Parasites in Food: Occurrence and Detection

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Introduction

Despite causing a high burden of disease and resulting in considerable suffering, parasitic infections have generally not received the same level of attention as other foodborne hazards. Nevertheless, in September 2012, an expert meeting was convened by FAO (Food and Agriculture Organization of the United Nations) and WHO (World Health Organization) that attempted to rank foodborne parasites in order of importance from a global perspective and identify most relevant transmission vehicles.

A total of 24 parasites (species, genera, or families) were ranked as listed in Table 1. Weighting was predominantly driven by public health importance; other factors included global distribution, potential for increases in disease rates, trade impacts, and socioeconomic effects of infection.

As demonstrated in Table 1, all classes of endoparasites are covered, with eight protozoa, seven nematodes (roundworms), five cestodes (tapeworms), and four trematodes (flukes) listed. Although protozoa and nematodes predominate, the three parasites ranked as being of greatest importance are all cestodes, due to the potentially severe pathology that may be caused when humans act as accidental, aberrant intermediate hosts in the parasites' life cycles.

Among the range of food matrices that are of relevance for these parasites, all the major food types are included, such as meat, fresh produce, fruit juice, milk, and fish. The latter includes both freshwater fish and marine fish, depending on parasite species. And it is also worth noting that for the Anisakidae, which includes the species *Anisakis simplex*, *Anisakis pegreffii*, and *Pseudoterranova decipiens*, the potential hazard to human health is limited not only to the possibility of infection occurring but also to the potential for gastroallergic reactions. Such reactions, which may be severe, are usually facilitated by a hypersensitivity reaction, most frequently to a major secretory/excretory antigen/allergen of the Anisakidae, and may even be activated if the parasite is not alive.

In the following sections, the eight most highly ranked foodborne parasites are described in greater detail. For each parasite, a brief overview of the parasite is provided (life cycle, prevalence, global distribution, and disease) and then some details on foodborne infection, including, where applicable, a description of methods of detection in the relevant food matrices.

The Highest-Ranked Foodborne Parasites

Taenia solium

Taenia solium is also known as the pork tapeworm because transmission to humans, the definitive host in the life cycle, is by ingestion of infective larval cysts in undercooked pork. Prevalence of *T. solium* infection varies greatly according to local practices regarding consumption of pork (occurs very rarely in Muslim or Jewish communities), as well as pig husbandry practices and general sanitation. *T. solium* is endemic in several developing countries, including Central and South America, sub-Saharan Africa, Southeast Asia, and Western Pacific. It is considered an emerging disease in United States and parts of Europe due to increased immigration and international travel; over 50 million people are estimated infected worldwide.

Although the sheer size of adult *T. solium* (between 2 and 7 m in length) inhabiting the human intestine sounds disagreeable, taeniasis produces only mild abdominal symptoms, the main clinical sign being passive passage of proglottids – the mature segments of tapeworm that pass out with the feces and contain around 50 000 eggs each. These eggs are infective to pigs and, when ingested, hatch in the intestine, invade the intestinal wall, and migrate to the tissues where they encyst into cysticerci. The cysticerci are infective to humans and, when ingested, develop into adult worms in the intestine, thereby completing the life cycle.

If *T. solium* eggs are ingested by humans (not pigs), they also hatch and invade the intestinal wall and migrate to the tissues and develop into cysticerci. They are more common in subcutaneous tissues but are also relatively common in the liver, eyes, and central nervous system (CNS). This clinical disease, cysticercosis, is far more serious than taeniasis, with symptoms resulting from the development of cysticerci. The most important clinical manifestation occurs when the cysticerci are in the CNS. This disease, neurocysticercosis, can result in various symptoms including epilepsy-type seizures, mental disturbances, and death. Ocular, cardiac, or spinal lesions and associated symptoms occur when cysticerci occur in those organs.

While taeniasis is exclusively a foodborne infection, associated with the consumption of undercooked pork containing the larval stages (cysticerci) of the parasite, cysticercosis requires consumption of eggs excreted from an infected human. This can be direct hand-to-mouth or via a vehicle such as food. It is particularly likely to occur when human excreta (night soil) is used for manure on vegetables that are not cooked before consumption.

Routine meat inspection of pigs for cysticerci is conducted at slaughter, and, if detected, the meat is condemned (or, in countries where infection is common, might be passed for cooking). The cysticerci are around 10×5 mm (pea size) or larger. Although relatively easy to see, it should be noted that in countries where they are not expected, inspection may be cursory and light infections may be overlooked.

