA1c ≥ 5.7; Diabetes: HbA1c ≥ 6.5. Medication with metformin, insulin, or GLP-1-receptor agonist	Neuropathy, Retinopathy, Nephropathy, atherosclerotic cardiovascular disease
Dyslipidemia	Lipid panel for patients with risk factors	Usually no signs or symptoms	When patients are obese and have average of 2 fasting LDL-C above 160, consider plant sterols and statin therapy	Atherosclerosis, premature cardiovascular disease
Hypertension	Take blood pressure at every visit for children 3 years and older with correct size cuff; echocardiogram at time of starting medication	Headache, chest pain, elevated BP	See below for diagnosis for HTN[a]; Look for underlying reasons for elevated BP, start anti-hypertensive therapy after LMT for 6 months	Left ventricular hypertrophy, cardiovascular disease, stroke
NASH/NAFLD	Biannual screening starting at 10 years age for ALT and AST	Occasionally right upper quadrant pain/tenderness or mild hepatomegaly	Refer to liver specialist with ALT > 2 times upper limit of normal; Ultrasound cannot show degree of inflammation or fibrosis; Need liver biopsy for diagnosis	Fibrosis and cirrhosis of liver
Orthopedic Concerns: Blount Disease, SCFE	Questions about musculoskeletal pain or pain with movement	Blount Disease: Visible bowing of lower extremity SCFE: pain with walking, impaired ROM of hip	Referral to orthopedic surgeon	Osteoarthritis
Obstructive Sleep Apnea	Questions regarding sleep and energy level during the day, polysomnogram (sleep study)	Loud snoring with pauses in breathing, restless sleep, daytime sleepiness, poor attention or academic performance, tonsillar hypertrophy on exam	Continued Positive Airway Pressure (CPAP) machine for sleeping; Tonsillectomy if noted to have hypertrophy of tonsils	Right ventricular hypertrophy and pulmonary hypertension

(*Continued*)

TABLE 25.2 (*Continued*)
Co-morbidities of Obesity

Co-morbidity	Screening	Clinical Signs/Symptoms	Management & Treatment in Addition to LMT	Complications from Co-morbidity
Polycystic Ovarian Syndrome	Questions regarding menses, pelvic ultrasound, testosterone, FSH, LH, prolactin, TSH, hCG	Infrequent menses, hirsutism, excessive acne, acanthosis nigricans	Clinical diagnosis with abnormal menses and clinical and/or biochemical evidence of hyperandrogenism medication with oral contraceptives, metformin, or spironolactone	Anovulatory infertility, pregnancy complications
Idiopathic Intracranial Hypertension	Questions regarding severe headaches	Severe headache with photophobia, blurred optic disks on fundoscopic exam	Urgent referral to neurology if suspected	Vision loss

[a] Blood pressure readings should be taken at every visit if patients are 3 years and older. In 2017, the AAP updated definitions of pediatric blood pressure values. If children are less than 13 years old, evaluating their blood pressure requires looking at their age, sex, and height-specific systolic and diastolic percentile. Many electronic medical records can calculate the systolic and diastolic percentile, but if not, there are normative blood pressure tables that provide appropriate measurements for a patient's age, sex, and height. A systolic or diastolic percentile at or above the 90th percentile is considered elevated. If one of the readings is at or above the 95th percentile, this is considered stage 1 hypertension, and if one of the readings is above the 95th percentile + 12 mmHg, this is stage 2 hypertension. If patients are 13 years or above, percentiles are no longer used. Elevated blood pressure is systolic BP 120-129 and diastolic >80. Stage 1 hypertension is 130/80 to 139/89, and stage 2 hypertension is anything above 140/90. The diagnosis of hypertension can be made if blood pressure is in stage 1 range or higher at three visits or more with auscultatory-confirmed measurements.

Legend: PHQ-9, patient health questionnaire – 9; SSRI, selective serotonin-reuptake inhibitor; FSH, follicle-stimulating hormone; HCG, human chorionic gonadotropin; LH, luteinizing hormone; LMT, lifestyle-modification therapy; NASH, non-alcoholic steatohepatitis; NAFLD, non-alcoholic fatty liver disease; SCFE, slipped capital femoral epiphysis; TSH, thyroid stimulating hormone.

Hyperlipidemia

Hyperlipidemia is a co-morbidity of obesity, but there can be other causes of hyperlipidemia as well. It can be inherited but can also be due to secondary conditions such as diabetes mellitus, nephrotic syndrome, chronic renal disease, post-orthotopic heart transplant, Kawasaki disease or other chronic inflammatory disease, hypothyroidism, or taking medications such as corticosteroids, isoretinoin, beta-blockers, oral contraceptives, and various chemotherapeutic or antiretroviral medications.

Familial Hypercholesterolemia (FH) is an autosomal codominant genetic disease associated with elevated LDL-C from birth due to a genetic mutation in the LDL receptor gene. Xanthomas, which are deposits of cholesterol in extravascular tissues, are found in untreated adults and patients with homozygous FH. These patients are at significant risk of early-onset atherosclerotic disease. Research has shown that adolescents with significantly high LDL cholesterol levels caused by FH have abnormal levels of coronary calcium, increased carotid intima medial thickness, and impaired endothelial function, which precedes cardiovascular disease (Table 25.3).

TABLE 25.3
Risk Factors for Dyslipidemia

High-Level Risk Factors for Dyslipidemia	Moderate-Level Risk Factors for Dyslipidemia
Hypertension, requiring medication	Hypertension, not requiring medication
BMI ≥ 97th percentile	BMI > 95th percentile, but <97th percentile
Kawasaki disease with aneurysms	Kawasaki with regressed coronary aneurysms
Chronic kidney disease	Nephrotic syndrome
Cigarette smoking	HDL < 40 mg/dL
Diabetes mellitus	Chronic inflammatory disease (systemic lupus erythematosus, juvenile rheumatoid arthritis)
Post-orthotopic transplantation	Human immunodeficiency virus (HIV) infection

Acquired Hypertriglyceridemia

Hypertriglyceridemia does not significantly increase cardiovascular disease in itself, but it is associated with other conditions that increase the risk of cardiovascular disease, such as type 2 diabetes mellitus, NAFLD, and obesity.

Other disorders of Lipid Metabolism

While there are other disorders of lipid metabolism, further discussion of these is outside the scope of this chapter. The lipid disorders included here are primarily associated with overweight and obesity.

NUTRITION MANAGEMENT

Nutrition Assessment

Growth Chart

Once a child has been diagnosed with overweight or obesity, the standard BMI chart can be used to assess improvement. BMI is a reliable measurement of pediatric obesity and is associated with adult obesity. BMI levels correlate with body fat as well as a patient's health risks, especially cardiovascular risk factors. BMI should be interpreted in the context of patient's history, physical exam, and lab studies.

In patients with severe obesity, an extended BMI chart may need to be used. Another important consideration is the use of the BMI *z*-score. The *z*-score can give a better indication of progress than changes in absolute BMI. BMI percentile categories for overweight and obesity are as follows:

- 85th–95th percentile = overweight
- ≥95th to 120% of 95th percentile = class I obesity
- ≥120% of 95th percentile to 140% of 95th percentile = class II obesity
- ≥140% of 95th percentile = class III obesity

Nutrient Intake

An important part of the nutrition assessment is gathering information about the patient's typical nutrient intake, lifestyle, and habits. This is usually completed by conducting a lifestyle assessment. A lifestyle assessment includes information about nutrient intake as well as other pertinent information related to the patient's habits and behaviors. There are a variety of nutrition assessments to

choose from including a 24-hour recall, 3- or 7-day food record, and food frequency questionnaires (FFQ). Bear in mind that no assessment tool will capture all of the information but more will be revealed in frequent follow-up visits. Some important points to be addressed in a nutrition assessment include, but are not limited to:

- Frequency of meals and snacks and specific foods consumed at these times
- Portion sizes of meals and snacks
- Late-night eating habits
- Daily intake of vegetables and fruits
- Daily intake of low-nutrient-dense "junk food" and sugar-sweetened beverages or fruit juices
- Frequency of fast food and eating foods prepared outside the home

For patients with hyperlipidemia, it is not only important to obtain information about the patient's typical daily intake, but also a food frequency-style assessment of the consumption of various foods that affect serum lipid levels the most. These should not only include sources of saturated fat, but also sources of mono- and polyunsaturated fats and fiber.

Physical Activity/Screen Time Assessment

There are a variety of ways that physical activity can be assessed. During the initial visit, a self-reported description of activity or exercise such as type of activity, duration, and frequency may suffice. If you would like more detailed information about the patient's activity level, other self-report tools or motion-sensor tools may be appropriate. Self-report tools include questionnaires, diaries, and logs. A few motion-sensor options are accelerometers, pedometers, heart rate monitors, and multi-sensor devices (these are more commonly used in research). Screen time is also an important component of the lifestyle assessment as evidence of a correlation between screen time and overweight and obesity continues to grow. Important evaluation components of physical activity and screen time include:

- Time spent in moderate physical activity (includes organized physical activity and unstructured activity like active play)
- Daily activity patterns, such as walking to school or performing yard work
- Sedentary behavior, including hours of screen time (includes but is not limited to television, tablets, cell phones, video games, and computer use)

It is also important to ask questions regarding the safety and accessibility of outdoor and indoor spaces that could be utilized for exercise/physical activity.

Sleep Patterns

Short sleep duration is a significant risk factor for overweight and obesity. It has been found that children who sleep less than 10 hours/night are at 89% greater risk of being obese than their peers who sleep more than 10 hours/night. With research continuing to show more evidence of the relationship between sleep and overweight and obesity, it is an important factor to consider during an assessment. Gathering information about sleep and wake times, difficulty sleeping, daytime sleeping habits, obstructive sleep apnea symptoms, and screen use at bedtime can provide a better picture of the child's sleep routine.

Common Physical Exam and Laboratory Findings

Acanthosis Nigricans

Acanthosis nigricans is a darkening in the creases of the neck, inside elbow and back of the knee. It is common in those with overweight and obesity and tends to improve/lighten with decreases in

BMI. Children with acanthosis nigricans are at higher risk for developing type 2 diabetes, as it is often associated with insulin resistance.

Abdominal Obesity

Children with overweight and obesity often have a high waist circumference, which places them at increased risk for co-morbidities. The most prevalent concerns are elevated triglycerides with low HDL cholesterol, and insulin resistance. Waist circumference measurements should be taken above the umbilicus below the ribcage with a flexible measuring tape. In children and adolescents with obesity, it is important to ensure that a long enough tape measure is used to prevent the stigmatizing effect of running out of tape while measuring.

Body Composition

BMI and BMI *z*-scores are surrogate methods for estimating body composition. Using more direct methods to measure body composition can be useful in assessing a patient's progress. Simple methods may be useful in the clinical setting, such as skinfold thickness or bioelectrical impedance measurements, but more sophisticated methods may be preferred for their improved reliability and validity, such as air-displacement plethysmography or dual-energy X-ray absorptiometry. Regardless of the method, it is advantageous to assess body composition bi-annually or more frequently.

Laboratory Assessment

Laboratory assessments are collected to screen for co-morbidities of obesity and nutritional deficiencies. Generally, it is recommended that screening for co-morbidities be commenced when BMI ≥ 85th percentile, especially if there is a strong family history of any co-morbidities. Of note, a universal screening of total cholesterol is recommended for all children 9–11 years old regardless of weight status, but a lipid panel should be done sooner if a patient has obesity or a strong family history of hyperlipidemia or cardiovascular disease.

Hemoglobin A1c (HbA1c) provides the average level of blood glucose over the past 2–3 months. It is collected to screen for T2DM.

A lipid panel consists of total cholesterol, high-density lipoprotein-cholesterol (HDL-C), low-density lipoprotein-cholesterol (LDL-C), very-low-density lipoprotein-cholesterol (VLDL-C), and triglyceride (TG) Level. Typically, obese children and adolescents exhibit dyslipidemia of obesity which is usually elevated TG, and low HDL-C with the other values in the normal range.

Alanine Aminotransferase (ALT) and Aspartate Aminotransferase (AST) are liver enzymes that are typically elevated in NAFLD. They are typically 2–5 times the upper limit of normal range and the AST:ALT ratio is typically less than 1.0.

A basic metabolic panel and urinalysis should be done with patients who have the diagnosis of HTN. Increased blood urea nitrogen (BUN) or creatinine or hematuria/proteinuria may reveal underlying kidney disease. Also, glycosuria is found with diabetes mellitus.

Iron deficiency is associated with obesity. A complete blood count and iron levels may be performed if patients report of symptoms associated with anemia, such as fatigue, increased heart rate, and shortness of breath.

Vitamin D levels are typically low in individuals with obesity due to sequestration of vitamin D in fat. Routine screening is controversial, but typically vitamin D requirements are higher in adolescents with obesity compared to those of normal weight.

Genetic studies should be done in children who exhibit extremely early onset of obesity (<5 years of age) and have developmental delay or clinical features of genetic obesity syndromes such as hyperphagia and/or a family history of extreme obesity

Thyroid Stimulating Hormone (TSH)/Thyroxine (T4) should not be assessed unless there is poor linear growth or short stature. Of note, mildly elevated TSH is more often found in children with obesity as compared to normal-weight children but is considered a consequence of obesity and not a cause.

Nutrition Diagnosis

Common terms used in the diagnosis of overweight and obesity include:

- Overweight, pediatric
- Obese, pediatric
- Excessive growth rate
- Undesirable food choices
- Physical inactivity
- Excessive energy intake
- Altered nutrition related laboratory values (specify)

Nutrition Intervention

Effective pediatric weight management interventions target both the child/adolescent and the caregiver and not only provide information about appropriate feeding, but also exercise, stimulus control, goal setting, self-monitoring, contingent rewards, and problem solving.

Nutrition Prescription

Energy needs can be calculated using the Institute of Medicine Total Energy Expenditure equations for overweight children and adolescents aged 3–18 years (Table 25.4).

Common Nutrition Interventions

Feeding/Eating Habits

There are numerous eating habits that should be included in the intervention portion, but the initial assessment will allow the clinician to narrow the focus for each individual child and family. It is not appropriate to assume that all children with overweight/obesity and their families practice exclusively unhealthy eating habits, so gleaning specific information with a nutrition assessment in the beginning will allow the dietitian to avoid assumptions and tailor recommendations to the patient. Some recommendations to consider in education and counseling include:

- Decreased sugar-sweetened beverage intake
- Decreased frequency of food from outside the home

TABLE 25.4
Predictive Equations for Energy Needs of Overweight Children Ages 3–18 Years

Gender	Total Energy Expenditure (TEE)	Activity Factor
Male	For weight maintenance: TEE = 114 − (50.9 × age in years) + (physical activity × [19.5 × weight in kilograms] + [1161.4 × height in meters]) For weight loss: TEE − 108	Sedentary: 1 Low active: 1.12 Active: 1.24 Very active: 1.45
Female	For weight maintenance: TEE = 389 − (41.2 × age in years) + (physical activity × [15.0 × weight in kilograms] + [701.6 × height in meters]) For weight loss: TEE − 108	Sedentary: 1 Low active: 1.18 Active: 1.35 Very active: 1.60

Source: Adapted from *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids*. Institute of Medicine. Washington, DC: The National Academies Press. 2005. https://doi.org/10.17226/10490.

- Increased consumption of vegetables and fruit with a decrease in consumption of low-nutrient-dense food (specific focus on saturated fat and added sugars)
- Portion control

The dietitian may wish to provide the family with a meal plan, but it is best to keep the meal plan focused on portion control and balance versus a specific dictation of what to eat daily. It is critical to avoid supporting the "dieting mentality" of restriction and focus on overall healthy habits. Another helpful tool is a list of foods in a "stoplight" format, emphasizing frequent consumption of "green light" foods and only occasional consumption of "red light" foods. Using the words "good" or "bad" should be avoided when describing food choices and "healthy" versus "less healthy" used instead.

Physical Activity/Screen Time

The recommendations for physical activity in the overweight pediatric population include at least 20 minutes of moderate to vigorous physical activity every day with a goal of at least 60 minutes. The dietitian may need to assist the family in brainstorming indoor exercise ideas if the child is unable or does not wish to exercise outside. It is important for clinical treatment programs to include supervised physical activity sessions when possible.

The AAP recommends no television viewing before the age of 2 years and no more than 2 hours of screen time per day after age 2. It is also recommended that televisions and other screens be removed from the child's primary sleeping area.

Specific Diagnoses and Effect on Nutrition Intervention

Many children and adolescents with obesity suffer from medical co-morbidities. While nutrition recommendations may change slightly to address specific conditions, the message of health and wellness through improvements in lifestyle habits do not change based on any specific diagnosis. The vast majority of co-morbidities of obesity can be improved through healthy lifestyle habits alone. Below are some examples of focused recommendations for a select few co-morbidities:

- **Dyslipidemia**: focus on decreased consumption of saturated fat with increased consumption of unsaturated fat (being mindful of total energy intake), dietary fiber, vegetables, and fruit (Table 25.5). Supplementation of plant sterols can be in the form of a fortified buttery spread or a capsule. When working with children and adolescents with obesity, it may be best to use the capsule form to avoid intake of excess energy.
- **Hypertriglyceridemia**: healthy eating behaviors and increased physical activity to improve other risk factors for cardiovascular disease are the primary treatment for hypertriglyceridemia. A one-time triglyceride level above 1,000 mg/dL or persistently elevated levels above 500 mg/dL can cause acute pancreatitis. If triglyceride levels average above 400 mg/dL, patients can be started on high-dose fish oil (2–4 g/day). Fibric acid derivatives can also be started, which increase HDL-C and lower triglyceride levels. Diet recommendations consist of a low saturated fat diet (<7% of energy), increased omega-3 fatty acid intake (2–4 g/day), preferably through fatty fish consumption but supplementation may be helpful, and reducing simple carbohydrates.
- **Hypertension**: focus on decreased intake of added salt and sugar with increases in cardiovascular exercise.
- Type 2 Diabetes Mellitus (see Chapter 24).

Motivational Interviewing

Motivational interviewing (MI) is widely applicable in all behavior change and is particularly effective for treatment of obesity. Understanding and utilizing MI is essential for dietitians, especially those working in weight management. The five general principles of MI are:

TABLE 25.5
Dietary Recommendations for Youth with Familial Hypercholesterolemia

Nutrient	Recommended Daily Intake
Total fat	25%–30% of energy
Saturated fat	<7% of energy
Unsaturated fat (MUFA and PUFA)	18%–23% of energy Emphasize sources of polyunsaturated fats
Trans fat	None
Cholesterol	<200 mg
Dietary fiber	Age + 5 g
Plant sterols/stanols	2 g

Legend: MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

1. Express empathy with reflective listening
2. Show discrepancy between patient's current behavior and their goals/values and encourage patient to make progress toward change
3. Never argue or be confrontational with the patient
4. Instead of opposing patient's resistance, direct the patient toward positive change
5. Help build the patient's confidence in meeting goals

Stimulus Control, Goal Setting, and Contingent Rewards

The most successful pediatric weight management programs utilize stimulus control, goal setting with self-monitoring, and contingent rewards. Dietitians can help families practice stimulus control by encouraging them to minimize the amount of "tempting" or low-nutrient-dense foods that are available in the home and by setting limits on screen time.