No methods are in place for inspecting vegetables or other possible transmission vehicles for *T. solium* eggs; reduction of taeniasis by appropriate control of pork is a sensible approach to reducing cysticercosis and also encouraging thorough cooking to inactivate the tissue cysts (heating to a core temperature of at least 60 °C). Tissue cysts are also inactivated by freezing to

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Table 1 Foodborne parasites ranked in order of global importance

Parasite	*Group*	*Order of ranking*
Taenia solium	Cestode	1
Echinococcus granulosus	Cestode	2
Echinococcus multilocularis	Cestode	3
Toxoplasma gondii	Protozoa	4
Cryptosporidium spp.	Protozoa	5
Entamoeba histolytica	Protozoa	6
Trichinella spiralis	Nematode	7
Opisthorchiidae	Trematode	8
Ascaris spp.	Nematode	9
Trypanosoma cruzi	Protozoa	10
Giardia duodenalis	Protozoa	11
Fasciola spp.	Trematode	12
Cyclospora cayetanensis	Protozoa	13
Paragonimus spp.	Trematode	14
Trichuris trichiura	Nematode	15
Trichinella spp.	Nematode	16
Anisakidae	Nematode	17
Balantidium coli	Protozoa	18
Taenia saginata	Cestode	19
Toxocara spp.	Nematode	20
Sarcocystis spp.	Protozoa	21
Heterophyidae	Trematode	22
Diphyllobothriidae	Cestode	23
Spirometra spp.	Nematode	24

Source: WHO/FAO (2014). Multicriteria-based ranking for risk management of foodborne parasites. Report of a Joint FAO/WHO Expert Meeting, 3–7 September 2012, FAO Headquarters, Rome, Italy. Microbiological Risk Assessment Series. ISBN 978 92 4 156470 0 (WHO); ISBN 978-92-5-108199-0 (print) (FAO); E-ISBN 978-92-5-108200-3 (PDF) (FAO); ISSN 1726-5274.

−10 °C or lower for at least 10 days. Additionally, use of human excreta for fertilizer on crops should be discouraged, particularly in places where taeniasis is endemic.

Echinococcus granulosus

Echinococcus granulosus is a small (3–5 mm) tapeworm, also called dog dwarf tapeworm, with canids as definitive hosts. A range of mammals are suitable as intermediate hosts, including sheep, goats, buffalos, cattle, camels, pigs, kangaroos, and cervids. Eggs passed in the feces of an infected dog may be ingested by an intermediate host, and the oncosphere that hatches in the intestine penetrates the intestinal wall and migrates into various organs, especially the liver and lungs. Here, it develops into a hydatid cyst that gradually enlarges, producing protoscolices and daughter cysts that fill the cyst interior. Canids are infected by consuming parts of an animal that contains these cysts. A common source of infection for dogs is offal from infected livestock.

Infection of humans occurs due to accidental ingestion of *E. granulosus* eggs from dog feces and results in the disease cystic echinococcosis (CE). The strain usually associated with human infection is the common sheep strain (G1). Transmission is influenced by extent of domestic and wildlife reservoirs and is closely affected by human activities, behavior, environmental factors, and local policies.

E. granulosus has a global distribution; endemic foci are found on every continent. However, local distribution and prevalence depend on the presence of large numbers of sheep, cattle, goat, or camel flocks (intermediate hosts) and close contact between them and canine definitive hosts. Prevalence of CE is highest in temperate zone countries, including several parts of Eurasia, Australia, some areas of America (especially South America), and North and East Africa.

Clinical manifestations of CE are variable and determined largely by site, number, and size (can be over 20 cm diameter) of cysts. Strain of parasite may also affect the symptoms. Nevertheless, unless cysts are located in the brain or eye, clinical manifestations of most cases of CE are generally mild for a considerable period. Most cysts (>65%) are located in the liver, followed by the lungs (25%), but cysts have also been reported from the spleen, kidneys, heart, bone, and CNS. For cysts in the liver, signs include hepatic enlargement, right epigastric pain, nausea, biliary duct obstruction, and vomiting. Pulmonary involvement can result in chest pain, cough, and hemoptysis. Although CE is rarely fatal, death may occur due to anaphylactic shock or cardiac tamponade. Furthermore, if a cyst ruptures, release of cyst contents can cause allergic reactions and produce fever and mild to fatal anaphylactic shock. It has been estimated that CE results in the loss of 1–3 million disability-adjusted life years (DALYS) per annum.