Dietitians can utilize MI to facilitate the goal-setting process for their patients. Encouraging patients to set 2–3 SMART goals (Specific, Measurable, Acceptable, Rewarding, and Timely) will allow them to focus their behavior change; however, it is important to consider their readiness to change. It is helpful to have patients self-monitor their progress with the goals that they have set and to be able to earn non-food rewards from caregivers for successful meeting of their goals.

Nutrition Education

Utilizing the list of points given in the previous section, educational modules can be created by the dietitian. Educational modules should not only involve the written and spoken message, but also hands-on demonstrations as often as possible. For example, a dietitian could use food models to help children learn visually and kinesthetically about portion control. Education regarding wellness and weight management should involve the caregivers and the child or adolescent.

Other Specialty Referrals

It may be necessary to refer patients to other specialists, depending on the specific needs of the child and caregivers. This may include, but is not limited to, psychologists or psychiatrists, hepatologists, speech therapists for feeding concerns (often encountered in children with autism spectrum disorder), nephrologists, or endocrinologists.

Nutrition Monitoring and Evaluation

Follow-Up Frequency/Contact Time

According to USPSTF recommendations, effective interventions involved a total of at least 26 contact hours over a 6-month period. Greater improvements, including decreases in cardiovascular metabolic risk factors, were realized with 52 contact hours or more.

Adherence

The effectiveness of any intervention relies heavily on the amount of time the clinician and patient spend together. Building rapport with the patient and family in addition to implementing frequent appointment reminders will assist in maximizing this contact time. Weight management programs may also want to consider creating a feeling of community with their patients and families by implementing social media, newsletters, social gatherings, etc.

Anthropometrics

Monitoring changes in weight, BMI, and body composition are helpful tools in managing pediatric obesity. A BMI *z*-score reduction is associated with improvements in cardiovascular measures and

TABLE 25.6
ADIME Summary for Obesity and Lipid Disorders

- Assessment
  - Growth assessment (BMI)
    - 85th–95th percentile = overweight
    - ≥95th to 120% of 95th percentile = class I obesity
    - ≥120% of 95th percentile to 140% of 95th percentile = class II obesity
    - ≥140% of 95th percentile = class III obesity
  - Nutrition-focused physical exam
  - Nutrient intake
  - Physical activity
  - Screen time
  - Sleep patterns
  - Labs
    - HbA1c
    - Lipid panel
    - Aspartate aminotransferase and alanine aminotransferase (AST and ALT)
  - Gastrointestinal findings
  - Medications/side effects
    - See Table 25.1
- Diagnosis
- Intervention
  - Nutrition prescription
    - See Table 25.4
  - Common nutrition interventions
    - Oral
      - Decreased sugary beverage intake
      - Increase fruit and vegetable consumption
      - Portion control
      - See Table 25.5 for familial hyperlipidemia
    - Motivational interviewing
    - Education
    - Laboratory monitoring
    - Supplements
    - Other specialty referrals
- Monitoring and evaluation

metabolic risk factors. However, meeting set goals and maintaining current weight or BMI *z*-score may still be considered significant clinical improvement (Table 25.6).

Pediatric obesity is a significant public health concern with significant co-morbidities. Untreated pediatric obesity may persist into adulthood. Nutrition counseling and MI are key components in the management of pediatric obesity and lipid disorders. Coordination with a multidisciplinary team is essential in improving outcomes and managing co-morbid conditions.

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26 Oncology and Bone Marrow Transplantation

Deena Altschwager, MS, RD, LDN, CNSC and McGreggor Crowley, MD

CONTENTS

Cancer is the second leading cause of death in children, and in 2021, over 10,000 children under the age of 15 will be diagnosed with cancer in the USA. Novel treatment methods including monoclonal antibodies, kinase inhibitors, and genetically engineered T-cell immunotherapies have increased the 5-year survival rate for these children from 58% in the 1970s to over 84% today.

Unlike adult cancers, many pediatric cancers are strongly influenced by genetics and are not typically linked to lifestyle or environmental causes. Leukemia, including acute lymphocytic leukemia (ALL) and acute myeloid leukemia (AML), is the most common type of childhood cancer, accounting for 28% of new pediatric oncologic diagnoses. Cancers of the brain and spinal cord, including medulloblastoma, are the second most common type of childhood cancer, representing 26% of new diagnoses, while neuroblastoma, a type of cancer in immature nerve tissue within the adrenal glands and sympathetic nervous system, accounts for 6% of childhood cancers and is the third most common type of cancer in children.

About half of children with cancer will experience malnutrition at some point during their illness trajectory (Table 26.1), and this can contribute to increased morbidity and mortality. Because patients who are well-nourished often have better treatment tolerance, experience fewer complications, and recover more quickly than their malnourished peers, nutrition optimization in oncology patients is of central importance.

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TABLE 26.1
Oncologic Conditions Increasing the Risk of Malnutrition

Tumor Types

- Neuroblastoma
- Wilms tumor
- Rhabdomyosarcoma
- Ewing's sarcoma
- Osteosarcoma
- Multiple relapsed and some high-risk leukemias
- Head and neck tumors
- Diencephalic tumors

Treatment Modalities

- Irradiation to the gastrointestinal tract
- Major abdominal surgery
- Hematopoietic cell transplant
- Intense intervals (<3 weeks) between chemotherapy cycles

Source: Adapted from Academy of Nutrition and Dietetics. Pediatric Nutrition Care Manual. https://www.nutritioncaremanual.org. 2021. Accessed August 29, 2021.

NUTRITION MANAGEMENT

Nutrition Screening

Given the large number of pediatric oncology patients treated within hospitals and cancer treatment centers, a dietitian must identify which subset of patients will benefit most from evaluation and nutrition recommendations. Prioritization of patient evaluation is accomplished through nutrition screening (see Chapter 3). The Academy of Nutrition and Dietetics (The Academy) recommends pediatric oncology patients be screened for nutrition risk upon diagnosis, during each admission to the hospital, during outpatient treatment (chemotherapy and radiation sessions), and in follow-up visits with medical providers. In addition, patients with high-risk cancers or those with intensive treatment regimens should be screened monthly at a minimum. Patients who are well-nourished at diagnosis should be screened at least every 3–6 months, and patients who have completed treatment should be screened yearly.

Pediatric oncology patients should be evaluated by a dietitian if they are underweight or malnourished at diagnosis, have a decreased appetite (oral intake less than 85% of nutrition needs for 3–5 days), experience rapid and significant weight changes (3%–5% in 1 month), report frequent nausea and emesis that cannot be controlled with medication, and/or experience frequent diarrhea that could lead to malabsorption. A nutrition assessment may be indicated in patients receiving nutrition support, following a modified or restrictive diet, starting corticosteroids, experiencing steroid-induced diabetes, managing one or more food allergies, and/or using complementary or alternative medicine.

Nutrition Assessment

Appendix F contains two example notes for fictional pediatric patients with cancer, which include all parts of the ADIME process. The nutrition assessment is the first part of the Nutrition Care Process (Chapter 3). When possible, collecting dietary information directly from patients (and in the case of younger children, from their caregivers) will provide the most accurate data. If a patient or caregiver is unavailable for an interview, data can be collected from the medical record, referring provider, and through observation.

The dietitian should review the patient's history, including medical history, family history, and social history. The medical history may be brief, but for initial consultations in pediatric oncology patients, it is important to reference the date of cancer diagnosis and the management steps that have taken place in the interim, including major operations, chemotherapeutic regimens, number of days since stem cell transplantation and whether the patient has fully engrafted, and prior treatment failures. Important nutrition history may also be included, including prior use of parenteral nutrition (PN) and history of gastrointestinal complications including feeding intolerance and malabsorption, as well as prior use and tolerance of enteral nutrition (EN).

Treatment Types and Complications

Before an oncology patient starts a treatment course, goals of treatment must be defined by the family and the medical team. Intention of therapy can be:

- Curative, to prevent a recurrence in the area being treated
- Control, to manage the size of the tumor
- Palliative, to optimize the comfort of the patient; or
- Prophylactic, to prevent metastasis in cancers that are known to spread.

In addition to the intent of therapy, it is important for the medical team to discuss nutrition goals of care with the family, especially if the patient will undergo treatment that is not curative.

Accomplishing treatment goals may include a combination of chemotherapy, radiation, surgery, and bone marrow transplantation (BMT), each of which has its own complications. Common symptoms resulting from these treatments include anorexia, nausea, vomiting, constipation, and diarrhea and can arise at any point during treatment.

Less common side effects of treatment include typhlitis, tumor lysis syndrome, and veno-occlusive disease. Typhlitis is ileocecal inflammation that generally occurs in neutropenic patients approximately 3 weeks after cytotoxic chemotherapy, when neutropenia is the most profound. Patients experience fever, cramping, abdominal distention, tenderness, nausea, vomiting, and bloody diarrhea. Treatment of typhlitis often involves bowel rest, nasogastric suction, and the need for PN until symptoms resolve.

Tumor lysis syndrome (TLS) is a condition that can occur following the start of cytotoxic therapy when destruction and turnover of tumor cells release large amounts of potassium, phosphate, and nucleic acids into systemic circulation. Patients with TLS should limit their intake of potassium and phosphorus and have serum electrolytes monitored every 6 hours. For patients with TLS on PN, consider temporarily removing potassium and phosphorus from the PN prescription and supplementing with calcium due to TLS-related hypocalcemia.

Veno-occlusive disease (VOD) is a condition that generally presents within 30 days after BMT and is characterized by transfusion-refractory thrombocytopenia, hepatomegaly, ascites, and jaundice, rapidly progressing to multiorgan dysfunction and death, if untreated. If VOD is suspected, weights and fluid status should be carefully monitored, and caution should be exercised when interpreting serum electrolytes due to third-spacing of fluids. In patients with VOD, fluids should be restricted, necessitating concentration of enteral formula or fluid-restricted PN. Patients with severe VOD may also experience abdominal distention due to ascites, leading to the placement of an abdominal drain; these patients should be closely monitored for significant electrolyte shifts.

BMT can be either autologous, where the patient receives her own previously harvested cells, or allogeneic, where the patient receives the cells from a donor, sibling, or umbilical cord. Patients undergoing allogeneic transplant may require ablation of their immune system prior to transplant, an intensive chemotherapeutic and radiotherapeutic regimen associated with mucositis, diarrhea, and a prolonged period of decreased oral intake. In patients undergoing allogeneic transplant, graft-versus-host disease (GVHD) may be encountered when donor T cells attack recipient tissue. GVHD can develop in one or more systems including the liver, skin, eyes, and lungs, and in the gastrointestinal (GI) tract. GI-GVHD may result in severe secretory diarrhea, malabsorption, and bleeding. Unfortunately, there

are no data to guide nutrition plans for patients with GVHD, but depending on the severity, patients may require bowel rest during treatment with corticosteroids. Pending response to first-line treatment, patients may advance to an oral diet or EN. In steroid-refractory GVHD, patients may require a second-line therapy with calcineurin inhibitors and require longer courses of PN.

Food- and Nutrition-Related History

Obtaining a detailed history of a patient's food and fluid intake is an important initial part of the nutrition assessment. A 24-hour recall can help the clinician gain insight into a typical day in the child's life. However, when asking for a recall from an oncology patient, it is important to ask the patient and caregivers to provide history from a time in the child's life when she was healthy, generally prior to the diagnosis. When a baseline recall is known, it can then be contrasted with how the child has been eating recently to further determine the patient's need for nutrition intervention. Table 26.2 lists specific questions to consider asking during a nutrition assessment, and

TABLE 26.2
Questions to Ask During Nutrition Assessment

Oral Intake

- Does the child eat foods from all five food groups (grains, protein, fruit vegetables, dairy)?
- How often does she eat fruits and vegetables?
- Are there any foods she will not eat? (This will change often in the pediatric oncology patient.)
- How does eating change during the week and on weekends?
- What does the patient like to drink and how much does she drink in a day?
- If the patient has experienced treatment already, how does eating and drinking change during a treatment cycle, and how long does this change last?
- Does the child have any known food allergies? Any family history of food allergies?
- Is the child taking any vitamin or mineral supplements?

For Infants

- What type of nutrition does the child receive? (i.e., human milk or formula)
- If breast fed, how often does she feed per day, and how long is she at the breast?
- How long are you hoping to breastfeed?

For Formula-Fed Patients

- What type of formula does she take?
- Is this the formula she has always been on?
- What other formulas have they tried and why did they not work?
- How do you prepare the formula?
- How much does she drink and how often?
- Does she take any solid foods?

Enteral Nutrition

- Has the child ever required nutrition support, and if so, what type and for what duration?
- Were there any issues with tolerance?
- What type of formula was used, and did she require any formula changes?
- If currently on enteral feeds, what is the regimen at home?
- Is the regimen different during treatment cycles?

Parenteral Nutrition

- How many days does the patient receive parenteral nutrition? How many days do they receive lipids?
- What types of lipid are they receiving?
- What is the nutrition prescription? (This will likely need to be obtained from the prescribing institution)

Current Symptoms

- Is the child currently experiencing any problems with nausea, vomiting, diarrhea, or constipation?
- Is the child experiencing any taste changes? (These are common in patients receiving carboplatin, cisplatin, methotrexate, doxorubicin, and cyclophosphamide)

these questions will help the dietitian determine how the patient is obtaining their nutrition via oral intake, EN, and/or PN.

Anthropometrics

For patients with oncological diseases, measuring height, weight, and body mass index (BMI) assists in identifying those patients who may benefit from nutrition optimization and those whose nutrition is negatively impacted by the pharmacological, medical, and surgical interventions involved in treating the cancer. Abnormally high or low BMI at time of diagnosis, for example, has been associated with poorer outcomes in patients with solid tumors such as Ewing's sarcoma, osteosarcoma, and rhabdomyosarcoma, owing perhaps to differences in both lean tissue and fat mass and their impact on distribution of chemotherapeutic drugs, metabolism, and drug clearance.

When obtaining anthropometric measurements in the inpatient setting, especially daily weights, careful attention should be paid to a patient's fluid volume status. For example, abdominal ascites from VOD and third-spacing with peripheral edema from protein malnutrition due to GI-GVHD can artificially and falsely increase a patient's apparent weight. A "dry" or pre-admission weight may provide some clarity in patients with edema, and in some situations, trending mid-upper arm circumference (MUAC) may be required. Certain drugs such as corticosteroids may also impact a patient's weight, necessitating regular pharmacological review.

During the course of treatment for their oncological disease, most pediatric patients should be expected to grow normally and will benefit from close monitoring of anthropometric data in conjunction with goal setting for weight and height accrual. Some patients, especially those treated with busulfan or lomustine or who underwent pituitary radiation, are at increased risk for lower adult height. Additionally, increased rates of obesity have been observed in patients previously treated for childhood leukemias, underscoring the long-term need for anthropometric monitoring and nutrition vigilance in this population.

Biochemical Data, Medical Tests, and Procedures

Dietitians working with patients undergoing active treatment for their oncological processes may be inundated with information including laboratory data, results from medical tests, and outcomes from procedures such as endoscopies, tumor resections, and central venous line placements. However, careful attention paid to both specific results and long-term trends optimizes patient safety and offers the dietitian opportunities to guide the medical team in integrating these results into the nutrition plan.

In pediatric oncology patients, monitoring of electrolytes is especially important in conditions such as TLS, where sodium, potassium, calcium, and phosphorus may be altered. Generally, however, important laboratory values extend well beyond the standard electrolyte panel to include micronutrients such as vitamin D, iron, and a thyroid panel. In VOD and other conditions that impact the liver, bilirubin (both total and direct) and aminotransferases (AST and ALT) should be trended.

Findings from many medical tests, including imaging studies or GI procedures such as endoscopy or colonoscopy, are directly related to the patient's nutrition plan and should also be reviewed. Examples include GI-GVHD identified via endoscopy and abdominal ultrasound detection of ascites and hepatic congestion in VOD.

Finally, pediatric oncology patients may undergo procedures such as BMT, radiotherapy to the abdominal viscera, and operative resection of tumor burden, each of which may importantly impact nutrition status in different ways. For patients post BMT, the note should document the number of days post-transplantation and whether a patient has fully engrafted (two factors impacting fluid status), dietary options, and medical management. Patients who undergo radiotherapy may be expected to have increased protein requirements and face both the acute and chronic effects of abdominal radiation on enterocyte function, ranging from diarrhea to malabsorption to protein-losing enteropathy,

and in extreme cases, intestinal failure. Cranial radiation for treatment of central nervous system tumors like medulloblastoma and malignant gliomas may lead to subsequent endocrinopathies, especially growth hormone deficiency and its long-term impact on vertical growth. Operations for debulking or resecting tumors also negatively impact nutrition due to prolonged suboptimal intake in the postoperative period, development of postoperative ileus, and rarely, intestinal resection.

Nutrition-Focused Physical Exam

Nutrition-focused physical exam findings frequently encountered in pediatric oncology patients include alopecia secondary to chemotherapy, oral mucositis, facial edema, temporal wasting, Cushingoid facies secondary to prolonged corticosteroid use, tachypnea, abdominal distention due to ascites or VOD, and cachexia. Findings not specific to oncologic processes should also be reported, including observations about subcutaneous fat stores and muscle bulk; fluid status, including mucosal hydration, skin tenting, or sunken eyes; and markers of nutrition deficiencies, such as cheilosis, bruising, and rashes.

The dietitian should also review the patient's output (including urine, stool, enteral tubes, chest tube, and/or abdominal drains) to evaluate hydration status, constipation, and diarrhea which can necessitate changes to the nutrition care plan.

Medications

Pediatric oncology patients may be prescribed numerous medications during the treatment of their disease. Given the wide variety and purpose of these medications, it may be helpful to classify and conceptualize these medications by the intent of their prescription.

Chemotherapeutic drugs are those medications used to directly treat cancer or to ablate the immune system in preparation for transplantation. These drugs include carboplatin, which is used to treat solid tumors such as hepatoblastoma and neuroblastoma and is associated with the development of mucositis; PEG-L-asparaginase, a treatment for acute lymphoblastic leukemia (ALL) may cause acute pancreatitis; and 6-mercaptopurine (6MP), another medication for ALL that can suppress appetite and lead to abdominal pain.

Many children undergoing chemotherapy or radiotherapy experience considerable medication-related side effects that impact nutrition intake and are also treated pharmacologically with symptom-management drugs (Table 26.3). Reference to these medications should be included when assessing a patient, and identification of optimal provision times may assist the medical team with both managing treatment side effects and blunting the impact of these side effects on nutrition intake.

Children with cancer are at increased risk for infection due to their immunocompromised status, and in patients with fever, vital-sign instability, or specific physical findings, antibiotic, antifungal,

TABLE 26.3
Medications Used for Treatment-Related Side Effects

Medication	Use
Anti-emetics (ondansetron, aprepitant, marinol)	Prevent nausea and vomiting
Stool softeners (polyethylene glycol)	Treat constipation
Bowel stimulants (senna)	Treat constipation
Ursodiol	Treat cholestasis
Diuretics (furosemide)	Treat third-spacing and edema
Steroids	Anti-inflammatory, pain management, chemotherapeutic purposes
Appetite stimulants (cyproheptadine)	Increase appetite
Opioids and anxiolytics	Pain management
Viscous lidocaine	Mucositis-related pain

and antiviral drugs may be prescribed. Each may have an impact on a patient's nutrition status, ranging from the volume and carrier fluid in which the medication is provided to the tendency for the medication to cause electrolyte disturbances. Amphotericin B, for example, is a nephrotoxic antifungal drug used in patients with cancer and is associated with potassium wasting and subsequent hypokalemia. Close communication with the medical team about the initiation or discontinuation of these medications can assist the dietitian in predicting risk for and preventing clinically important electrolyte shifts.

Lastly, patients may be prescribed medications for non-oncologic purposes, including pre-existing conditions or conditions acquired in the treatment of their underlying disease. Asthma, rashes, psychiatric disorders, and insomnia (to name just a few) are frequently encountered in the pediatric population and are treated pharmacologically. Though these medications may not uniformly impact a patient's nutrition, some drugs can directly impact electrolyte levels (e.g., albuterol's association with hypokalemia), necessitating careful review during the nutrition consultation.

Nutrition Diagnosis

The nutrition diagnosis differs from the patient's medical diagnosis, and if the dietitian is unable to help a patient improve the problem at that time, an alternate diagnosis should be chosen. For example, if a patient who is overweight presents for inpatient oncology treatment, it may not be the appropriate time to address an overweight diagnosis. Instead, it may be more helpful to address the patient's increased nutrition (protein) needs given they will be starting treatment soon.

Common nutrition diagnoses include:

- Inadequate energy intake
- Inadequate oral intake
- Inadequate enteral nutrition infusion
- Limited food acceptance
- Malnutrition (undernutrition)
- Inadequate vitamin intake (specify)
- Inadequate mineral intake (specify)
- Predicted inadequate nutrient intake (specify)
- Altered gastrointestinal function
- Overweight/Obese
- Growth rate below expected
- Food- and nutrition-related knowledge deficit
- Disordered eating pattern
- Undesirable food choices

If the patient does not require nutrition intervention at the time of assessment, the diagnosis "No nutrition diagnosis at this time" should be used. Caution should be exercised when using this diagnosis in pediatric oncology patients because intake can change with each new cycle or stage in treatment. Instead, consider using a diagnosis of "predicted inadequate energy intake".

Nutrition Intervention

Nutrition Prescription

Energy

Pediatric oncology patients may require even more energy than their healthy peers due to the metabolic demands of their underlying disease and its treatments. However, these patients often experience decreased levels of physical activity due to frequent clinic visits and inpatient hospitalizations.

Additionally, their needs will change throughout the disease and treatment course and as the patient gets older and continues to grow.

The most accurate method of assessing energy needs, indirect calorimetry (IC), is especially helpful in evaluating critically ill or obese patients. Because IC is not always available, predictive equations are often used to estimate needs (Chapter 3). The Academy recommends the use of the estimated energy requirement (EER) equation for normal-weight patients, though other methods for estimating, including the Schofield equation and the FAO/WHO/UNU equation, are also employed. For the Schofield and FAO/WHO/UNU equations, consider a patient stress factor of 1.4–1.6 for patients actively receiving oncology treatment; 1.3–1.5 for patients undergoing BMT; and 1.5–2 for patients with chronic malnutrition who are not meeting their growth or weight-gain goals.

Protein

Patient's protein needs should be estimated based on the DRI set for the patient's age group and adjusted to reflect their clinical status. For patients <1 year old, up to 3 g/kg of protein can be used; with patients 1–10 years of age, consider using up to 2 g/kg of protein; and for patients 10 years of age and older, consider using 1.5 g/kg protein as a basal amount. Patients who require additional protein include those with malnutrition, active infections, or pressure ulcers; those who are critically ill; and those with GI-GVHD. Measuring nitrogen balance (such as with a 24-hour urinary urea nitrogen test) can be helpful to determine an individual patient's specific protein needs. However, it is particularly challenging to collect 24-hour urine excretion in pediatric patients, especially those in diapers.

Fluid

To calculate the fluid needs of a pediatric oncology patient, the Holliday-Segar method should be used. Patients with fever, physiological stress, diarrhea, ostomy or drain loss, and diabetes insipidus may require additional fluids. Conversely, patients with heart failure, renal failure, fluid overload, or syndrome of inappropriate antidiuretic hormone secretion (SIADH) may require less fluid. The dietitian should always confirm the patient's goal fluids with the medical team and update these goals as treatment progresses.

Common Nutrition Interventions

Nutrition interventions must be individualized to each patient based on diagnosis, treatment plan, and need for growth/catch-up growth. For pediatric oncology patients, the goals of nutrition intervention are to preserve lean body mass, prevent unintended weight loss, manage treatment-related side effects, prevent or reverse nutrition deficiencies, minimize morbidity and mortality, and maximize quality of life.

Oral Feedings

Throughout treatment, patients should be encouraged to consume a general, healthy diet whenever possible. However, patients can experience symptoms while going through treatment that will affect oral intake, and patients will benefit from encouragement to eat and drink. For patients with loss of appetite, consider small frequent meals, adding additional energy to foods (via butter, oil, or modulars), introducing nutrient-dense beverages, and reserving favorite foods for after treatment to avoid development of an oral aversion. If anorexia persists for an extended period, the medical team may prescribe anti-nausea or appetite-stimulant medications. Additionally, the use of EN should be considered.

In patients experiencing nausea and vomiting, consider optimizing the time of day when the patient feels best to offer meals. Additionally, for patients using anti-emetics, consider timing these medications before mealtimes. Other strategies include offering cold foods or dry, salty foods such as potato chips; encouraging slower eating and drinking; and avoiding strong odors by cooking food away from patients or opening windows when cooking. Some patients find additional relief with

ginger or lemon in beverages or candies. With persistent, uncontrolled retching or vomiting, patients may require post-pyloric EN or PN.

For mouth sores and other forms of mucositis, bland, soft, and/or pureed foods may be better tolerated, while cold foods such as popsicles, ice cream, milkshakes, and smoothies can be soothing to patients. Adding butter, gravy, sauce, or salad dressings can also be helpful along with avoiding highly seasoned or hard, crunchy foods. Good oral hygiene should also be recommended.

When taste changes arise, consider using strong flavors, marinades, and/or seasonings while cooking (cumin, paprika, garlic). Adding hot sauce, barbeque sauce, or vinegar can also help patients taste food. During this time, it is recommended that patients avoid sweet foods and instead consume salty or sour foods.

If a patient is struggling with constipation, encourage extra liquids, foods rich in fiber, and ambulation. Ultimately, given the number of medications and intensive treatment courses, patients may require medications to stool regularly. Conversely, for patients with diarrhea, foods that are lower fat, lactose free, and bland can be helpful.

For younger oncology patients, the ability to breastfeed may be impacted negatively by their treatment. For example, infants treated with thiotepa, a chemotherapy agent secreted through bodily fluids including sweat, are prevented from having skin-to-skin contact, including that incurred while feeding at the breast. These patients, some who have solely breastfed previously, will need to transition to a bottle to take expressed human milk or formula. Limits on breastfeeding also may be encountered in patients with certain diagnoses such as severe combined immunodeficiency (SCID) or those undergoing BMT. There is currently no consensus on breastfeeding in oncology patients, and each institution may have different guidelines and restrictions.

Certain oncology patients may require a therapeutic diet, including a diabetic diet for steroid-induced diabetes, a low-fat diet for chyle leak, or a low-bacteria or neutropenic diet for patients undergoing BMT. Of note, the data supporting the use of a low-bacteria diet for patients post BMT is limited and imposing strict limitations on the type of foods that patients can ingest risks decreasing their oral intake.

Enteral Nutrition

When a patient is unable to meet her nutrition needs despite the strategies listed above, she will likely require a form of nutrition support. It may be prudent to introduce nutrition support in conversations with patients and families early on in treatment rather than after a problem has developed. If a patient's GI tract is functional, EN is preferred over PN. Though patients and their families may express hesitancy with this modality, enteral access can provide nutrition as well as reduce the number of oral medications a patient must take. Obtaining enteral access can occasionally be timed around a procedure, allowing the patient to be sedated for placement of a short-term enteral-access device. If a patient has an upcoming procedure, the dietitian should consider recommending coordinated placement of an enteral-access device.

In patients with enteral access, there are a variety of formulas to choose from, including standard, peptide-based, and elemental, with peptide-based formulas being better tolerated in the oncology population (Chapter 8). Commercial blenderized formulas, some of which are peptide-based, are relatively new and minimal data exists regarding their efficacy in promoting weight gain and preventing nutrition deficiencies. Caution and close nutrition follow-up should be used if a patient is on a commercial blenderized formula.

Nutrition is often one part of a child's treatment that a family can control, and there are families that have strong preferences regarding their child's formula. When starting a child on EN, a clinician should consider several formula options and present them to the family. Formula choice is often further complicated by limitations of in-hospital and home-care company formularies.

Throughout treatment, the patient's EN will need to be adjusted due to growth and treatment-related side effects. Often, continuous feeds will need to be utilized during treatment cycles to provide a lower rate of feedings. Additionally, there may be times during treatment when the patient is unable

to tolerate her full feeds, or any feeds at all, until she is able to recover from her current treatment cycle. Depending on how long intolerance lasts, PN may be required.

Parenteral Nutrition

Patients with nonfunctional GI tracts, severe mucositis, intractable emesis, typhlitis, GI-GVHD, or VOD may require PN if they are expected to be without adequate nutrition for 5 or more days. Though PN is both more expensive and associated with more risks and side effects than EN, it is an effective means of providing full nutrition support for pediatric oncology patients with central venous access.

Though patients undergoing oncology treatment often have central venous access, a conversation should occur between the dietitian, bedside nurse, and medical team to ensure the patient has adequate access for PN, chemotherapy, other medications, blood products, and potential electrolyte boluses. Encouraging these conversations prior to the start of PN allows for proactive placement of a peripheral intravenous line or additional central access (such as a catheter with two lumens instead of one) and avoidance of interruptions in treatment or nutrition provision.

Pediatric oncology patients are treated with various medications that can cause significant electrolyte abnormalities that may be exacerbated by aggressive PN prescriptions (see Table 26.4). Additionally, patients with poor intake leading up to PN initiation may be at risk for refeeding syndrome. During initiation of PN, electrolytes should be monitored daily at a minimum and appropriately repleted through the PN prescription, if able. If unable to fully replete electrolytes via PN, patients may require electrolyte boluses via central or peripheral lines, infusions that may take up to 6 hours in the case of potassium phosphate and compete with other medications, blood products, and chemotherapy regimens.

Intravenous lipid emulsions (ILEs) are another important aspect of PN in pediatric oncology patients, and dietitians have multiple types of ILE at their disposal. Clinicians should consider access in patients prior to starting ILE because not all ILEs have the same compatibility with medications, and newer types of ILEs have fewer compatibility data available. Additionally, because certain medications such as cyclosporine can increase serum triglyceride levels, monitoring triglyceride levels and avoiding elevations can help prevent pancreatitis.

Hybrid Nutrition Support

Nutrition is rarely perfect in pediatric oncology patients due to the complex treatment these patients undergo, and occasionally several nutrition strategies must be deployed simultaneously to ensure that

TABLE 26.4
Medication and Supplements with Significant Nutrition Implications

Medication/Supplement	Nutrition Implication
Folic acid	Avoid in patients receiving methotrexate; Folic acid can decrease the medication's chemotherapeutic effects
Iron	In patients undergoing bone marrow transplantation, contraindicated in the setting of frequent red blood cell transfusions these patients may require. Providing iron to these patients may cause iron overload
Amphotericin B	Hypokalemia, hypomagnesemia, and hyperchloremic acidosis
Foscarnet	Hypocalcemia, hypomagnesemia, and hypokalemia
Cyclosporine and tacrolimus	Glucose intolerance, hyperlipidemia, hyperuricemia, hyperkalemia, hypomagnesemia
Furosemide	Hypokalemia, metabolic alkalosis

a patient meets her nutrition needs. Protein is the most challenging and arguably the most important macronutrient during acute treatment, and if a patient is unable to meet basal protein requirements, PN will likely be needed. For those patients able to meet their protein needs with oral intake or EN, dextrose-containing fluids and intravenous lipids can be used to fulfill energy requirements. During treatment, patients will experience a variety of symptoms that will affect nutrition intake. Unconventional approaches, such as running EN at a rate lower than goal while providing dextrose-containing fluids, may be necessary to help patients continue to meet their growth and weight-gain goals.

Nutrition Education

There are several types of education that the dietitian can provide to patients and their families, such as guiding improved intake during treatment through small, frequent meals of high-energy foods; describing the relationship between adequate nutrition and treatment tolerance; ensuring food safety and low-bacteria or neutropenic diets for BMT patients; detailing the benefits of nutrition support; and preventing unintentional weight gain when on corticosteroids.

Vitamins and Minerals

If a patient has a laboratory-confirmed nutrition deficiency, supplementation recommendations should be provided. When making recommendations, it is important to consider the patient's treatment course and the potential for interactions with existing medications (Table 26.4).

Coordination of Nutrition Care

There are many services that are beneficial to collaborate with during a nutrition assessment, including recommendations for physical therapy to provide evaluation/treatment of deconditioning, speech therapy to assess the ability of a patient to safely swallow, social work to identify resource needs of the family with suspected food insecurity, child-life services to help the child cope with placement of nasogastric tubes, and palliative care consultation to ensure improved management of the patient's goals of care. The dietitian may also suggest a coordinated meeting with the family and the medical team to discuss nutrition goals in the setting of persistent feeding intolerance. Additionally, as part of discharge planning, the inpatient dietitian should determine the need for and recommend outpatient dietitian follow-up as needed.

Monitoring and Evaluation

The dietitian should set desired nutrition outcomes for the patient, measure the amount of progress made for the nutrition intervention, and determine if the nutrition-related goals and outcomes are being met. Examples of nutrition monitoring and evaluation measures that pertain to pediatric oncology patients are listed in Table 26.5. During each follow-up visit for a patient, progress on the patient's goals should be updated. If patients have met or are unable to meet the original goals set, consider changing those goals as appropriate.

The role of the dietitian during pediatric oncology treatment is vital to prevent malnutrition to optimize the patient's treatment outcome. Screening patients at regular intervals in the inpatient and outpatient setting will help identify patients who are at nutrition risk. A detailed nutrition history will help the dietitian learn about the patient's baseline habits and changes that may have already occurred around the time of diagnosis. The dietitian can then use this information to drive nutrition recommendations that can include nutrition education, increasing oral intake, starting or modifying EN, and the use of PN when needed (Table 26.6).

TABLE 26.5
Monitoring and Evaluation Terms for Use in Pediatric Oncology

Category	Food/Nutrition-Related History Outcomes	Anthropometric Measurement Outcomes	Biochemical Data, Medical Tests, and Procedure Outcomes	Nutrition-Focused Physical Finding outcomes
Example of Measures	• Nutrition knowledge and beliefs • Food and beverage intake (amount of food, meal and snack patterns, diet quality, ability to self-feed) • Human milk/formula intake • Enteral nutrition intake (formula and volume given) • Parenteral nutrition intake (composition) • Diet order • Access to food, safe food storage	• Height • Weight • Body mass index • Growth patterns/percentiles/*z*-scores • Weight history	• Laboratory data • Electrolytes • Lipid profile (triglycerides and cholesterol levels) • Iron studies (hematocrit, mean corpuscular volume, vitamin B_{12}, ferritin, methylmalonic acid, folate) • Vitamin and mineral levels • Urine studies • Tests (abdominal films, stool cultures)	• Physical appearance • Muscle and fat wasting • Vital signs • Swallowing function • Appetite • Affect

TABLE 26.6
ADIME Summary for Oncology and Bone Marrow Transplant

Assessment
- Medical history
  - Date of diagnosis
- Treatment plan and treatment dates
- Growth assessment
  - Abnormally high or low BMI at time of diagnosis has been associated with poorer outcomes in patients with solid tumors
  - Weight may be affected by fluid status. Consider using dry weight
- Nutrition-focused physical exam
  - Common findings include alopecia secondary to chemotherapy, oral mucositis, facial edema, temporal wasting, Cushingoid facies secondary to prolonged steroid use, tachypnea, abdominal distention due to ascites or veno-occlusive disease (VOD), and cachexia
- Nutrient intake
  - See Table 26.2
- Labs
- Gastrointestinal findings
  - Treatment side effects including anorexia, nausea, vomiting, constipation, and diarrhea
- Medications/side effects
  - Pay careful attention to medications as many side effects alter nutrient intake

(*Continued*)

TABLE 26.6 (*Continued*)
ADIME Summary for Oncology and Bone Marrow Transplant

Diagnosis
Intervention
  Nutrition prescription
    Energy needs may change throughout treatment course
    Consider indirect calorimetry
    Protein needs may be increased with malnutrition, active infections, pressure ulcers, critically ill patients, and patients with gastrointestinal graft-versus-host disease (GI-GVHD)
    Confirm fluid goals with medical team
  Common nutrition interventions
    Oral
      General healthy diet
      Consider diet changes based on treatment side effects
    Enteral nutrition
      Consider in patients unable to meet needs by mouth
      Peptide based are better tolerated in oncology population
    Parenteral nutrition
      Consider in patients with nonfunctional gastrointestinal tracts, severe mucositis, intractable emesis, typhlitis, GI-GVHD, or VOD with abdominal compression of the viscera
    Education
    Laboratory monitoring
    Supplements
    Other specialty referrals
Monitoring & evaluation

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27 Restricted Diets

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CONTENTS

Food preferences and diet patterns vary significantly from person to person and can change throughout a person's life. Many factors influence food choices and diet patterns at the individual level. From infancy through adulthood, development of eating behaviors and purposeful choices to adopt a particular style of eating are influenced by biological, psychological, social, cultural, environmental, and personal factors. This chapter explores restricted diets, self-selected diet patterns adopted by individuals that restrict or eliminate certain categories or types of foods and emphasize other categories or types of foods. Restricted diets that are prescribed by a healthcare provider are discussed elsewhere and are not included in this chapter.

Restricted diets followed by children may be directed by caregivers, peer influences, or internally driven by the child. Assessment of restricted diets not only requires knowledge of nutrition needs for the child's age and medical history but also an understanding of how the child's nutrition-related knowledge, the family environment, and other social factors influence a child's eating habits. In younger children specifically, food preferences or avoidance of certain types or categories of foods may depend on sensory processing. Older children and adolescents have an increased capacity to make decisions around food and may begin to develop beliefs or opinions about specific foods and categorize food in different ways. Adolescents also make many more food choices on their own and exert greater autonomy over their eating. These factors can lead to the adoption of self-selected, restricted diets and purposefully setting eating goals based on various motivations. Common motivations that may prompt diet restrictions include the desire to improve health, manage weight, enhance body image, or improve athletic performance, among others. Influences on a child's opinions and beliefs about various foods or food groups include religious and family customs or modeling, nutrition knowledge, observing peer food preferences, diet trends in popular culture, and others. In children, restricted diets may impact nutrient intake and growth. It is important for the dietitian to understand dietary restrictions and make nutrition recommendations that allow the child to meet the nutrient needs for growth and development.