E. granulosus is not strictly a foodborne pathogen, and contact with infected dogs seems to be a common risk factor for infection. However, the eggs are highly resistant to environmental factors, remaining infective for many months in a moist environment. Thus, if eggs contaminate a food product that is not cooked before eating, then food may act as a transmission vehicle.

There are no data on the occurrence of *E. granulosus* eggs on food, and there is no standard method for analyzing food products for these eggs. Minimizing *E. granulosus* infection is directed toward breaking the life cycle. The main approaches are frequent deworming of dogs in endemic areas and not feeding raw offal to dogs or leaving raw offal accessible to scavenging canids.

Echinococcus multilocularis

The fox tapeworm, *Echinococcus multilocularis*, has a similar life cycle to that for *E. granulosus* but is mostly associated with a sylvatic life cycle, with foxes usually serving as definitive hosts. Other canids (e.g., dogs, raccoon dogs, wolves, and coyotes) may also act as definitive hosts. Various different genera of rodents (also some lagomorphs) may act as intermediate hosts, being infected by ingestion of eggs released from the tapeworms in the definitive hosts. A number of nonrodent mammals, including humans and pigs, may also be infected as aberrant or accidental intermediate hosts; in humans, this may result in the disease state known as alveolar echinococcosis (AE).

Data on the prevalence of AE in humans are scattered and patchy, probably partly due to diagnostic challenges, particularly in early stages of infection. *E. multilocularis* infection apparently does not occur in Australasia, Africa, and South or Central America, but countries in Asia and Europe, as well as North America, are important endemic areas. In particular, Russia and adjacent countries, various regions in China, and the Japanese island of Hokkaido are of importance. By far the largest numbers of human cases are reported from foci in China, with prevalences ranging up to 4% in Gansu and northwestern Sichuan. Although the number of human cases of AE in Europe remains low, there appears to be widespread, expanding prevalence in wildlife and trends of AE in humans appear to follow parasite abundance in wildlife.

While the tiny (3–6 mm) adult *E. multilocularis* tapeworms normally cause little harm to canine definitive hosts, in intermediate hosts, including humans, ingested eggs develop to oncospheres, which penetrate the intestinal wall and are carried via blood to, in particular, not only the liver but also other organs where they form multilocular cysts. From ingestion of eggs to onset of clinical symptoms in people may be from months to years, or even decades, depending on cyst location and speed of growth. In most AE cases, metacestodes of *E. multilocularis* initially develop in the liver. These cysts, varying from a few millimeters to 15–20 cm or more in diameter, can also reproduce aggressively by asexual lateral budding. This gradual invasion of adjacent tissue in a tumorlike manner is the basis for the severity of AE. Metacestodes may also spread from the liver to other organs, such as the lungs, spleen, heart, and kidney. Symptoms of severe hepatic dysfunction appear in the advanced clinical stage, in addition to symptoms from other affected organs. While there is negligible acute morbidity, the chronic morbidity of AE is severe and potentially fatal.

As with CE, the proportion of AE cases that are actually foodborne is difficult to estimate, as diagnosis usually occurs long after infection; it is difficult to associate an infection with a foodborne event many years previously. However, the tapeworm eggs may contaminate various types of food, including fruits and vegetables. Although sensitive to desiccation and heat, the eggs are extremely tolerant of environmental conditions, including cold; freezing at −20 °C does not affect egg infectivity. Thus, there is a large potential for foodborne infection via raw produce. However, there are currently no tools for detecting *E. multilocularis* eggs on food. Current control regimes include deworming of dogs in endemic areas, monitoring prevalence in wild canids, and, in some areas, treating wild canids with impregnated bait.

Toxoplasma gondii

Toxoplasma is a protozoan parasite, infectious to practically all warm-blooded animals, including humans, livestock, birds, and marine mammals. Although the genus has only one species, *Toxoplasma gondii*, there are different genetic groups of differing virulence. *T. gondii* is perhaps the most widespread protozoan parasite affecting humans; between 1 and 2 billion of the world's population have been estimated to be infected at any one time. It should be emphasized that most of these infections do not cause clinical illness.