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VEGETARIAN AND VEGAN DIETS

One of the most common restrictive diets in the USA is the vegetarian diet in its multiple forms. Approximately 4% of US children and adolescents aged 8–18 years follow a vegetarian diet and about one-quarter of these individuals follow a vegan diet. Reasons for following a vegetarian or vegan diet are numerous. A primary motivator for implementation is to improve diet quality. Vegetarian and vegan diets are well documented to include lower intakes of cholesterol, saturated fat, and total fat; higher intakes of fruits, vegetables, and fiber; and are associated with lower rates of childhood obesity compared to non-vegetarian diets. Families as a whole might follow a vegetarian diet and thereby dictate the child's diet. Older children may choose to remove animal products from their diet for ethical reasons or to contribute to societal efforts to reduce climate change. Certain religions traditionally encourage a vegetarian diet including Jainism, Hinduism, and Buddhism. Islam and Judaism prohibit consumption of pork but allow other animal products. Younger children may avoid meat due to an aversion to the taste or texture of animal products (Table 27.1).

The term "plant-based" is a popular marketing phrase found in food advertisements, on food packages, and promoted by public figures. Although people following a "plant-based" diet are not always truly vegetarian, they may limit consumption of animal products. Another term for a diet pattern intentionally limiting but not eliminating meat consumption is a "flexitarian" diet.

Adolescents in particular might implement vegetarian diets due to influence from celebrities or peers, or in an effort to control or reduce their weight. Adolescents with eating disorders are more likely to follow a vegetarian diet for weight control, and those who engage in disordered eating may learn that a vegetarian or vegan diet is a socially acceptable way to restrict their eating.

It is the position of the Academy of Nutrition and Dietetics, the American Academy of Pediatrics, and the Dietary Guidelines for Americans that vegan, lacto-vegetarian, ovo-vegetarian, and lacto-ovo-vegetarian diets can meet the nutrient needs of infants, children, and adolescents to sustain normal growth and development. However, eating patterns of vegetarians and vegans can vary greatly, and diets should be well-planned and ensure adequacy of common nutrients that might otherwise be deficient in these diets. While some of these diets, especially when unplanned, include some degree of nutrition risk, these risks are likely to be highest in very young children and children with chronic disease.

Key nutrients at risk of deficiency in vegetarian or vegan diets include protein, vitamins B_{12} and D, zinc, iron, iodine, and omega-3 fatty acids. Because eating patterns of vegetarians and vegans can vary greatly, detailed nutrition assessment and planning is needed to ensure their adequacy. Patients receiving vegan enteral formulas may also be at risk of these nutrient deficiencies.

GLUTEN-FREE, CASEIN-FREE DIET

The gluten-free, casein-free (GFCF) diet is a popular dietary approach for management of Autism spectrum disorders (ASD). ASD represent a significant public health issue affecting one in 54

TABLE 27.1
Categories of Vegetarian Diets

Diet	Animal Product Omitted
Lacto-ovo-vegetarian	Meat, fish, poultry
Lacto-vegetarian	Meat, fish, poultry, egg
Ovo-vegetarian	Meat, fish, poultry, milk
Pescatarian	Meat and poultry
Vegan	All animal products – meat, poultry, fish, eggs, milk
Flexitarian	Reduced intake of various animal products

children in the USA. No universally effective management approach for ASD exists; therefore, many caregivers gravitate toward complementary and alternative medicine and dietary interventions. Multiple factors affect the nutrition status in children with ASD with most falling into two main categories, medical/nutrition factors and behavioral factors.

The GFCF diet is based on the theory that peptides from both gluten and casein affect opioid receptors in the brain and that, by removing these foods, certain impairments of autism will improve. A recent meta-analysis and systematic review showed no effect of a GFCF diet on clinician-reported autism core symptoms, communication traits, or behavioral problems, findings consistent with similar analyses performed in earlier years. Notable, however, is that all GFCF diet studies have had significant methodological limitations yielding very low quality of evidence leading to significant imprecision. There are several case reports and uncontrolled trials of GFCF diets but relatively few randomized controlled trials with sufficient number of participants of long duration to be definitive.

The GFCF diet is itself a challenge to implement as wheat and dairy are ubiquitous in Western and other cultures and GFCF versions of foods tend to be more expensive. Importantly, many children with ASD can have highly restricted dietary intakes with self-selected dietary monotony or feeding aversions due to oral texture sensitivity. Implementation of a GFCF diet further restricts dietary options and increases the risk of significant micronutrient and even macronutrient deficiencies.

The state of current evidence, therefore, is not sufficient to recommend a GFCF diet for children with ASD unless there is another medical reason for a gluten-free diet as in celiac disease or non-celiac gluten sensitivity or a milk-free diet for milk allergy. However, some caregivers feel strongly that a GFCF diet is beneficial. In one of the few double-blind randomized controlled trials to study a GFCF diet in children with ASD, many caregivers reported improvements in behavior and language outcomes and the majority elected to have their child continue a GFCF diet upon study completion despite no objective evidence for its efficacy. A firm belief by some caregivers of a benefit of a GFCF diet is not uncommon and, in such a situation, the emphasis is to then ensure that the GFCF diet is otherwise nutritionally balanced and complete.

PALEOLITHIC DIET

The Paleolithic diet, also known as the Stone-Age Diet or simply Paleo, is described as a nutrition pattern for hunter-gatherers from approximately 10,000 to 2.5 million years ago. It originates from the evolutionary discordance hypothesis that human evolution ceased 10,000 years ago, thus our genetics are ill-equipped to process the modern diet and sedentary lifestyle and predispose humans to "diseases of civilization". The principles of this diet include consuming foods that would only have been available to our ancestors during the Paleolithic age including lean meat (grass-fed preferred), seafood, eggs, fruit, vegetables, nuts, seeds, and oils including avocado while limiting grains such as wheat and barley (which are the primary ingredients in bread, pasta, rice, and crackers), beans and other legumes, dairy products, potatoes and other starchy vegetables, and processed foods such as cookies, pastries, soda, and candy.

Several randomized controlled trials in adults have demonstrated weight and body-fat reduction with metabolic improvements including improved hemoglobinA1c, blood pressure, and lipid profile, decreased waist circumference, and improvements in anti-inflammatory biomarkers, but these have required very restricted diets which may not be sustainable for majority of the population. A recent study comparing the effects of several restricted diets reports that Paleo consumers had the lowest consumption of ultra-processed foods with adequate intake of fiber and calcium while other studies have reported significantly lower sources of calcium when following this diet.

Some aspects of the Paleo diet are desirable including an increased consumption of vegetables and elimination of low-nutrient, processed foods that are high in sugar and/or sodium. However, the diet has not been adequately assessed to determine if the elimination of additional food groups, including dairy, legumes, and grains, are beneficial to health as claimed. Furthermore, no studies have been conducted on efficacy of weight loss of the diet in children or adolescents, and overall,

there is a lack of data on the Paleo diet in this population. Ultimately, there is hesitancy in recommending a diet for children and teens that would eliminate otherwise be healthy foods, such as whole grains, beans, lentils, and yogurt, and vegetables like potatoes and tomatoes. There is simply a lack of data on the Paleo diet for teens and children.

KETOGENIC DIET

The ketogenic diet (KD), also known as simply keto, is a high-fat, low-carbohydrate, adequate-protein pattern of eating resulting in a ketogenic state of human metabolism. Generally, it is defined as a diet consisting of 70%–80% energy from fat, 5%–10% carbohydrate, and 10%–20% protein and aims to force the body to break down lipids instead of glucose for energy metabolism, thus mimicking fasting or starvation. The liver converts fatty acids into ketone bodies as an alternate source of fuel for the brain and other tissues within the body. Clinical KDs typically restrict daily carbohydrate intake to 20–50 g/day.

The KD originated in the 1920s as a treatment for pediatric epilepsy under a medical team. Foods emphasized in the KD include butter, oil, heavy whipping cream, cheese, bacon, avocado, nuts, eggs, and fatty fish such as salmon, and non-starchy vegetables with the elimination of foods containing sugar such as grains, breads, fruit, rice and pasta, and juice. The Protein-Sparing Modified Fast (PSMF) is typically not considered a KD although individuals on this diet achieve ketosis, but it differs because the main source of energy comes from protein instead of fat.

Several meta-analyses have examined the efficacy of low-carbohydrate, high-fat (LCHF) versus high-carbohydrate, low-fat (HCLF diets) for weight loss in individuals with obesity. Short-term (less than 6 months) hypocaloric, low-carbohydrate and very low-carbohydrate diets may result in greater weight loss than hypocaloric HCLF diets. However, results are weaker on long-term follow-up, most likely because very low-carbohydrate diets are difficult to maintain with attrition rates approximately at 30%, thus indicating that personal preference should be a factor when selecting a weight-loss diet. The initial weight loss with the KD is primarily due to a loss of body water and may result in a greater loss of lean body mass. The results of LCHF and KD on blood pressure have been inconsistent. A very low-energy KD is associated with high efficacy for weight loss with reductions in BMI, waist circumference, HbA1c, total cholesterol, triglycerides, liver enzymes, and blood pressure.

KDs have been used safely over the past century in the management of drug-resistant epilepsy in children. The most common adverse effects of the KD, often referred to as the "keto flu", include lightheadedness, dizziness, fatigue, difficulty exercising, poor sleep, and constipation which typically resolve within a few weeks. People on insulin or oral hypoglycemic medications should consult with a physician before initiating the KD because of the risk of hypoglycemia. Blood pressure medications may also need to be changed. Additional side effects include reduced level of electrolytes including sodium, magnesium, and potassium due to the diuretic effect of the diet, thus optimizing fluid and electrolyte intake is important. More studies are warranted on the efficacy of weight loss with KD in children or adolescents.

INTERMITTENT FASTING

Intermittent fasting (IF) encompasses several different forms of daily or weekly food intake patterns, often with the goal of weight management, improving cardiovascular risk factors, or increasing longevity. Fasting is a common religious practice in many cultures including an approximately month-long, daytime fast during Ramadan in the Muslim faith. The most studied IF protocols include complete alternate-day fasting (ADF) in which fasting days alternate with regular days, modified alternate-day fasting (MADF) which involves different variations of ADF. 5:2 is the most common, which allows normal food intake for 5 days with 2 days/week of absolute fasting or restricted intake to no more than 25% of daily needs. Time-restricted feeding (TRF) involves fasting for a specific time each day with 16:8 being more common (16 and 8 hours of fasting and

unrestricted feeding, respectively). Diets that reduce energy intake on one or more days each week (e.g., consumption of 500–700 cal/day) increase the level of ketone bodies, which act as signaling molecules that influence many aspects of health and aging including an enhanced antioxidant response, DNA repair, protein quality control, mitochondrial biogenesis, and autophagy (cellular repair) and reduced inflammation.

The focus of most studies has been on ADF and MADF regimens with fewer on TRF. On an MADF regimen, higher loss of fat mass compared to the control group following daily energy restriction (75% of daily energy needs) has been reported with no difference in total weight loss. In a study of the ADF, ADF and energy restriction demonstrated improvements in weight loss with improvements in insulin sensitivity in those following the ADF. Despite the lack of definitive benefits, it is important to note that both MADF and ADF have been reported to be safe with no serious adverse effects.

TRF trials have only been conducted more recently; however, this is reported to be the most popular type of IF in clinical practice. Some studies have shown benefits while others have not. Because of the low number of quality randomized controlled trials, there is a lack of scientific evidence demonstrating a benefit of TRF over other IF protocols with the main advantage being energy reduction by limiting the feeding window.

Few studies have examined IF protocols in children and adolescents. An Australian pilot study on an intermittent energy restriction (IER) protocol for obese adolescents demonstrated that IER consisting of 3 days/week of energy restriction and 4 days of healthy eating for 26 weeks to be safe, feasible, and effective with a reduction in BMI and triglycerides as well as improvements in emotional eating, quality of life, and vascular function. Currently, there is a lack of evidence to recommend intermittent fasting for children and adolescents.

AUTOIMMUNE DIET

The Autoimmune Protocol Diet (AIP) or Autoimmune Paleo Diet is based on the general premise that certain foods cause inflammation in the body and increase gastrointestinal permeability, thus promoting autoimmune disorders in sensitive people. In this concept, avoidance of such foods allows the body to heal and restore the intestinal integrity thereby enabling improvement in attributable symptoms or avoiding the inflammatory process altogether. This diet typically involves at least two phases. Phase 1 is usually 3 weeks in duration and requires strict elimination of gluten, dairy, and sugar from the diet along with any foods to which an individual is known to be sensitive. Fresh or frozen, locally grown, and organic foods are encouraged. Gluten-free grains are allowed as well as organic soy and corn, grass-fed meats, free-range eggs, and wild-caught seafood. Processed meats are avoided but unlimited intake of vegetables is encouraged. Fruits are only limited if they exceed one's "personal threshold". If relief is not found in Phase 1, Phase 2 involves further restrictions including removal of soy, any other type of grain, corn, nightshade vegetables (e.g., potatoes, tomatoes, eggplant, bell peppers), and foods high in FODMAPs. See Chapter 16 for more information about FODMAPs. If symptoms are relieved after Phase 1 or by week 7, foods are added back one at a time while monitoring for tolerance.

This diet also restricts calcium, many B vitamins, and fiber with the degree of nutrition risk dependent on the duration of food group avoidance. Additionally, allowed foods are typically more expensive than eliminated foods. To date, the evidence to support this diet as a prophylactic measure to treat or reduce autoimmune disorders is scant, and, given the nutrition risk and restrictive nature of the diet, caution is advised (Table 27.2).

NUTRITION MANAGEMENT OF RESTRICTED DIETS

Nutrition management of children and adolescents following any type of restricted diet should identify the specific type of diet the child follows and determine which foods are eliminated and which

TABLE 27.2
Nutrients of Concern with Common Restricted Diets

Diet	Foods Restricted	Nutrients of Concern
Vegetarian or vegan diet	Animal products (see Table 27.1)	Energy, protein, vitamins B_{12} and D, zinc, iron, iodine, and omega-3 fatty acids
Gluten-free casein-free diet for autism spectrum disorder	Gluten (found in wheat, barley, and rye) and casein (found in products made from cow's milk)	Energy, protein, B vitamins including folate, iron, fiber, Vitamins A and D, calcium, and phosphorus
Paleolithic diet	Grains, beans and other legumes, dairy products, potatoes and other starchy vegetables, processed foods	Energy, protein (especially in younger children), B vitamins including folate, iron, fiber, vitamins A and D, calcium, and phosphorus
Ketogenic diet	Limits carbohydrates to 5%–10% of total energy and protein to 10%–20% of total energy	Energy, protein, B vitamins including folate, iron, fiber, vitamins A and D, calcium, and phosphorus
Intermittent Fasting	Limits eating to specific times (for example, 16 hours of fasting and 8 hours of eating)	Depends on foods eaten during allowed time periods
Autoimmune diet	Gluten, dairy, sugar	Energy, protein, B vitamins including folate, iron, fiber, vitamins A and D, calcium, and phosphorus

are regularly consumed. Children who follow a diet that fails to meet energy and nutrient needs are at risk for poor growth and development, vitamin and mineral deficiencies, and morbidities related to these deficiencies. Definition of specific nutrients missing in a child's diet will facilitate development of interventions to prevent deficiencies and ensure adequate growth and development.

Nutrition Assessment

A thorough nutrition assessment is essential in determining nutrient deficiencies (Chapter 3). Adequacy of intake of the following nutrients should be assessed in all children following a vegetarian or vegan diet: protein, iron, zinc, calcium, vitamin B_{12}, vitamin D, and omega-3 fatty acids. It is a common misconception that plant-based proteins (such as beans and legumes, soy products, whole grains, and nuts) are inferior to animal-based proteins, and evidence supports the fact that protein needs can be easily met with a vegetarian or vegan diet when energy intake is adequate. However, careful planning is required to ensure children on a vegan diet meet their requirements for protein and energy. For children following a vegan diet, there is a risk of vitamin B_{12} deficiency unless a vitamin-B_{12} supplement or food fortified with the vitamin is regularly included in the diet. Foods often fortified with vitamin B_{12} include some plant-based milk-alternative beverages, cereals, and meat substitutes. If dairy products and eggs are included in the diet, these can also serve as a good source of the vitamin. Vitamin D supplementation may be indicated for children following a vegetarian or vegan diet if sun exposure or intake of fortified foods is inadequate. For zinc and iron, plant-based sources of these nutrients can have lower bioavailability than animal-based sources, and the needs of vegetarian children are up to 80% higher than meat-eating children. Inhibitors of zinc and iron absorption can also increase risk for deficiency and include foods high in phytates, calcium supplements, soy foods, and polyphenols/tannins found in tea and coffee. Vegetarians who do not use iodized salt or sea vegetables may be at risk for inadequate iodine intake. Lastly, although vegetarian diets can include excellent sources of alpha-linolenic acid, they contain little or no eicosapentaenoic acid and docosahexaenoic acid (DHA) unless supplemented.

Diets which restrict gluten, grains, casein, or dairy in the diet should be evaluated for adequate intake of B vitamins including folate, iron, fiber, protein, vitamins A and D, calcium, and phosphorus. Assessment of additional nutrients might be needed depending food choices and health status. Based on the results of the food and nutrition-related history, certain biochemical tests might be indicated.

Biochemical data might include comprehensive metabolic panel, lipid profile panel, specific vitamin and mineral labs suspected to be deficient based on diet recall, and anemia status. It is also important to consider bioavailability of plant-based sources of these vitamins and minerals compared to animal sources; bioavailability of certain nutrients is lower than from animal product sources of the same nutrient (e.g., with plant-based iron vs. heme iron from meat).

Nutrition-focused physical findings include physical appearance such as sparse hair, muscle and fat wasting, swallow function, appetite, and gastrointestinal symptoms (e.g., nausea, vomiting, diarrhea, constipation, reflux) may reflect nutrition inadequacies.

Restricted diets in children can be directed by caregivers, peer influences, or internally driven by the child. Motivation or rationale for following a restricted diet should be evaluated, as well as whether the whole family or only the child follows a particular diet. Duration of diet adoption and whether the child ever eats restricted foods should also be assessed. Careful attention must be paid to potential signs of disordered eating (Chapter 22). It is important for the dietitian to assess how patients react if they do not follow their diet; feelings of guilt or shame indicate possible presence of an eating disorder. The level of attention given to implementation of the restricted diet might also lead to preoccupation or obsession. The caregiver's view of the child's diet should also be evaluated, especially in the cases when caregivers implement dietary restrictions without the recommendation of medical professionals due to their belief that a diet may eliminate undesired symptoms, such as the GFCF diet by some families of children with autism.