The life cycle of *Toxoplasma* is somewhat complicated, containing two distinct cycles, a sexual cycle and an asexual cycle. The definitive hosts are members of the cat family (Felidae); thus, the sexual cycle occurs only within the intestinal epithelial cells of felids. Oocysts are excreted unsporulated (uninfectious) in cat feces. Oocyst sporulation in the environment usually takes around three days, depending on factors such as temperature and humidity. Oocysts are environmentally robust and can retain infectivity in a cool damp environment for months.

The asexual cycle occurs when consumption of tissue cysts (see succeeding text) or oocysts results in infection of the intestine, and the tachyzoite form of the parasite multiplies asexually in the cells of lamina propria until the cells rupture, releasing tachyzoites into the surrounding tissues and resulting in systemic infection. Circulating tachyzoites infect new cells throughout the body, and after several more rounds of asexual division, tissue cysts are formed. Tissue cysts of *T. gondii* are microscopic (5–100 μm) and contain bradyzoites, which are infectious when ingested with the surrounding tissue. If ingested by a felid, then the sexual cycle occurs and the life cycle is complete; if ingested by any other host, then the asexual cycle occurs, as previously described. If a female host is pregnant when first infected, then circulating tachyzoites may move to the fetus (intrauterine or congenital transmission).

The clinical picture of *Toxoplasma* infection is greatly influenced by the immune status of the infected person and also by the virulence of the parasite strain. In immunocompetent people, *T. gondii* infection is usually asymptomatic but may cause mild to moderate flu-like illness. In some cases, ocular toxoplasmosis may occur, possibly with partial or total loss of vision. Ocular disease appears to be more severe in South America, presumably due to more virulent *Toxoplasma* genotypes. Although latent *Toxoplasma* infection is generally considered benign in the immunocompetent, some studies indicate that the parasite may affect behavior, being a contributory, or even causative, factor in various psychiatric disorders including depression, anxiety, and schizophrenia.

In the immunocompromised and immunodeficient patients, severe or life-threatening disease can result from acute *Toxoplasma* infection or reactivation of previously latent infection. Encephalitis is the most clinically significant manifestation. Congenital toxoplasmosis is another serious potential manifestation, usually occurring when *Toxoplasma* is passed to the fetus from a first infection acquired by the mother immediately before or during pregnancy. Symptoms commonly associated with transplacental infection include spontaneous termination, fetal death, and intracranial calcification. Congenitally infected children that are asymptomatic at birth may suffer from mental retardation or retinochoroidal lesions later in life.

With the exception of congenital transmission, most *T. gondii* infections are considered to be foodborne, although waterborne infection has been suggested to be the major source of *Toxoplasma* infection in developing countries.

There are three potentially infectious stages of *Toxoplasma*: tachyzoites, bradyzoites, and oocysts, two of which – bradyzoites and oocysts – are particularly relevant to foodborne transmission. Bradyzoites may be ingested with tissue of an infected intermediate host, while oocysts may be ingested with any foodstuff that has been contaminated with feces of an infected felid; this is particularly likely for fruit and vegetables that are eaten raw, and *Toxoplasma* oocysts are particularly robust, being able to survive in the environment for weeks or months.

Human infection via bradyzoites in meat depends on various factors, including prevalence of *Toxoplasma* infection in meat animals (most livestock species are susceptible to infection), cultural factors regarding meat consumption and meat preparation, and factors of the person exposed (e.g., age and immunologic status). Parasite factors are probably relevant also. In some countries, sheep and goats are the most important hosts of *T. gondii* and the main source of infection to humans. In other countries, for example, the United States, lamb and mutton are relatively minor food commodities; of the major meat animal species investigated in the United States to date, pig (particularly organically raised) is the only species frequently found to harbor the parasite. Although poultry are also susceptible to *T. gondii* infection and theoretically pose a source of infection to humans, the relatively limited life span of poultry and the fact that they tend to be well-cooked before consumption limit their importance as sources of infection for humans. Game animals are also considered as potentially important sources of meatborne toxoplasmosis, particularly as such meat is often consumed undercooked; wild boar and venison are particularly implicated in Europe, while consumption of undercooked meat from marine mammals is an important risk factor for human infection in Arctic regions.

There is no systematic monitoring of meat for *Toxoplasma*, as the cysts are very small and can occur in almost all tissues. For high-risk groups, ensuring that meat is thoroughly cooked is important. Similarly, no standard method exists for monitoring for contamination with oocysts, although some research surveys have demonstrated quite widespread contamination.