Nutrition Diagnosis

Common nutrition diagnoses for patients following restricted diets include those related to energy intake, micro- and macronutrient deficiencies and behavioral-environmental (e.g., knowledge, attitudes, beliefs, food safety, or access to food). Additionally, misconceptions about healthy eating patterns are common; food- and nutrition-related deficits, disordered eating, and less than desirable food choices might be diagnosed. Potential nutrition diagnoses include:

- Inadequate energy intake
- Inadequate vitamin intake (specify)
- Inadequate mineral intake (specify)
- Food- and nutrition-related knowledge deficit
- Undesirable food choices

Nutrition Intervention

The nutrition prescription for patients following restricted diets is similar to that of their healthy peers. Energy, protein, and fluid needs can be calculated using standard equations (Chapter 3). Specific micronutrient needs may be increased if deficiencies are noted during the nutrition assessment (Chapter 2).

Nutrition intervention is individualized to the child based on the nutrition diagnosis or risk of inadequacy based on dietary intake assessment to resolve or minimize problems or address specific signs and/or symptoms. The nutrition interventions might include changes to food and/or nutrient delivery, nutrition education, nutrition counseling, and/or coordination of nutrition care to improve nutrition-related problems and optimize growth.

Interventions of food and nutrient delivery might include a change in the composition of meals and snacks, supplementation with specific vitamins and minerals, and/or alteration of nutrition-related medications. Nutrition education includes formal training of the child and family to improve

knowledge and skills to manage food, nutrition, and physical activity choices to optimize the child's health. Nutrition counseling such as goal setting, self-monitoring, stimulus control, problem solving, contingency management, cognitive restructuring, use of incentives and rewards, and social supports are often warranted to address the nutrition diagnosis for patients following a restricted diet. Coordination of care with referrals to other healthcare providers and/or institutions might be needed to assist with management of the nutrition-related problems. Vitamin and mineral supplements are indicated when dietary intake of specific vitamins or minerals is inadequate and nutrition education has not been effective to improve dietary intake.

Nutrition Monitoring and Evaluation

Nutrition monitoring and evaluation include the monitoring of specific indicators, evaluation of goal achievement, implementation of a nutrition prescription, and the status of the patient's nutrition diagnoses and whether they are resolved, improved, unchanged, or worsened. General goals for pediatric patients following restricted diets aim to ensure appropriate growth velocity, correction of nutrient deficiencies, and increase confidence in self-management of one's lifestyle choices. Specific indicators include food intake related to meal/snack patterns; amount of food consumed; anthropometric data such as body composition, BMI, and growth pattern indices; and biochemical data including lipid profile panel, vitamin and mineral status, and anemia status. Gastrointestinal symptoms and nutrition-focused physical exam as well as food and nutrition knowledge/skills are an additional focus of the evaluation. Additional indicators relate to food and nutrition skills to target adherence/self-management as well as avoidance behavior, restricted eating patterns, and mealtime behavior such as willingness to try previously restricted foods. In some instances, caregiver goals may need to be considered when working to meet the nutrition needs of the child specifically in

TABLE 27.3
Summary of ADIME for Restricted Diets

- Assessment
  - Growth assessment
  - Nutrition-focused physical exam
    - Look for signs of deficiency of specific nutrients of concern based on diet assessment
  - Nutrient intake
    - Determine foods excluded from diet and substitutions utilized
    - Understand potential nutrient deficiencies with common restricted diets (see Table 27.2)
    - Understand reasons for following restricted diet
  - Labs
    - Specific micronutrient labs based on diet assessment
  - Gastrointestinal findings
  - Medications/side effects
- Diagnosis
- Intervention
  - Nutrition prescription
  - Common nutrition interventions
    - Oral
      - Recommend foods and beverages to meet deficient nutrients within the limits of the restricted diet, when able
    - Education
    - Laboratory monitoring
    - Supplements
      - Supplement for deficiencies identified in nutrition assessment
      - Other specialty referrals
- Monitoring and evaluation

relation to children with autism since caregivers' perceptions of the efficacy of the diet may be biased (Table 27.3).

This chapter reviews some of the more common self-selected restricted diets that children and adolescents might follow. Because of the vital role nutrition status plays to optimize growth during a critical life phase, a thorough nutrition assessment is paramount for optimization of patient care and nutrition status. Nutrition assessment should identify growth parameters including weight status, micro- and macronutrient intake and potential deficiencies, and biochemical labs, in addition to assessing food-related behaviors and motivation to address any disordered eating and correct nutrition-related deficiencies. The nutrition assessment guides the nutrition diagnoses which will direct the nutrition intervention. Monitoring and evaluation should be an ongoing process with continued nutrition reassessment as part of the nutrition care process performed by the dietitian to optimize the child's long-term health and well-being.

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Appendix A
Standard Growth Charts

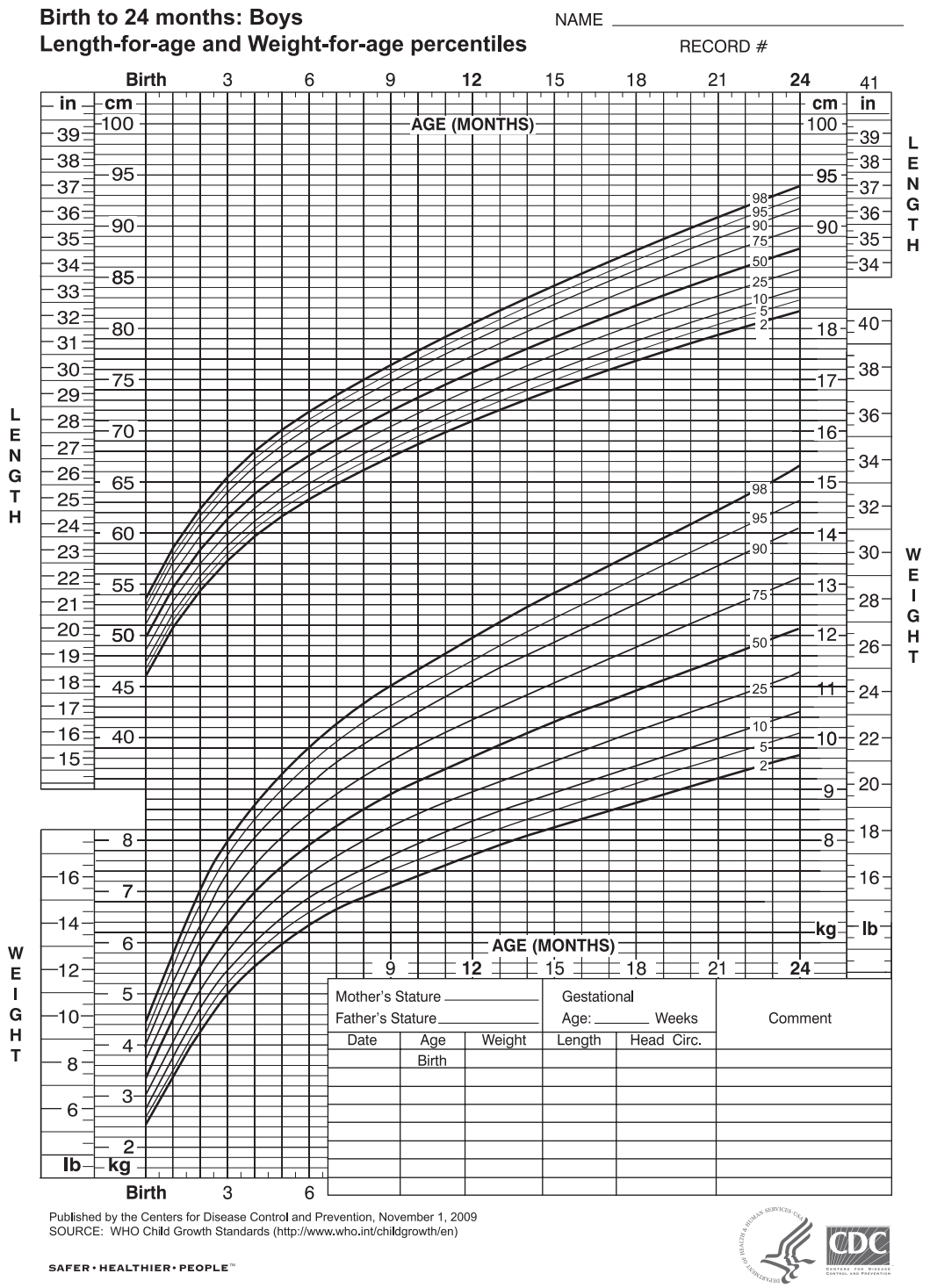


FIGURE A.1 Boys WHO 0–24 months Length-for-age and Weight-for-age. (CDC. Reference to specific commercial products, manufacturers, companies, or trademarks does not constitute its endorsement or recommendation by the U.S. Government, Department of Health and Human Services, or Centers for Disease Control and Prevention. Available at www.cdc.gov free of charge.)

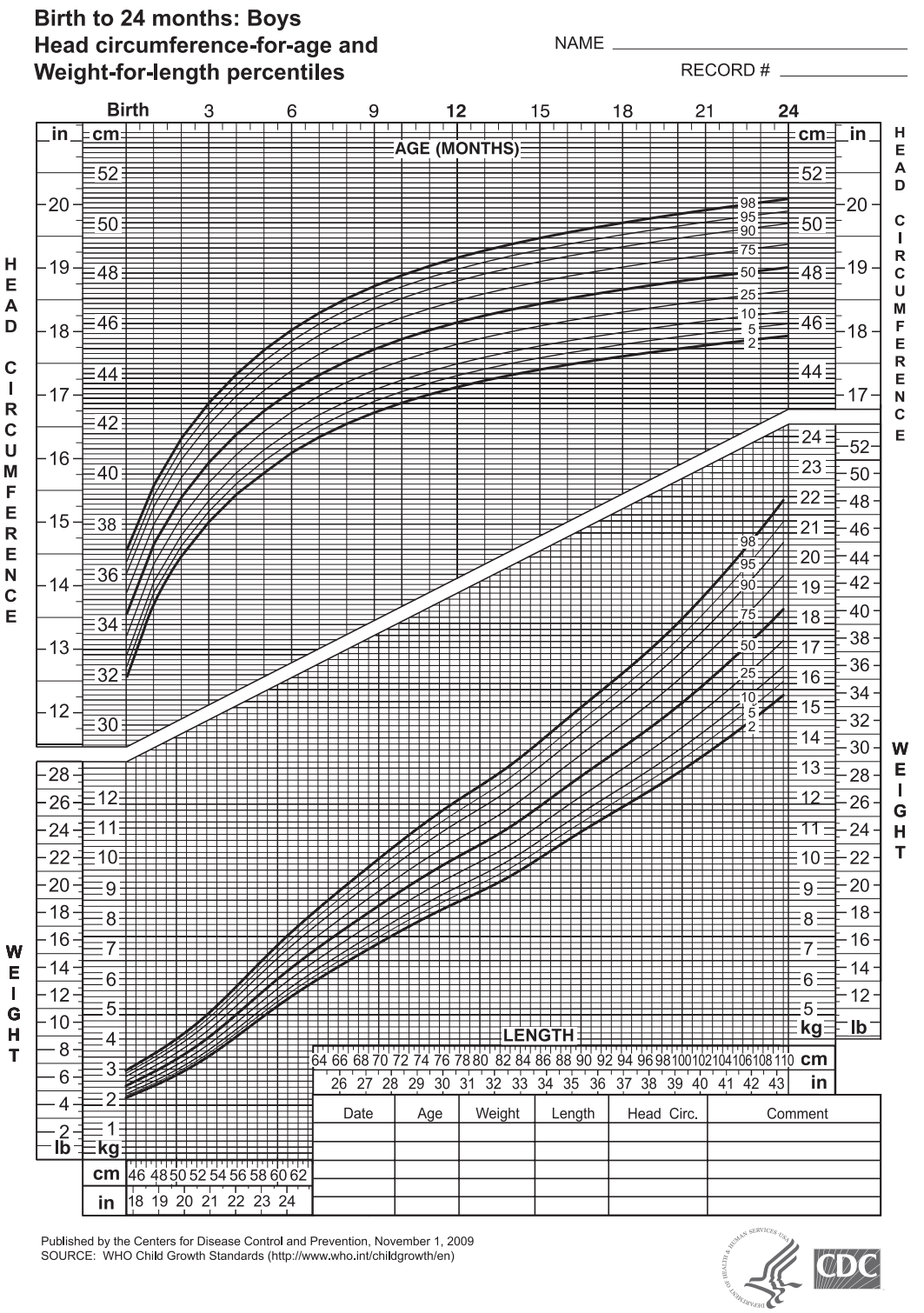


FIGURE A.2 Boys WHO 0–24 months Head Circumference-for-age and Weight-for-length. (CDC. Reference to specific commercial products, manufacturers, companies, or trademarks does not constitute its endorsement or recommendation by the U.S. Government, Department of Health and Human Services, or Centers for Disease Control and Prevention. Available at www.cdc.gov free of charge.)

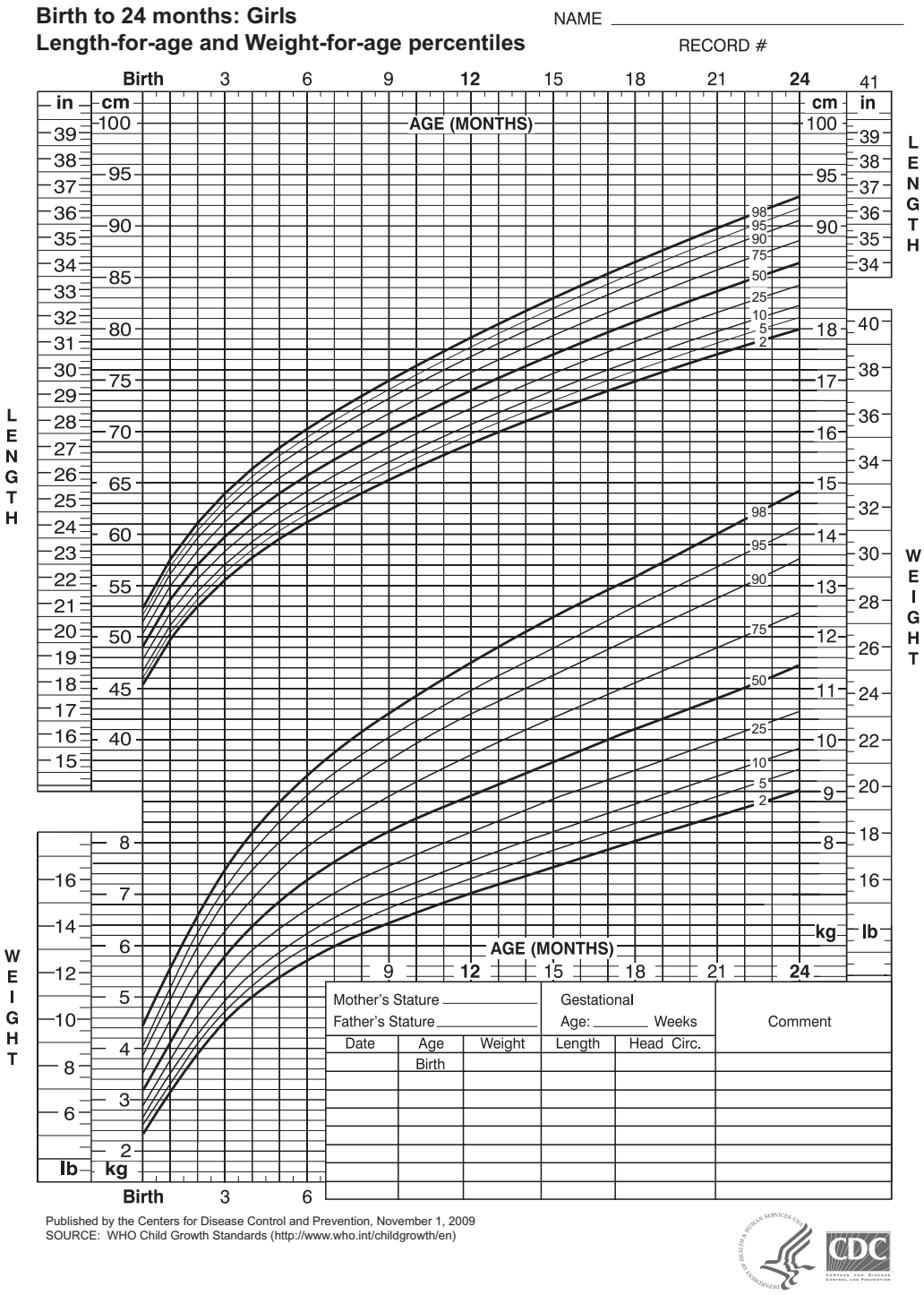


FIGURE A.3 Girls WHO 0–24 months Length-for-age and Weight-for-age. (CDC. Reference to specific commercial products, manufacturers, companies, or trademarks does not constitute its endorsement or recommendation by the U.S. Government, Department of Health and Human Services, or Centers for Disease Control and Prevention. Available at www.cdc.gov free of charge.)