Cryptosporidium spp.

Cryptosporidium spp. are protozoan parasites that have been reported from a large variety of different hosts, including humans, globally. Around 25 species of *Cryptosporidium* have been identified to date, of which approximately 50% have been reported as infectious to humans. However, most reported human infections involve *Cryptosporidium parvum* (an important zoonotic species, particularly associated with infections in calves) or *C. hominis*, which is found primarily in humans. Other species considered important for human infection in some areas are *C. meleagridis*, particularly in children in South America, but primarily considered as infecting turkeys, and *C. cuniculus*, also associated with infections in rabbits. Although prevalence data are patchy, *Cryptosporidium* infection has emerged as a global public health problem and has been reported from over 100 countries.

The life cycle of *Cryptosporidium* is direct (no intermediate host). When a viable oocyst is ingested by a susceptible host, it excysts in the small intestine where the resultant sporozoites invade epithelial cells and locate epicellularly (within the cell but not within the cytoplasm). Repeat cycles of asexual reproduction result in destruction of these cells and the production of vast numbers of parasites. A sexual cycle results in oocyst production. These are excreted in the feces and are immediately infectious but are also very robust and can survive for long periods under cool, moist conditions.

Cryptosporidiosis is an enteric disease, characterized by watery diarrhea, abdominal pain, and related symptoms. It is self-limiting in immunocompetent individuals, although a high relapse rate has been reported. However, in some immunocompromised patients, the symptoms may become chronic, debilitating and potentially life-threatening; drug development for this vulnerable group has been largely unsuccessful.

Waterborne transmission is important in cryptosporidiosis; numerous waterborne outbreaks of cryptosporidiosis have occurred worldwide due to oocyst contamination of drinking water sources. The largest waterborne illness outbreak of any kind in the United States occurred in 1993 when over 400 000 people acquired cryptosporidiosis in Milwaukee. More recently, around 27 000 people suffered from waterborne cryptosporidiosis in Östersund, Sweden, in 2010.

Although foodborne transmission of cryptosporidiosis is considered much less common than waterborne or person-to-person transmission, it is emerging as a public health issue. Several foodborne outbreaks of cryptosporidiosis have been reported, mainly in United States and northern Europe, and in some instances, tens or hundreds have been infected. Implicated foods have largely been fresh produce (e.g., ready-to-eat spinach, green onions, parsley, lettuce, and salad bar items), but there have also been outbreaks associated with apple cider and fresh milk. Some outbreaks have been attributed to contamination from infected food handlers, but others have implicated other contamination routes. Surveys performed worldwide have reported *Cryptosporidium* oocysts, albeit at low concentrations, on a wide variety of fresh produce items, in irrigation water, and also in shellfish. Different methods have been proposed and used in research products for the identification of *Cryptosporidium* oocysts on fresh produce, often in combination with the detection of *Giardia* cysts. A standard ISO method for the analysis of leafy green vegetables and berry fruits is under development and is based broadly on elution from the product, concentration of eluate, isolation from debris by immunomagnetic separation, and detection using immunofluorescent staining.

The likelihood of contamination of produce can be reduced by implementing appropriate measures both preharvest and postharvest and also at the consumer level. Although robust, oocysts do not survive prolonged freezing at below −15 °C and are killed by cooking.

Entamoeba histolytica

Many species of *Entamoeba* have been described, of which several may inhabit the human intestinal tract, but only *E. histolytica* is a proved human pathogen causing the disease amebiasis, although only around 10% of individuals infected with *E. histolytica* develop symptoms. *E. dispar* is considered apathogenic; *E. moshkovskii* may be pathogenic under some conditions. That these pathogenic and nonpathogenic species are morphologically indistinguishable means that the occurrence of amebiasis was previously overestimated, and therefore, older data or data not obtained with molecular tools are unreliable. Nevertheless, *E. histolytica* is considered to occur globally and is considered a particular health risk in countries where sanitation is poor. Disease burden has been estimated to be approximately 50 million infections, resulting in an estimated 40 000–110 000 deaths, annually.

The life cycle of *E. histolytica* includes the infectious cyst form and the trophozoite, the invasive, disease-causing stage. Following ingestion of an infectious cyst, trophozoites are released in the small intestine and multiply through divisions.