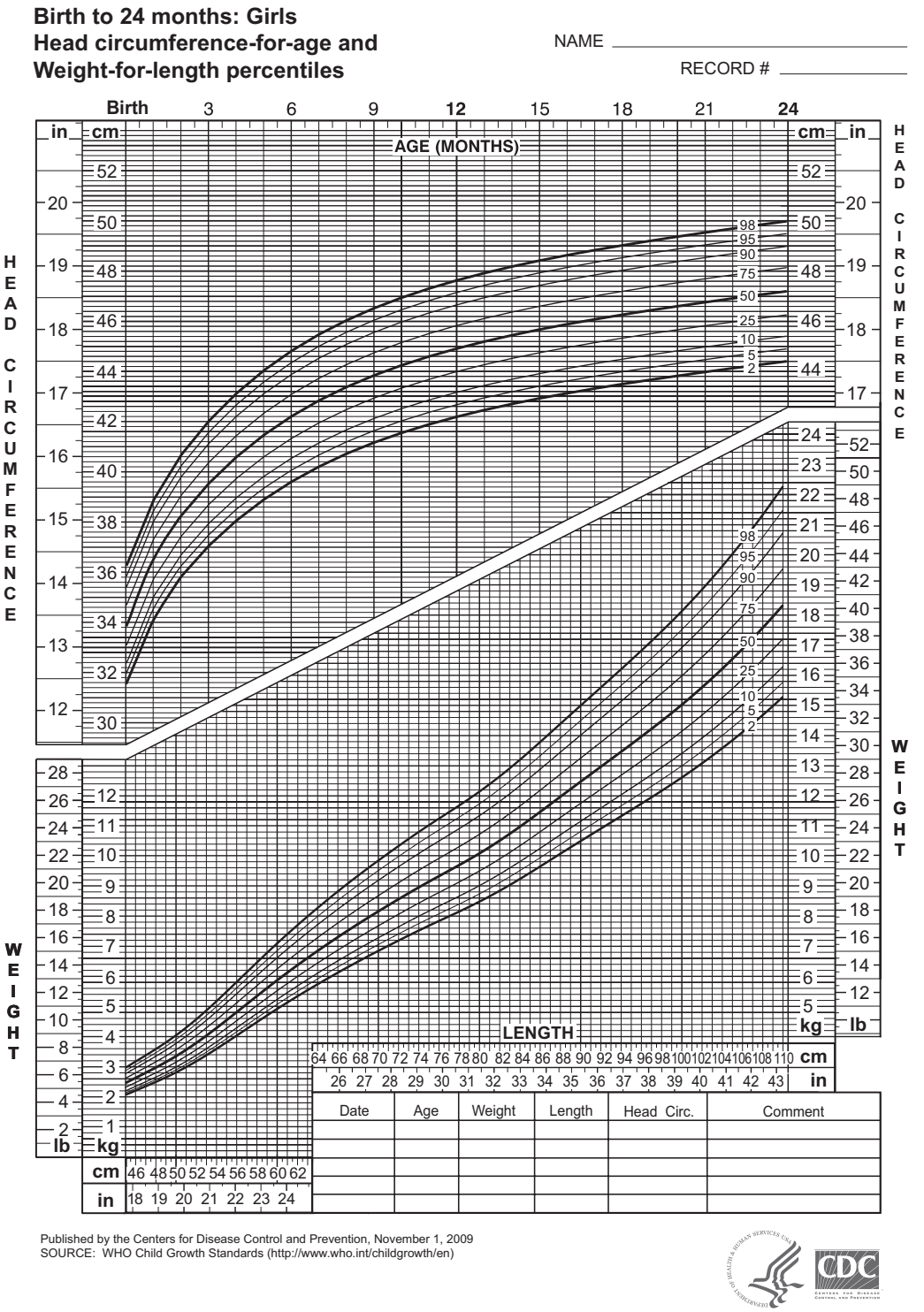


FIGURE A.4 Girls WHO 0–24 months Head Circumference-for-age and Weight-for-length. (CDC. Reference to specific commercial products, manufacturers, companies, or trademarks does not constitute its endorsement or recommendation by the U.S. Government, Department of Health and Human Services, or Centers for Disease Control and Prevention. Available at www.cdc.gov free of charge.)

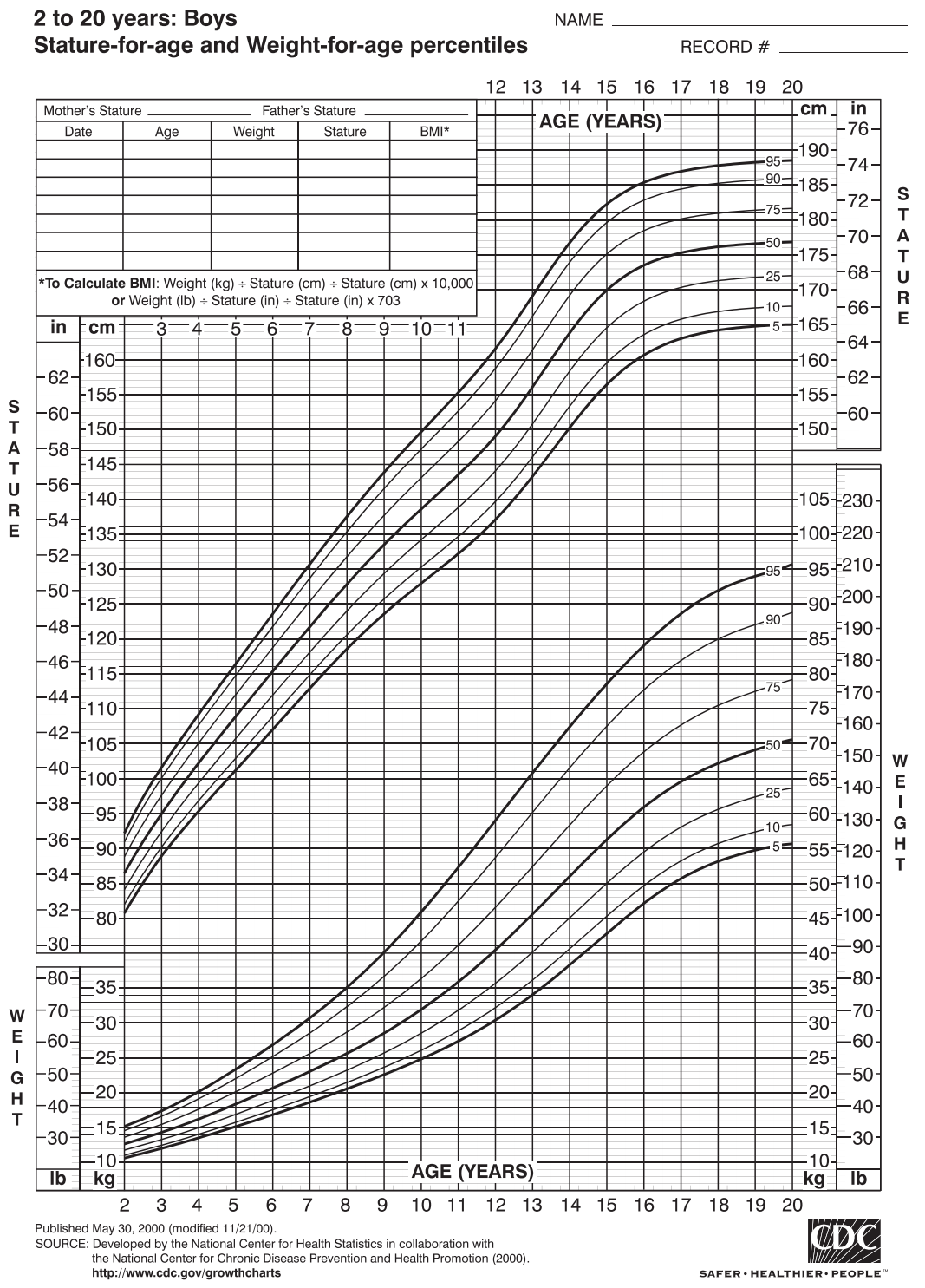


FIGURE A.5 Boys CDC 2–20 years Height-for-age and Weight-for-age. (CDC. Reference to specific commercial products, manufacturers, companies, or trademarks does not constitute its endorsement or recommendation by the U.S. Government, Department of Health and Human Services, or Centers for Disease Control and Prevention. Available at www.cdc.gov free of charge.)

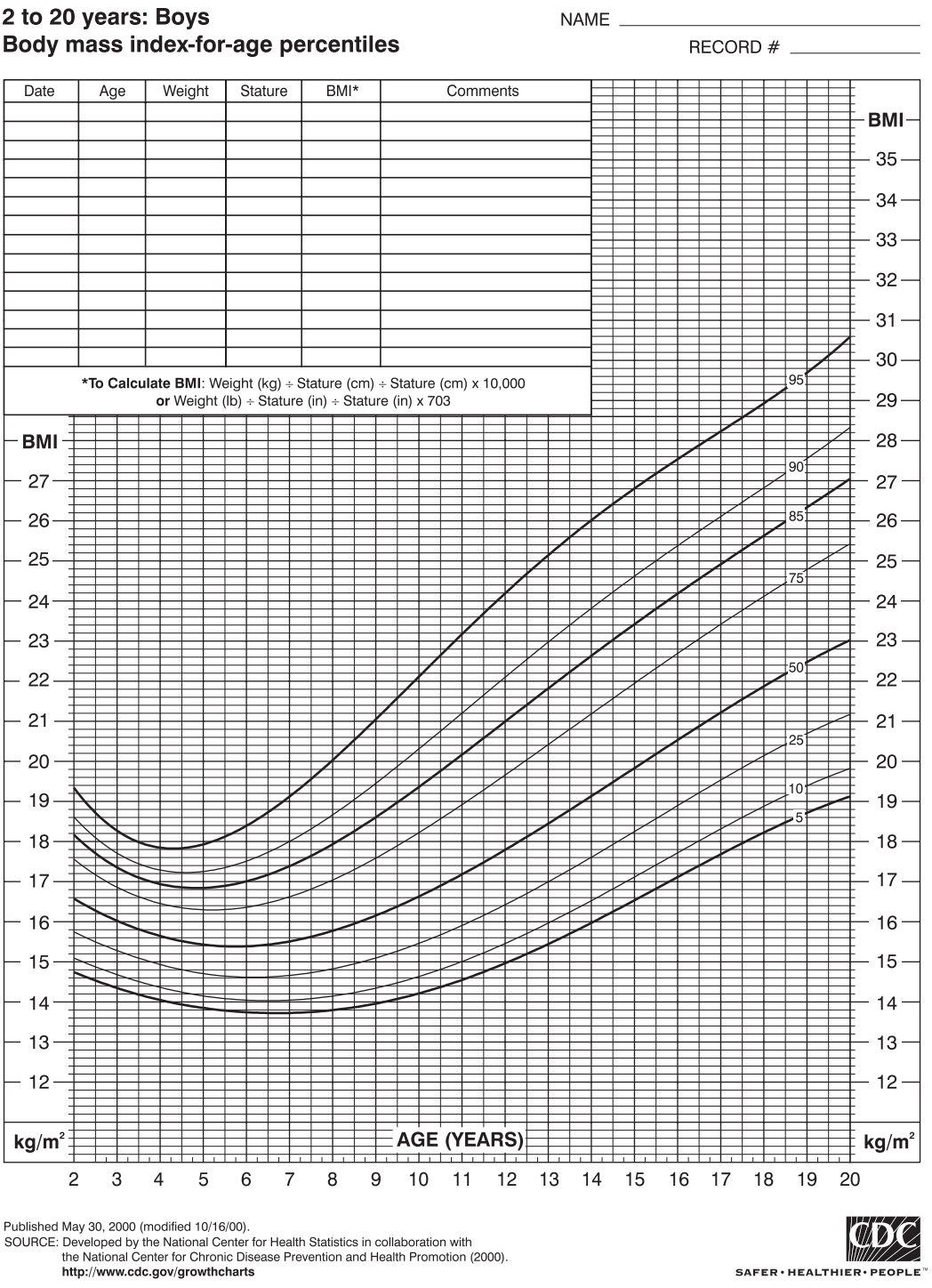


FIGURE A.6 Boys CDC 2–20 years BMI-for-age. (CDC. Reference to specific commercial products, manufacturers, companies, or trademarks does not constitute its endorsement or recommendation by the U.S. Government, Department of Health and Human Services, or Centers for Disease Control and Prevention. Available at www.cdc.gov free of charge.)

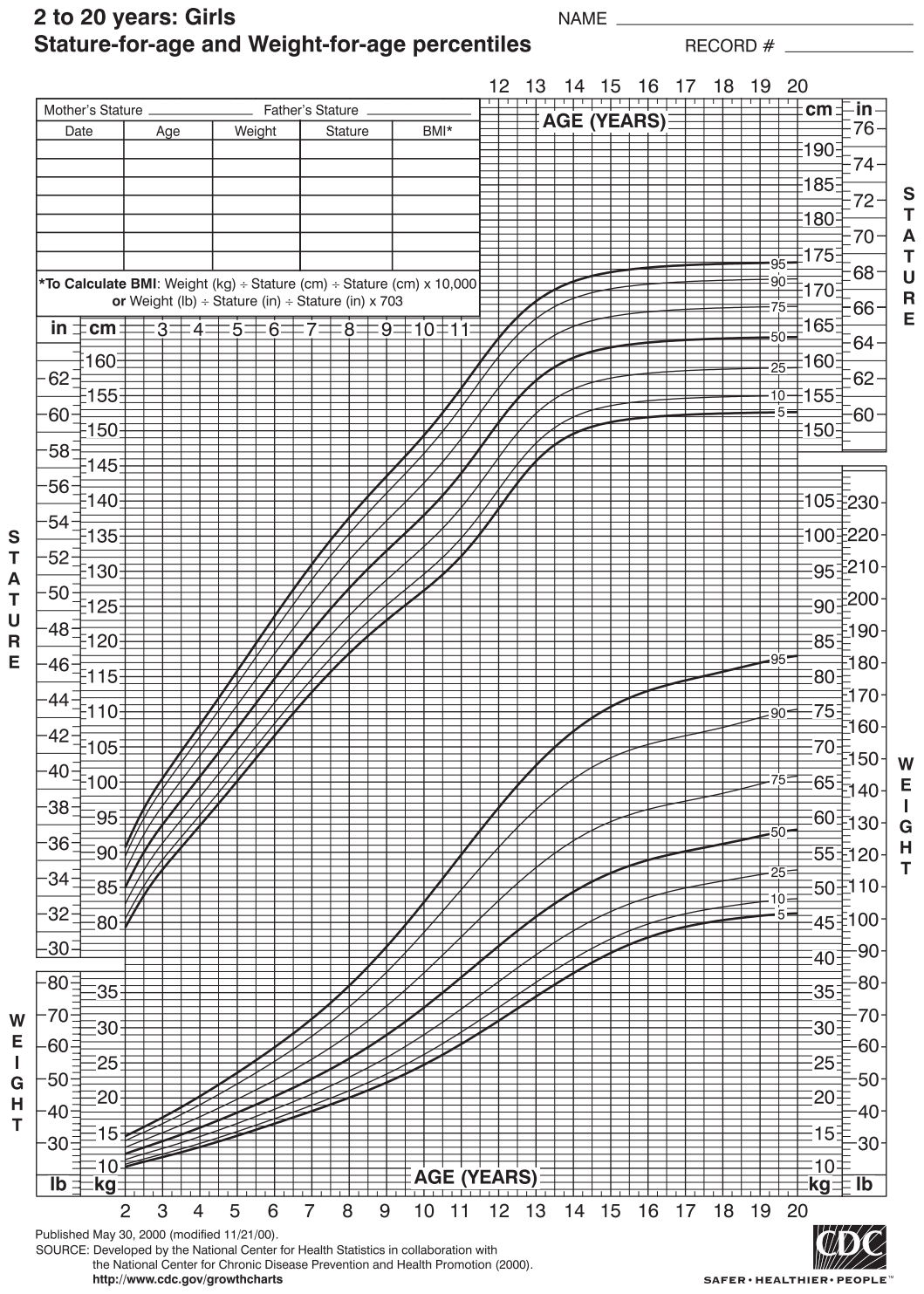


FIGURE A.7 Girls CDC 2–20 years Height-for-age and Weight-for-age. (CDC. Reference to specific commercial products, manufacturers, companies, or trademarks does not constitute its endorsement or recommendation by the U.S. Government, Department of Health and Human Services, or Centers for Disease Control and Prevention. Available at www.cdc.gov free of charge.)

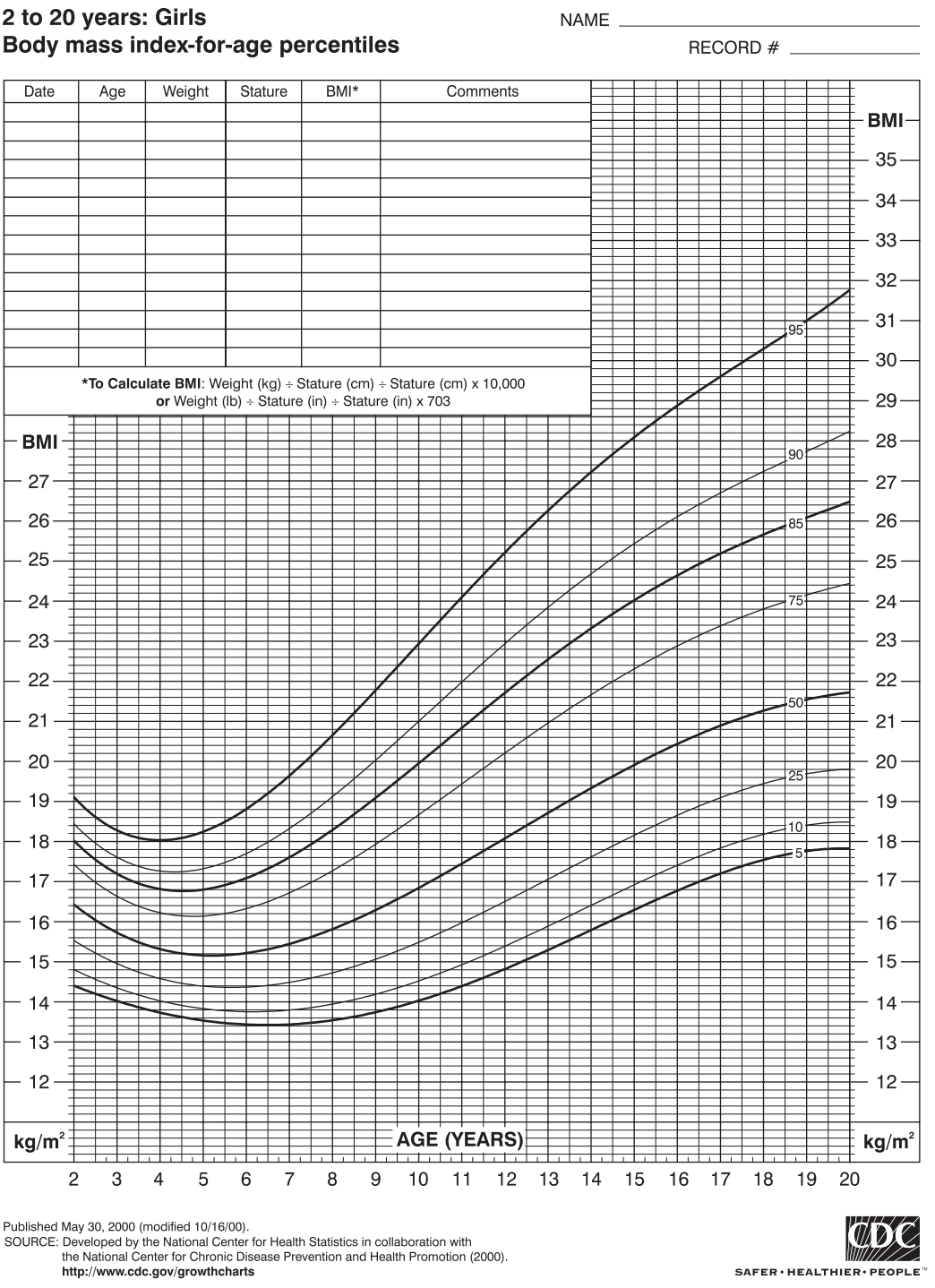
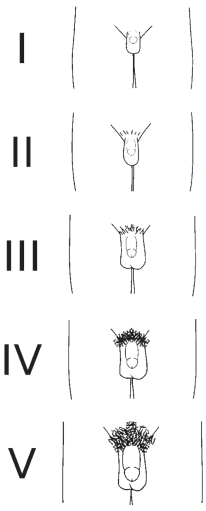


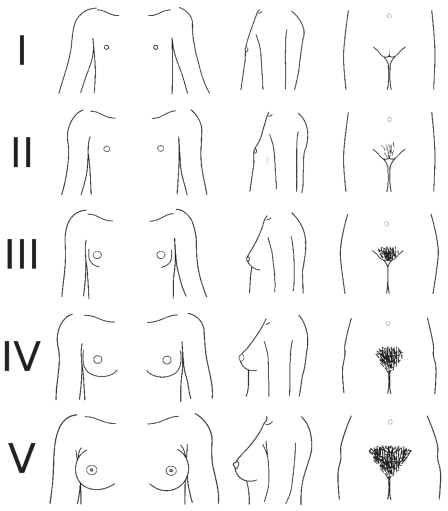
FIGURE A.8 Girls CDC 2–20 years BMI-for-age. (CDC. Reference to specific commercial products, manufacturers, companies, or trademarks does not constitute its endorsement or recommendation by the U.S. Government, Department of Health and Human Services, or Centers for Disease Control and Prevention. Available at www.cdc.gov free of charge.)