The trophozoites generally migrate to the large intestine, localizing to the cecum and adjacent ascending colon, where encystation occurs. Both trophozoites and cysts may be excreted in the feces, although the former rapidly disintegrate and are not considered infectious. Cysts, however, can survive for considerable periods outside the host, and thus, new infection can occur via contamination of food and water. *E. histolytica* is not considered as zoonotic.

For infected individuals who experience clinical amebiasis, symptoms range from mild colitis to severe invasive and/or disseminated infection. Amoebic colitis includes bloody diarrhea with multiple mucoid stools and abdominal pain. Chronic infection, with persistent nondysenteric diarrhea, has also been reported. Fulminating amoebic colitis occurs in about 0.5% of infections and is a serious form of invasive infection, usually presenting with profuse bloody diarrhea, abdominal pain, and fever. Colonic perforation and peritonitis may occur, and a mortality rate of around 40% has been estimated. Extraintestinal spread of *E. histolytica* trophozoites occurs through the portal venous system. Amoebic liver abscess (ALA) is the most common extraintestinal manifestation, and associated symptoms include fever, right upper quadrant pain, and hepatic tenderness, usually not concurrent with amoebic colitis. Spread to other sites is rare and usually occurs secondarily to ALA; pleuropulmonary amebiasis, amoebic brain abscess, and amoebic skin abscess have all been reported.

Although infection is generally considered to occur most frequently from ingestion of contaminated food or water, only a few outbreaks of waterborne amebiasis have been reported and no foodborne outbreaks. This could be because around 90% of people infected would not experience symptoms. Studies of parasitic infections in food handlers have often reported *E. histolytica* infection, and unhygienic food handling is commonly considered a contamination route. However, those very few studies that have investigated food for a range of parasites, including *Entamoeba*, tend not to report contamination with *E. histolytica* cysts, and no standard methods have been developed for examining food products for this parasite.

Trichinella spiralis

Trichinella spiralis is an intracellular parasitic nematode of mammalian striated muscles, found worldwide in many carnivorous and omnivorous animals. There is no stage in the life cycle that is external to the host (in the environment), and transmission is solely from ingestion of another infected host. Human infections are mainly associated with the consumption of undercooked pork, and the parasite is endemic in pig-breeding/pork-producing facilities in several countries in eastern Europe, Russia (some areas), China (various provinces), Southeast Asia (Laos and Thailand), and South America (except Brazil). Other species of *Trichinella* are also infectious to humans and are often particularly associated with specific geographic regions or species of game animal.

The life cycle commences with the ingestion of encysted larvae in the striated muscle tissue of another infected host. Following exposure to gastric acid and pepsin, the larvae are released from the cysts and invade the mucosa of the small intestine where they develop into adult worms, just a couple of millimeters in length. Hundreds of new larvae are produced and these are spread with the blood around the body, settling in the muscle cells where they become encapsulated into tissue cysts. These infective encysted larvae can survive for years in tissue and also remain infectious for several weeks in dead animals, thus enabling infection of carrion eaters.

Although animal infection with *T. spiralis* is considered asymptomatic, human infection causes a serious clinical disease, trichinellosis, which can cause much suffering and may be fatal. Symptoms of trichinellosis are related to life cycle stages, with enteric, migratory, and muscle phases. During invasion of the intestinal epithelium, abdominal pains, diarrhea, and vomiting may occur. During larval migration, symptoms may include fever, facial edema myalgias, rashes, and tachycardia. Establishment of larvae within the muscle cells and the encystment of muscle larvae are associated with symptoms such as myalgia and severe asthenia. The most frequently affected muscles are those of the cervix, trunk, and upper and lower extremities. The severity of muscle pain reflects the intensity of the infection, and mobility may be restricted. Severe myalgia generally lasts for 2–3 weeks. Although the infection is persistent, as dictated by the life cycle, only a few cases become 'clinically chronic' with recurrent muscle pain. Brain abnormalities have also been reported. Although case mortality is low, for severe infection without treatment, it may rise to over 10%.

Infection with *T. spiralis* can occur only via the foodborne route, and pigs are submitted to compulsory veterinary controls to ensure meat is *Trichinella*-free. EU regulations require that pigs are systematically sampled at the slaughterhouses, with samples taken from the predilection sites and examined by the recommended method, 'the magnetic stirrer method for pooled sample digestion,' which is considered to have the best sensitivity (EU Commission regulation EC 2075/2005; International Commission on Trichinellosis Recommendations). In this method, larvae are identified after artificial digestion of muscle samples from carcasses. Derogations from testing are possible for meat from domestic swine when the pig holdings have been officially recognized as *Trichinella*-free by the competent authorities. This requires compliance with a considerable number of rules. In industrial countries, most marketed pigs are reared in high-containment-level farms and consequently are *Trichinella*-free, but backyard pigs that have more environmental contact are more likely to be infected, and 'organic' pork is also more likely to be infected. Meat from domestic swine that has been frozen under the supervision of competent authorities can also be exempted of *Trichinella* examination.

Prevention of human infection is accomplished by meat inspection, meat processing, and prevention of exposure of food animals to infected meat. Although freezing can kill *T. spiralis* larvae, other species of *Trichinella* are resistant to freezing. Ensuring that pork is thoroughly cooked before eating ensures against infection with both *T. spiralis* and *Taenia solium*.

Opisthorchiidae

The Opisthorchiidae is a family of fishborne zoonotic trematodes that includes the Southeast Asian liver fluke (*Opisthorchis viverrini*), the cat liver fluke (*O. felineus*), and the oriental liver fluke (*Clonorchis sinensis*). For all these flukes, the definitive hosts are fish-eating mammals (including not only humans but also cats and dogs). Millions of people have been estimated to be infected with these trematodes: approximately 15 million with *C. sinensis*, 10 million with *O. viverrini*, and about 1 million with *O. felineus*. Up to 700 million (10% of the global population) have been considered to be at risk of infection. Geographically, populations in Asia and Europe are most at risk, with *C. sinensis* endemic in southern China, Korea, Taiwan, northern Vietnam, and Russia; *O. viverrini* endemic in areas of Thailand, Laos, Cambodia, and central Vietnam; and *O. felineus* reported from the former USSR and central–eastern Europe, with endemicity in over 12 European countries.

The life cycles of these trematodes include two intermediate hosts; eggs excreted in the feces of the infected definitive hosts are ingested by the first intermediate host, a freshwater snail. In the snail, an asexual cycle occurs that enables considerable multiplication from the single miracidium released from the egg. The final stage is the cercariae, and these emerge from the snail host and seek out the second intermediate host that includes various species of freshwater cyprinid fish (e.g., carp) and penetrate their flesh. Here, they encyst as metacercariae. When these are ingested with undercooked or raw fish, then they excyst in the duodenum and ascend into the biliary ducts, where they develop into adults, later producing eggs and thereby completing the life cycle.

When humans are infected by consumption of fish containing viable metacercariae, the infection primarily results in hepatobiliary pathology, which may subsequently cause bile duct cancer (cholangiocarcinoma (CCA)). Benign hepatobiliary infection may be asymptomatic and is characterized by cholangitis, obstructive jaundice, hepatomegaly, cholecystitis, and cholelithiasis, most of which are mild. In heavy infections, acute symptoms might occur with epigastric pain, fever, jaundice, and diarrhea. However, the main characteristic of these infections is chronic morbidity, with chronic illness occurring in around 10% of infected individuals who may develop severe disease (weakness, abdominal pain, chronic cholecystitis, gall stone, pyogenic cholangitis, and abscess) and also CCA. Once CCA develops, it is usually fatal; curative treatment is not available, and even with surgical treatment, the prognosis is very poor. Most CCA patients survived less than 5 years, and it is a leading cause of death in Asia; both *O. viverrini* and *C. sinensis* are described as type 1 carcinogens.

Opisthorchiidae are transmitted to humans solely via the foodborne route, with the consumption of the flesh of freshwater fish that is undercooked or has been prepared by salting, pickling, or smoking, all of which may be insufficient to inactivate the metacercariae. In some countries, control programs have been instigated. Strategies combine public health aspects with socioeconomic and cultural dimensions. No standard method has been established for examining fish for metacercariae, but researchers have used artificial digestion methods followed by microscopy for identification.

See also: Diarrheal Diseases; Emerging Foodborne Enteric Bacterial Pathogens; Food and Agriculture Organization of the United Nations; Food Poisoning: Tracing Origins and Testing; Foodborne Pathogens; HACCP and ISO22000: Risk Assessment in Conjunction with Other Food Safety Tools Such as FMEA, Ishikawa Diagrams and Pareto; Parasites in Food: Illness and Treatment; Risk Assessment of Foods and Chemicals in Foods; Water Supplies: Microbiological Analysis; World Health Organization; Zoonoses.

Further Reading

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