Appendix B
Tanner Staging



Pubic hair
Villus hair only
Sparse hair at the base of the penis
Thicker curly hair spreads to the pubis
Adult hair, does not spread to the inner thigh
Adult hair, spreads to the inner thigh

FIGURE B.1 Tanner Staging for males.



Breasts	Pubic hair
Elevation of papilla only	Villus hair only
Breast bud under the areola, areola enlargement	Sparse hair along the labia
Breast tissue grows but has no contour or separation	Coarser, curled, pigmented hair covers the pubis
Projection of areola and papilla, secondary mound formation	Adult hair, does not spread to the inner thigh
Adult-type contour, projection of papilla only	Adult hair, spreads to the inner thigh

FIGURE B.2 Tanner Staging for females.

Appendix C

Reference Data for Mid-Upper Arm Circumference (MUAC)

Males

Age (years)	L	M	S	Percentile 3rd	5th	10th	25th	50th (M)	75th	90th	95th	97th
1	−1.2654	15.8280	0.0607	13.9	14.2	14.6	15.2	15.8	16.5	17.3	17.9	18.4
1.5	−1.3434	16.0192	0.0629	14.1	14.3	14.7	15.3	16.0	16.8	17.6	18.2	18.7
2	−1.4215	16.2009	0.0651	14.2	14.5	14.9	15.5	16.2	17.0	17.9	18.5	19.0
2.5	−1.4995	16.3874	0.0674	14.4	14.6	15.0	15.7	16.4	17.2	18.1	18.8	19.3
3	−1.5768	16.6307	0.0698	14.5	14.8	15.2	15.9	16.6	17.5	18.5	19.2	19.8
3.5	−1.6520	16.8484	0.0725	14.7	14.9	15.4	16.0	16.8	17.8	18.8	19.6	20.2
4	−1.7238	17.0559	0.0753	14.8	15.1	15.5	16.2	17.1	18.0	19.1	19.9	20.6
4.5	−1.7903	17.2840	0.0784	14.9	15.2	15.7	16.4	17.3	18.3	19.5	20.4	21.0
5	−1.8471	17.4935	0.0818	15.1	15.4	15.8	16.6	17.5	18.6	19.8	20.8	21.5
5.5	−1.8902	17.6332	0.0854	15.1	15.4	15.9	16.7	17.6	18.8	20.1	21.1	21.9
6	−1.9179	17.6970	0.0892	15.1	15.4	15.9	16.7	17.7	18.9	20.3	21.4	22.3
6.5	−1.9299	17.8186	0.0932	15.1	15.4	15.9	16.8	17.8	19.1	20.6	21.8	22.7
7	−1.9266	18.0982	0.0973	15.3	15.6	16.1	17.0	18.1	19.5	21.1	22.3	23.3
7.5	−1.9084	18.4329	0.1016	15.5	15.8	16.3	17.3	18.4	19.9	21.6	23.0	24.1
8	−1.8760	18.8217	0.1059	15.7	16.0	16.6	17.6	18.8	20.4	22.2	23.7	24.9
8.5	−1.8302	19.1974	0.1101	15.9	16.3	16.8	17.9	19.2	20.8	22.8	24.4	25.7
9	−1.7726	19.5870	0.1142	16.1	16.5	17.1	18.2	19.6	21.3	23.4	25.1	26.5
9.5	−1.7050	20.0161	0.1180	16.3	16.7	17.4	18.5	20.0	21.9	24.1	25.9	27.3
10	−1.6288	20.4760	0.1214	16.6	17.0	17.7	18.9	20.5	22.4	24.8	26.6	28.2
10.5	−1.5454	20.8942	0.1243	16.9	17.3	18.0	19.3	20.9	22.9	25.4	27.3	28.9
11	−1.4566	21.3583	0.1265	17.1	17.6	18.3	19.7	21.4	23.5	26.0	28.0	29.5
11.5	−1.3646	21.8569	0.1280	17.5	18.0	18.7	20.1	21.9	24.0	26.6	28.6	30.2
12	−1.2720	22.4245	0.1288	17.9	18.4	19.2	20.6	22.4	24.6	27.3	29.3	30.9
12.5	−1.1821	23.0236	0.1289	18.3	18.8	19.7	21.2	23.0	25.3	27.9	30.0	31.5
13	−1.0993	23.6916	0.1282	18.8	19.4	20.2	21.8	23.7	26.0	28.7	30.7	32.2
13.5	−1.0268	24.4146	0.1269	19.4	20.0	20.9	22.4	24.4	26.8	29.4	31.4	32.9
14	−0.9653	25.1483	0.1252	20.1	20.6	21.5	23.1	25.1	27.5	30.2	32.1	33.6
14.5	−0.9160	25.8222	0.1231	20.6	21.2	22.2	23.8	25.8	28.2	30.9	32.8	34.2
15	−0.8819	26.4633	0.1209	21.2	21.8	22.8	24.4	26.5	28.9	31.5	33.4	34.8
15.5	−0.8635	27.0597	0.1185	21.8	22.4	23.3	25.0	27.1	29.4	32.1	33.9	35.3
16	−0.8579	27.5911	0.1162	22.3	22.9	23.9	25.5	27.6	30.0	32.6	34.4	35.8
16.5	−0.8609	28.0378	0.1141	22.8	23.4	24.3	26.0	28.0	30.4	33.0	34.8	36.1
17	−0.8677	28.4863	0.1121	23.2	23.8	24.8	26.4	28.5	30.8	33.4	35.2	36.5
17.5	−0.8727	28.9794	0.1103	23.7	24.3	25.3	26.9	29.0	31.3	33.9	35.7	37.0
18	−0.8710	29.4727	0.1086	24.2	24.8	25.7	27.4	29.5	31.8	34.4	36.2	37.5
18.5	−0.8587	29.8809	0.1071	24.6	25.2	26.1	27.8	29.9	32.2	34.8	36.5	37.8
19	−0.8343	30.1808	0.1057	24.9	25.5	26.4	28.1	30.2	32.5	35.0	36.8	38.1
19.5	−0.7970	30.3865	0.1044	25.1	25.7	26.6	28.3	30.4	32.7	35.2	36.9	38.2
20	−0.7477	30.5285	0.1033	25.2	25.8	26.8	28.5	30.5	32.8	35.3	37.0	38.2

Source: Addo OY, Himes JH, and Zemel BS. Reference ranges for midupper arm circumference, upper arm muscle area, and upper arm fat area in US children and adolescents aged 1–20 y. *Am J Clin Nutr*. 2017;105:111–120, with permission of Oxford University Press.

Semiparametric GAMLSS models with polynomial age splines were used to calculate all estimates. S denotes the generalized CV, L denotes the BoxCox power transformation of the objective function for each growth curve, and M denotes the median. z-scores can be calculated with the use of the LMS coefficients that are specific to the nearest completed month or one-half year of age for a child or adolescent for each measured MUAC with the following expression z-score = [(MUAC (cm) O M) L − 1] O S 3 L. This table, with estimates for every 6 months of age, shows the entire listing of LMS parameters and all percentiles (third through 97th) for males.

Females

				Percentile								
Age (years)	**L**	**M**	**S**	**3rd**	**5th**	**10th**	**25th**	**50th (M)**	**75th**	**90th**	**95th**	**97th**
1	−0.6662	15.4888	0.0618	13.5	13.8	14.2	14.8	15.5	16.2	17.0	17.6	18.1
1.5	−0.7745	15.7878	0.0643	13.7	14.0	14.4	15.1	15.8	16.6	17.4	18.0	18.5
2	−0.8818	16.0462	0.0669	13.9	14.2	14.6	15.3	16.0	16.9	17.7	18.4	18.9
2.5	−0.9872	16.2550	0.0696	14.0	14.3	14.8	15.5	16.3	17.1	18.0	18.8	19.3
3	−1.0889	16.4756	0.0725	14.2	14.5	14.9	15.7	16.5	17.4	18.4	19.1	19.7
3.5	−1.1849	16.7231	0.0755	14.3	14.7	15.1	15.9	16.7	17.7	18.7	19.5	20.2
4	−1.2719	16.9880	0.0789	14.5	14.8	15.3	16.1	17.0	18.0	19.1	20.0	20.7
4.5	−1.3465	17.2485	0.0825	14.7	15.0	15.5	16.3	17.2	18.3	19.5	20.5	21.2
5	−1.4039	17.4733	0.0863	14.8	15.1	15.6	16.5	17.5	18.6	19.9	20.9	21.7
5.5	−1.4409	17.6657	0.0905	14.9	15.2	15.7	16.6	17.7	18.9	20.3	21.4	22.2
6	−1.4566	17.7761	0.0949	14.9	15.2	15.8	16.7	17.8	19.1	20.6	21.7	22.7
6.5	−1.4522	17.8944	0.0995	14.9	15.2	15.8	16.7	17.9	19.3	20.9	22.1	23.1
7	−1.4308	18.1418	0.1042	14.9	15.3	15.9	16.9	18.1	19.6	21.3	22.7	23.7
7.5	−1.3962	18.4720	0.1089	15.1	15.5	16.1	17.2	18.5	20.0	21.9	23.3	24.4
8	−1.3518	18.9023	0.1136	15.3	15.8	16.4	17.5	18.9	20.6	22.5	24.1	25.3
8.5	−1.3013	19.3871	0.1180	15.6	16.1	16.7	17.9	19.4	21.2	23.2	24.9	26.2
9	−1.2481	19.8822	0.1221	15.9	16.4	17.1	18.3	19.9	21.8	24.0	25.7	27.1
9.5	−1.1956	20.2857	0.1257	16.1	16.6	17.4	18.7	20.3	22.3	24.6	26.4	27.8
10	−1.1488	20.6871	0.1288	16.4	16.9	17.6	19.0	20.7	22.7	25.1	27.0	28.5
10.5	−1.1121	21.1251	0.1311	16.7	17.2	18.0	19.4	21.1	23.3	25.7	27.6	29.1
11	−1.0885	21.6429	0.1328	17.1	17.6	18.4	19.8	21.6	23.8	26.4	28.4	29.9
11.5	−1.0791	22.2130	0.1337	17.5	18.0	18.9	20.3	22.2	24.5	27.1	29.1	30.7
12	−1.0850	22.8495	0.1339	18.0	18.5	19.4	20.9	22.8	25.2	27.9	29.9	31.5
12.5	−1.1054	23.4701	0.1334	18.5	19.1	19.9	21.5	23.5	25.9	28.6	30.7	32.3
13	−1.1371	24.0074	0.1325	19.0	19.6	20.4	22.0	24.0	26.4	29.2	31.4	33.0
13.5	−1.1767	24.4522	0.1311	19.4	20.0	20.9	22.4	24.5	26.9	29.7	31.9	33.5
14	−1.2223	24.8291	0.1295	19.8	20.4	21.2	22.8	24.8	27.3	30.1	32.3	33.9
14.5	−1.2719	25.1492	0.1278	20.2	20.7	21.6	23.1	25.1	27.6	30.4	32.6	34.3
15	−1.3228	25.4407	0.1260	20.5	21.0	21.9	23.4	25.4	27.9	30.7	32.9	34.6
15.5	−1.3721	25.7045	0.1244	20.8	21.3	22.1	23.7	25.7	28.2	31.0	33.2	34.8
16	−1.4169	25.9214	0.1229	21.0	21.5	22.4	23.9	25.9	28.4	31.2	33.4	35.1
16.5	−1.4551	26.0662	0.1217	21.2	21.7	22.5	24.1	26.1	28.5	31.3	33.5	35.2
17	−1.4852	26.1730	0.1206	21.3	21.8	22.7	24.2	26.2	28.6	31.4	33.6	35.4
17.5	−1.5066	26.2504	0.1198	21.4	21.9	22.7	24.3	26.3	28.7	31.5	33.7	35.5
18	−1.5209	26.3489	0.1191	21.4	22.0	22.8	24.4	26.3	28.8	31.6	33.9	35.6
18.5	−1.5289	26.4942	0.1187	21.6	22.1	23.0	24.5	26.5	28.9	31.8	34.1	35.9
19	−1.5311	26.6642	0.1185	21.7	22.2	23.1	24.7	26.7	29.1	32.0	34.3	36.2
19.5	−1.5276	26.8144	0.1185	21.8	22.3	23.2	24.8	26.8	29.3	32.2	34.6	36.5
20	−1.5203	26.9355	0.1187	21.8	22.4	23.3	24.9	26.9	29.4	32.4	34.8	36.7

Source: Addo OY, Himes JH, and Zemel BS. Reference ranges for midupper arm circumference, upper arm muscle area, and upper arm fat area in US children and adolescents aged 1–20 y. *Am J Clin Nutr*. 2017;105:111–120, with permission of Oxford University Press.

Semiparametric GAMLSS models with polynomial age splines were used to calculate all estimates. S denotes the generalized CV, L denotes the BoxCox power transformation of the objective function for each growth curve, and M denotes the median. z-scores can be calculated with the use of the LMS coefficients that are specific to the nearest completed month or one-half year of age for a child or adolescent for each measured MUAC with the following expression z-score = [(MUAC (cm) O M) L − 1] O S 3 L. This table, with estimates for every 6 months of age, shows the entire listing of LMS parameters and all percentiles (third through 97th) for females.

Appendix D
Common Nutrition Diagnoses Utilized for Pediatric Patients

Intake

Energy Balance
- Increased energy expenditure
- Inadequate energy intake
- Excessive energy intake
- Predicted inadequate energy intake
- Predicted excessive energy intake

Oral or Nutrition Support Intake
- Inadequate oral intake
- Excessive oral intake
- Inadequate enteral nutrition infusion
- Excessive enteral nutrition infusion
- Enteral nutrition composition inconsistent with needs
- Enteral nutrition administration inconsistent with needs
- Inadequate parenteral nutrition infusion
- Excessive parenteral nutrition infusion
- Parenteral nutrition composition inconsistent with needs
- Parenteral nutrition administration inconsistent with needs
- Limited food acceptance

Fluid Intake
- Inadequate fluid intake
- Excessive fluid intake

Nutrient
- Increased nutrient needs (specify)
- Inadequate protein energy intake
- Decreased nutrient needs (specify)
- Imbalance of nutrients

Fat and Cholesterol
- Inadequate fat intake
- Excessive fat intake
- Intake of types of fats inconsistent with needs (specify)

Protein
- Inadequate protein intake
- Excessive protein intake
- Intake of types of proteins inconsistent with needs (specify)

Amino Acids
- Intake of types of amino acids inconsistent with needs (specify)

(*Continued*)

Carbohydrate and Fiber
- Inadequate carbohydrate intake
- Excessive carbohydrate intake
- Intake of types of carbohydrate inconsistent with needs (specify)
- Inconsistent carbohydrate intake
- Inadequate fiber intake
- Excessive fiber intake

Vitamin
- Inadequate vitamin intake (specify)
- Excessive vitamin intake (specify)

Mineral
- Inadequate mineral intake (specify)
- Excessive mineral intake (specify)

Multinutrient
- Predicted inadequate nutrient intake (specify)
- Predicted excessive nutrient intake (specify)

Clinical

Functional
- Swallowing difficulty
- Biting/Chewing (masticatory) difficulty
- Breastfeeding difficulty
- Altered GI function
- Predicted breastfeeding difficulty

Biochemical
- Impaired nutrient utilization
- Altered nutrition related laboratory values (specify)
- Food medication interaction (specify)
- Predicted food medication interaction (specify)

Weight
- Underweight
- Unintended weight loss
- Overweight/obesity
  - Overweight, adult or pediatric
  - Obese, pediatric
- Unintended weight gain
- Growth rate below expected
- Excessive growth rate

Malnutrition Disorders
- Non illness related pediatric malnutrition
  - Mild non illness related pediatric malnutrition
  - Moderate non illness related pediatric malnutrition
  - Severe non illness related pediatric malnutrition
- Illness related pediatric malnutrition
  - Mild illness related pediatric malnutrition
  - Moderate illness related pediatric malnutrition
  - Severe illness related pediatric malnutrition

(*Continued*)

Behavioral-Environmental

Knowledge and Beliefs

- Food and nutrition related knowledge deficit
- Not ready for diet/lifestyle change
- Limited adherence to nutrition related recommendations
- Undesirable food choices

Physical Activity and Function

- Physical inactivity
- Excessive physical activity

Food Safety and Access

- Intake of unsafe food
- Limited access to food
- Limited access to nutrition related supplies
- Limited access to potable water

Other

- No nutrition diagnosis at this time

Source: Adapted from Nutrition Diagnostic Terminology. *Nutrition Care Process Terminology (eNCPT)*, 2020 Edition.

Appendix E

Dietary Reference Intakes (DRIs) for Infants, Children, Pregnancy, and Lactation

Recommended Dietary Allowances and Adequate Intakes: Vitamins and Minerals

Age	Vitamin A (mcg/day)[a]	Vitamin C (mg/day)	Vitamin D (mcg/day)[b]	Vitamin E (mg/day)[c]	Vitamin K (mcg/day)	Thiamin (mg/day)	Riboflavin (mg/day)	Niacin (mg/day)[d]	Vitamin B_6 (mg/day)	Folate (mcg/day)[e]
0–6 months	400[f]	40[f]	10	4[f]	2.0[f]	0.2[f]	0.3[f]	2[f]	0.1[f]	65[f]
6–12 months	500[f]	50[f]	10	5[f]	2.5[f]	0.3[f]	0.4[f]	4[f]	0.3[f]	80[f]
1–3 years	300	15	15	6	30[f]	0.5	0.5	6	0.5	150
4–8 years	400	25	15	7	55[f]	0.6	0.6	8	0.6	200
9–13 years	600	45	15	11	60[f]	0.9	0.9	12	1.0	300
14–18 years	male: 900, female: 700	male: 75, female: 65	15	15	75[f]	male: 1.2, female: 1.0	male: 1.3, female: 1.0	male: 16, female: 14	male: 1.3, female: 1.2	400
Pregnancy										
14–18 years	750	80	15	15	75[f]	1.4	1.4	18	1.9	600
19–50 years	770	85	15	15	90[f]	1.4	1.4	18	1.9	600
Lactation										
14–18 years	1,200	115	15	19	75[f]	1.4	1.6	17	2.0	500
19–50 years	1,300	120	15	19	90[f]	1.4	1.6	17	2.0	500

Source: Adapted from Dietary Reference Intakes (DRIs): Recommended Dietary Allowances and Adequate Intakes, Vitamins. Food and Nutrition Board, Institute of Medicine, National Academies, 2011.

[a] As retinol activity equivalents (RAEs).

[b] As cholecalciferol, under the assumption of minimal sunlight.

[c] As alpha-tocopherol.

[d] As niacin equivalents (NE).

[e] As dietary folate equivalents (DFE).

[f] indicates Adequate Intakes (AIs), all other values expressed as Recommended Dietary Allowances (RDAs).

Age	Vitamin B_{12} (mcg/day)	Pantothenic Acid (mg/day)	Biotin (mcg/day)	Choline (mg/day)	Calcium (mg/day)	Chromium (mcg/day)	Copper (mcg/day)	Fluoride (mg/day)	Iodine (mcg/day)	Iron (mg/day)
0–6 months	0.4[a]	1.7[a]	5[a]	125[a]	200[a]	0.2[a]	200[a]	0.01[a]	110[a]	0.27[a]
6–12 months	0.5[a]	1.8[a]	6[a]	150[a]	260[a]	5.5[a]	220[a]	0.5[a]	130[a]	11
1–3 years	0.9	2[a]	8[a]	200[a]	700	11[a]	340	0.7[a]	90	7
4–8 years	1.2	3[a]	12[a]	250[a]	1,000	15[a]	440	1[a]	90	10
9–13 years	1.8	4[a]	20[a]	375[a]	1,300	male: 25[a], female: 21[a]	700	2[a]	120	8
14–18 years	2.4	5[a]	25[a]	male: 550[a], female: 400[a]	1,300	male: 35[a], female: 24[a]	890	3[a]	150	male: 11, female: 15
Pregnancy										
14–18 years	2.6	6[a]	30[a]	450[a]	1,300	29[a]	1,000	3[a]	220	27
19–50 years	2.6	6[a]	30[a]	450[a]	1,000	30[a]	1,000	3[a]	220	27
Lactation										
14–18 years	2.8	7[a]	35[a]	550[a]	1,300	44[a]	1,300	3[a]	290	10
19–50 years	2.8	7[a]	35[a]	550[a]	1,000	45[a]	1,300	3[a]	290	9

Source: Adapted from Dietary Reference Intakes (DRIs): Recommended Dietary Allowances and Adequate Intakes, Vitamins. Food and Nutrition Board, Institute of Medicine, National Academies, 2011.

[a] indicates Adequate Intakes (AIs), all other values expressed as Recommended Dietary Allowances (RDAs).

Age	Magnesium (mg/day)	Manganese (mg/day)	Molybdenum (mcg/day)	Phosphorus (mg/day)	Selenium (mcg/day)	Zinc (mg/day)	Potassium (g/day)	Sodium (g/day)	Chloride (g/day)
0–6 months	30[a]	0.003[a]	2[a]	100[a]	15[a]	2[a]	0.4[a]	0.12[a]	0.18[a]
6–12 months	75[a]	0.6[a]	3[a]	275[a]	20[a]	3	0.7[a]	0.37[a]	0.57[a]
1–3 years	80	1.2[a]	17	460	20	3	3.0[a]	1.0[a]	1.5[a]
4–8 years	130	1.5[a]	22	500	30	5	3.8[a]	1.2[a]	1.9[a]
9–13 years	240	male: 1.9[a], female: 1.6[a]	34	1,250	40	8	4.5[a]	1.5[a]	2.3[a]
14–18 years	male: 410, female: 360	male: 2.2[a], female: 1.6[a]	43	1,250	55	male: 11, female: 9	4.7[a]	1.5[a]	2.3[a]
Pregnancy									
14–18 years	400	2.0[a]	50	1,250	60	12	4.7[a]	1.5[a]	2.3[a]
19–30 years	350	2.0[a]	50	700	60	11	4.7[a]	1.5[a]	2.3[a]
31–50 years	360	2.0[a]	50	700	60	11	4.7[a]	1.5[a]	2.3[a]
Lactation									
14–18 years	360	2.6[a]	50	1,250	70	13	5.1[a]	1.5[a]	2.3[a]
19–30 years	310	2.6[a]	50	700	70	12	5.1[a]	1.5[a]	2.3[a]
31–50 years	320	2.6[a]	50	700	70	12	5.1[a]	1.5[a]	2.3[a]

Source: Adapted from: Dietary Reference Intakes (DRIs): Recommended Dietary Allowances and Adequate Intakes, Vitamins. Food and Nutrition Board, Institute of Medicine, National Academies, 2011.

[a] indicates Adequate Intakes (AIs), all other values expressed as Recommended Dietary Allowances (RDAs).

Tolerable Upper Intake Levels (ULs): Vitamins and Minerals

Age	Vitamin A (mcg/day)[a]	Vitamin C (mg/day)	Vitamin D (mcg/day)	Vitamin E (mg/day)[b, c]	Niacin (mg/day)[c]	Vitamin B_6 (mg/day)	Folate (mcg/day)[c]	Choline (g/day)	Boron (mg/day)	Calcium (mg/day)	Copper (mcg/day)	Fluoride (mg/day)
0–6 months	600	–	25	–	–	–	–	–	–	1,000	-	0.7
6–12 months	600	–	38	–	–	–	–	–	–	1,500	-	0.9
1–3 years	600	400	63	200	10	30	300	1.0	3	2,500	1,000	1.3
4–8 years	900	650	75	300	15	40	400	1.0	6	2,500	3,000	2.2
9–13 years	1,700	1,200	100	600	20	60	600	2.0	11	3,000	5,000	10
14–18 years	2,800	1,800	100	800	30	80	800	3.0	17	3,000	8,000	10
Pregnancy												
14–18 years	2,800	1,800	100	800	30	80	800	3.0	17	3,000	8,000	10
19–50 years	3,000	2,000	100	1,000	35	100	1,000	3.5	20	2,500	10,000	10
Lactation												
14–18 years	2,800	1,800	100	800	30	80	800	3.0	17	3,000	8,000	10
19–50 years	3,000	2,000	100	1,000	35	100	1,000	3.5	20	2,500	10,000	10

Source: Adapted from Dietary Reference Intakes (DRIs): Recommended Dietary Allowances and Adequate Intakes, Vitamins. Food and Nutrition Board, Institute of Medicine, National Academies, 2011.

The following micronutrients were excluded as UL has not been established: vitamin K, thiamin, riboflavin, Vitamin B_{12}, pantothenic acid, biotin, carotenoids, arsenic, chromium, silicon, vanadium.

[a] As performed vitamin A only.

[b] As alpha-tocopherol; applies to any form of supplemental alpha-tocopherol.

[c] The ULs for vitamin E, niacin, and folate apply to synthetic forms obtained from supplements, fortified foods, or a combination of the two.

Age	Iodine (mcg/day)	Iron (mg/day)	Magnesium (mg/day)[a]	Manganese (mg/day)	Molybdenum (mcg/day)	Nickel (mg/day)	Phosphorus (g/day)	Selenium (mcg/day)	Zinc (mg/day)	Sodium (g/day)	Chloride (g/day)
0–6 months	–	40	–	–	–	–	–	45	4	–	–
6–12 months	–	40	–	–	–	–	–	60	5	–	–
1–3 years	200	40	65	2	300	0.2	3	90	7	1.5	2.3
4–8 years	300	40	110	3	600	0.3	3	150	12	1.9	2.9
9–13 years	600	40	350	6	1,100	0.6	4	280	23	2.2	3.4
14–18 years	900	45	350	9	1,700	1.0	4	400	34	2.3	3.6
Pregnancy											
14–18 years	900	45	350	9	1,700	1.0	3.5	400	34	2.3	3.6
19–50 years	1,100	45	350	11	2,000	1.0	3.5	400	40	2.3	3.6
Lactation											
14–18 years	900	45	350	9	1,700	1.0	4	400	34	2.3	3.6
19–50 years	1,100	45	350	11	2,000	1.0	4	400	40	2.3	3.6

Source: Adapted from Dietary Reference Intakes (DRIs): Recommended Dietary Allowances and Adequate Intakes, Vitamins. Food and Nutrition Board, Institute of Medicine, National Academies, 2011.

The following micronutrients were excluded as UL has not been established: vitamin K, thiamin, riboflavin, Vitamin B_{12}, pantothenic acid, biotin, carotenoids, arsenic, chromium, silicon, vanadium.

[a] Intake from pharmacologic agents only, do not include intake from food and water.

Appendix F
Example ADIME Notes

EXAMPLE ADIME NOTE #1

NUTRITION ASSESSMENT

Client history: Patient is a 26-month-old female with no significant prior medical history who presented to clinical care due to abdominal distension, occasional fevers, and weight loss. After an extensive work-up, she was diagnosed with high-risk neuroblastoma and has been admitted to the hospital for initial management.

Nutrition has been asked by the Oncology Service to consult given recent weight loss and the high risk of malnutrition associated with this diagnosis.

Allergies: No known food allergies

Family History: No history of gastrointestinal diseases (malabsorption, celiac disease, inflammatory bowel disease, diarrhea, or constipation), thyroid disorders, or disordered eating

Social History: Lives with her mother, father, and older sister. Patient A is in daycare. There are no food insecurity concerns identified.

Food/Nutrition-related History:

24 hour PO intake: 240 mL water, 120 mL whole milk, 1 slice of toast with butter, bites of rice

- Met with patient, mother, and father at bedside
- Typical intake (last ate like this over a month ago)
  - Breakfast: bowl of cereal with milk, piece of fruit
  - Snack: cheese stick, fruit
  - Lunch: chicken nuggets, mac and cheese
  - Dinner: rice, beans, chicken, vegetable
  - Snack: cookie
- Beverages: water, 1 glass of juice daily, milk with breakfast, does not drink soda
- Fruits: 2 servings daily
- Vegetables: at least 1 serving daily
- Recently, patient has not had a good appetite, has been consuming smaller portion sizes, and gets full quickly. Family is distressed by this acute change
- No history of nutrition support
- Is not taking any vitamins or mineral supplements

Diet Order: Appropriate for age

Access: Peripheral IV × 1

Anthropometric measurements:

Growth chart type: CDC

	Value	Percentile	Z-score
Weight (kg)	10.2	4%	–1.79
Stature (cm)	84.6	36%	–0.35
BMI-for-age	14.3	4%	–1.7

Patient presents as mildly malnourished without stunting

Anthropometric history/trends:

- Patient has historically tracked along the 50th percentile for weight; recently experienced a loss of 2 kg (16%) over about a month per family
- Baseline height/length has been tracking along the 30–35th percentile

Expected weight gain: 4.9 g/day; or 148 g/month

Expected growth: 0.8 cm/month

Biochemical Data, Medical Tests and Procedures:

Sodium 140; Potassium 3.6; Chloride 108; Bicarbonate 24; BUN 6; Creatinine 0.2; Glucose 102; Calcium 8.2; Magnesium: 1.8; Phosphorus 3.2

Medical Tests and Procedures:

- None to report

Nutrition-focused physical findings:

- Patient sitting up in bed, interactive but tired
- Minimal fat and muscle stores note in upper and lower extremities, with clavicular wasting noted
- 24-hour urine output: 2 mL/kg/hour
- 24-hour stool output: 0.2 mL/kg/hour

Medications:

IV fluids: D5 normal saline running @ maintenance rate

NUTRITION DIAGNOSIS

Acute, unspecified, severe malnutrition related to inadequate oral intake as evidenced by 2 kg (16%) weight loss over 1 month, clavicular wasting, limited muscle and adipose tissue stores, and parent report of consumption of <50% of energy needs

NUTRITION INTERVENTION

Nutrition Prescription:

Energy: 828 kcal/day (81 kcal/kg) using EER
Protein: 10.7 g/day (1.05 g/kg) using RDA
Fluid: 1,010 mL using Holliday-Segar

Intervention #1 : Meals and Snacks

- Recommend high-energy diet
- Encourage intake of small, frequent meals; high-energy/protein foods; shakes/smoothies; bland, salty foods for nausea; cool liquids, moist foods for mucositis
- Fortify foods with oil, butter, avocado, peanut butter, granola, whole-fat cream dairy products, cooked/pureed meats, hummus to increase energy density of solids

Intervention #2 : Enteral Nutrition

- Recommend placement of nasogastric tube given poor oral intake and severe malnutrition
- Recommend peptide-based formula (30 kcal/oz) @ 36 mL/hour × 24 hours to provide 864 mL formula; 85 kcal/kg, 2.5 g/kg protein, and 734 mL free water

- Will require additional 276 mL free water, in addition to feeds, to meet maintenance needs (can be accomplished with PO intake, fluids, medications, etc.)

Intervention #3 : Supplements
- Provided samples for patient to try

Intervention #4 : Nutrition Education
Provided and reviewed the following handouts:
- High Calorie Eating
- Nutrition Therapy Guidelines During Treatment
- Shakes/Smoothies Menu

Intervention #5 : Coordination of Care
- Consider checking multivitamin and mineral labs given degree of malnutrition
- Daily intake and output (I's/O's)
- Daily weight checks as able
- Monthly height

NUTRITION MONITORING/EVALUATION

1. Energy intake – to meet nutrition prescription
2. Biochemical data – within normal limits
3. Anthropometric measurements – age-appropriate weight gain

EXAMPLE ADIME NOTE #2

NUTRITION ASSESSMENT

Client history: Patient is a 2-year, 7-month-old female with high-risk neuroblastoma diagnosed about 6 months ago. Since that time she has undergone four cycles of chemotherapy, abdominal resection surgery, gastrostomy tube (G-tube) placement, and one out of two autologous stem cell transplants. Today is day +32 following her first transplant, and she is fully engrafted. She presents to the hospital this admission for her second transplant. Nutrition is consulting given baseline need for enteral feeds and high-risk therapy.
Allergies: No known food allergies
Family History: No history of gastrointestinal diseases (malabsorption, celiac disease, inflammatory bowel disease, diarrhea, or constipation), thyroid disorders, or disordered eating
Social History: Lives with her mother and father. Patient A has been home with her mother since her last discharge. There are no food insecurity concerns identified.

Food/Nutrition-related history:
24-hour oral intake: sips of water, bites of ice cream

- Met with patient and mother at bedside
- Prior to diagnosis, patient consumed 3 meals and 2 snacks per day
- Intake declined prior to diagnosis, nasogastric tube placed prior to start of first cycle of chemotherapy
- During cycles of chemotherapy, patient struggled with enteral tolerance and would require continuous feeds
- Between cycles of treatment, patient would take bites of foods, but rarely substantial amounts

- During first stem cell transplant, patient suffered from severe nausea that was not relieved by antiemetics, required parenteral nutrition for 11 days
- Patient was discharged on 24-hour continuous feeds and was condensed to 14 hours outpatient
- Currently, takes bites of foods and sips of water
- No vitamin or mineral use
- Family is concerned that patient will struggle with enteral tolerance again this admission

Diet Order: Low-bacteria diet
Access: Percutaneously inserted central catheter (PICC) with tip in the superior cavoatrial junction; G-tube
Home enteral regimen: Peptide-based formula (30 kcals/oz) @ 65 mL/hour × 14 hours to provide 910 mL formula, 75 kcals/kg, 2.3 g/kg protein, and 774 mL free water

- Free water flushes: 90 mL, 4 times daily. Total free water: 1,134 mL

Anthropometric measurements:

Growth chart type: CDC

	Value	Percentile	Z-score
Weight (kg)	12.1	23%	−0.74
Stature (cm)	89.2	35%	−0.39
BMI-for-age	15.2	26%	−0.64

Patient presents as appropriately nourished

Anthropometric history/trends:

- At diagnosis: 10.2 kg (WAZ: −1.79); BMI z-score −1.7
- Prior to diagnosis, patient with a 2 kg (16% weight loss) in 1 month
- Weight generally remains stagnant during treatment cycles, but able to gain between cycles

Expected weight gain: 4.9 g/day; Goal is ~10 g/day for catch-up growth

- Actual gain: 1.9 kg in 6 months (~10.56 g/day, meeting goal for catch-up growth)

Expected growth: 0.8 cm/month

- Actual growth: 4.6 cm in 6 months (~0.77 cm/month, slightly short of goal growth)

Biochemical data, medical tests and procedures:
Sodium 137; Potassium 4; Chloride 106; Bicarbonate 26; BUN 8; Creatinine 0.23; Glucose 124; Calcium 8.6; Magnesium: 1.9; Phosphorus 3.8;

Medical tests and procedures:
Five cycles of chemotherapy
Bone marrow transplant × 1 (August 2021)
Abdominal resection surgery (April 2021)
G-tube placement (April 2021)

Nutrition-focused physical findings:

- Patient playing in room, busy, but interactive
- Adipose tissue present on upper and lower extremities
- Alopecia

- 24-hour urine output: 2.3 mL/kg/hour
- 24-hour stool output: 0.5 mL/kg/hour

Medications:

Aprepitant (nausea); Conditioning agents: Cytarabine, cyclophosphamide, etoposide, carboplatin, melphalan

Cyproheptadine

IV fluids: D5 normal saline @ half maintenance rate

NUTRITION DIAGNOSIS

Inadequate oral intake related to treatment-related side effects (nausea, emesis) as evidenced by lack of intake recorded in flowsheet and parent report of intake.

NUTRITION INTERVENTION

Nutrition Prescription:

Energy: 997 kcal/day (82 kcal/kg) using EER
Protein: 12.7 g/day (1.05 g/kg) using RDA
Fluid: 1,105 mL using Holliday-Segar

Comparative Standards based on 12.1 kg:

REE: 58 kcals/kg (Schofield)
Stress/activity factor: 1.3–1.5 = 75–86 kcals/kg
EER for age: 82 kcals/kg
RDA for age (protein): 1.2 g/kg
Fluid (maintenance): 1,105 mL (Holliday-Segar)

Intervention #1: Meals and Snacks

- Encourage oral intake as tolerated

Intervention #2 : Enteral Nutrition

- Continue semi-elemental formula (30 kcal/oz) @ 65 mL/hour × 14 hours to provide 910 mL formula, 75 kcals/kg, 2.3 g/kg protein, and 774 mL free water
- If patient struggles with enteral tolerance, recommend extending time on feeds to 24 hours: 38 mL/hour × 24 hours to provide 912 mL formula, 75 kcals/kg, 2.3 g/kg protein
- Patient requires an additional 193 mL free water, in addition to full enteral feeds, to meet maintenance needs (can be accomplished with oral intake, fluids, medications, etc.)
- If patient is struggling with enteral feeds and oral intake, consider use of intravenous fluids

Intervention #3: Nutrition Education

- Reviewed the following handouts with the family:
- High Calorie Eating
- Nutrition Therapy Guidelines During Treatment
- Shakes/Smoothies Menu

Intervention #4: Coordination of Care

- Daily intake and output (I's/O's)
- Daily weight checks as able
- Monthly height

NUTRITION MONITORING/EVALUATION

1. Energy intake – to meet nutrition prescription
2. Biochemical data – within normal limits
3. Anthropometrics – age-appropriate weight gain

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