CHAPTER 9

Microbiological Hazards and Their Control: Parasites

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INTRODUCTION

Many types of parasites are food-borne, and humans can become infected following the ingestion of infected or contaminated meat, fish, molluscs, vegetables, or fruit, or products derived from these foods. In most cases, parasitic infections are acquired by eating raw or incompletely cooked food, or food that is partially pickled or smoked or poorly preserved. Most, if not all, infections are preventable if the food is prepared sufficiently to destroy the infective stages of the parasite. However, many infections are commonly associated with cultural and eating habits that have been in practice in populations for generations.

Meat from many species of animals has been a recognized source of many helminth, and some protozoal, infections, in man. In developed countries, the introduction of meat hygiene measures has resulted in reduced incidences of many of the traditionally recognized helminth infections. However, the eating of many traditional raw or lightly cooked meat dishes continues, and may occasionally result in infection in man. Raw, uncooked fish dishes are also commonly eaten in many cultures, and snails, clams, oysters, and a variety of other molluscs are part of the diets of many people worldwide. Although most food-borne helminth infections are reported from Third World countries, increased immigration, tourism, and desire to experience the culinary dishes of other cultures may increase the incidence of parasitic disease in other countries. As with some helminths, protozoan parasites are opportunistic infections that are often acquired as the result of poor hygiene or travel to foreign countries.

Fermented foods that use raw ingredients that have been contaminated or infected with infective or intermediate parasite stages have the potential to cause human infection. Although food-borne parasitic diseases continue to be reported globally, reports of human infection following the ingestion of fermented food are sparse. Cultural dishes such as *som fak* (a fermented Thai minced fish dish) have been reported to result in human infection with the helminth parasite, *Gnathostoma* (see Gnathostomosis). Infection with another protozoan parasite, *Giardia*, has been reported following the ingestion of cheese dip. Fermentation alone may therefore be insufficient to prevent the transmission of many food-borne parasites, and potentially infected material should be avoided wherever possible, or alternatively subjected to freezing or some form of heat treatment.

Many parasites infect humans, but reference is made only to those helminths and protozoa that are recognized as food-borne and a potential source of infection in fermented foods.

NEMATODES

The nematodes are a diverse group of parasitic or free-living unsegmented worms that are usually cylindrical and elongate in shape. With few exceptions, the sexes of nematodes are separate, and the life cycle may be direct or indirect,

involving an intermediate host. The general description and classification of the food-borne nematodes discussed in this chapter are summarized in Table 9–1.

Angiostrongylosis

Angiostrongylus cantonensis and *A. costaricensis* are parasites of rodents (predominantly rats) that can cause disease in humans through the ingestion of infected snails. Two other species, *A. malaysiensis* and *A. mackerrasse*, occur but have not been associated with human infection. Most human infections are acquired by eating infected snails, but can occur through eating infected shrimp and crab, or snail- or slug-contaminated raw vegetables.

Public Health Significance

A. cantonensis can cause meningitis and meningoencephalitis with mild to moderate symptoms, often of sudden onset, with intense headaches; vomiting; moderate intermittent fever; and, in approximately 50% of cases, coughing, anorexia, malaise, constipation, and somnolence.[176] In severe cases, coma and death may occur. Accidental ingestion of the slug intermediate host of *A. costaricensis* causes abdominal angiostrongylosis with symptoms similar to appendicitis, including fever, abdominal pain, anorexia, diarrhea, and vomiting.[96] Migratory larvae may cause gastroenteritis, tumor-like masses or abcessation of the intestines, liver enlargement, nervous signs, coma, and, occasionally, death.[108] Infection is normally diagnosed by confirming the presence of parasites or eggs in surgically removed tissues or fluids or by using serological assays.[37,144,169]

Life Cycle

Adult worms are found in the pulmonary arteries of rats. The life cycles of *A. cantonensis* and *A. costaricensis* are similar and are shown in Figure 9–1. The prepatent period (from infection to maturity) is 42–45 days.

Distribution

The distributions of *A. cantonensis* and *A. costaricensis* are summarized in Table 9–2. Most human infections and deaths associated with *A. cantonensis* have been reported from Taiwan, Thailand,[131,176] and some Pacific islands, but human infections have been reported in most countries where the parasite occurs and appears to be spreading.[33] The incidence of angiostrongylosis appears to be spreading, especially in those areas in which snails are an important part of the diet.

Epidemiology and Transmission

Humans become infected with angiostrongylosis by intentionally or accidentally eating infected snails or slugs. Rodents are infected by ingesting infected molluscs or by ingesting infective larvae present in "slime" on plants. In most endemic areas of Asia, both land and aquatic snails (*Achatina* and *Pila*) are eaten regularly. The giant African land snail, *Achatina fulica*, is a particular delicacy in many countries and is a good intermediate host. Slugs and snails (which are used for medicinal purposes in some cultures), land crabs, shrimp, and paratenic hosts such as toads and frogs have also transmitted infection. Sauces prepared from shrimp juices or unwashed contaminated vegetables have also been incriminated. The drinking of untreated water containing larvae released from dead snails has also been suggested as a means of infection. Infection continues to be reported from new areas of the world, in part due to the dissemination of the intermediate snail hosts, but also due to transportation of infected rats on ships. Most terrestrial and aquatic snails are susceptible to infection, and populations can be readily infected from carrier rats.

Prevention and Control

Angiostrongyliosis can be prevented by educating people in endemic areas to avoid eating uncooked molluscs, particularly land snails. Freezing will kill larvae present in snails if they are frozen at –15 °C for 12–24 hours. Paratenic hosts (i.e., shrimp, prawn, crabs) should be cooked before eating, and vegetables should be washed before eating raw. Little or no information is available on the survivability of infective larvae in fermented foods such as *balao-balao* (fermented shrimp).

Table 9–1 Food–Borne Helminths—Classification

Phylum	*Class*	*Order*	*Family*	*Genus*
Nemathelminthes	**Nematoda** (Roundworms) Elongate, cylindrical, unsegmented worms with fluid-filled body cavity. Sexes are separate. Life cycle direct or indirect.	Strongylida	Metastrongyloidae	*Angiostrongylus*
		Ascaridida	Anisakidae	*Anisakis*
		Enophida	Trichinellidae	*Trichinella*
			Capillaridae	*Capillaria*
		Dioctophymida	Dioctophymatidae	*Dioctophyma*
		Spirurida	Thelaziidae	*Gongylonema*
			Gnathostomatidae	*Gnathostoma*
Platyhelminthes	**Cestoda** (Tapeworms) Tape-like segmented body comprising head, neck, and strobila (proglottids). Bothria or suckers for attachment. Hermaphroditic. Indirect life cycles.	Pseudophyllidea	Diphyllobothridae	*Diphyllobothrium*
		Cyclophyllidea	Taeniidae	*Taenia*
	Trematoda (Flukes) Unsegmented leaf or lancet-shaped worms with two muscular suckers for attachment and well-developed oral sucker and pharynx. Hermaphroditic (generally). Indirect life cycles.	Echinostomida	Fasciolidae	*Fasciola* *Fasciolopsis*
			Echinostomatidae	*Echinostoma* *Hypoderaeum*
		Plagiorchiida	Troglotrematidae	*Paragonimus* *Nanophyetes*
		Opisthorchiidae	Heterophyidae	*Heterophyes* *Metagonimus*
			Opisthorciidae	*Opisthorcis (Clonorchis)*

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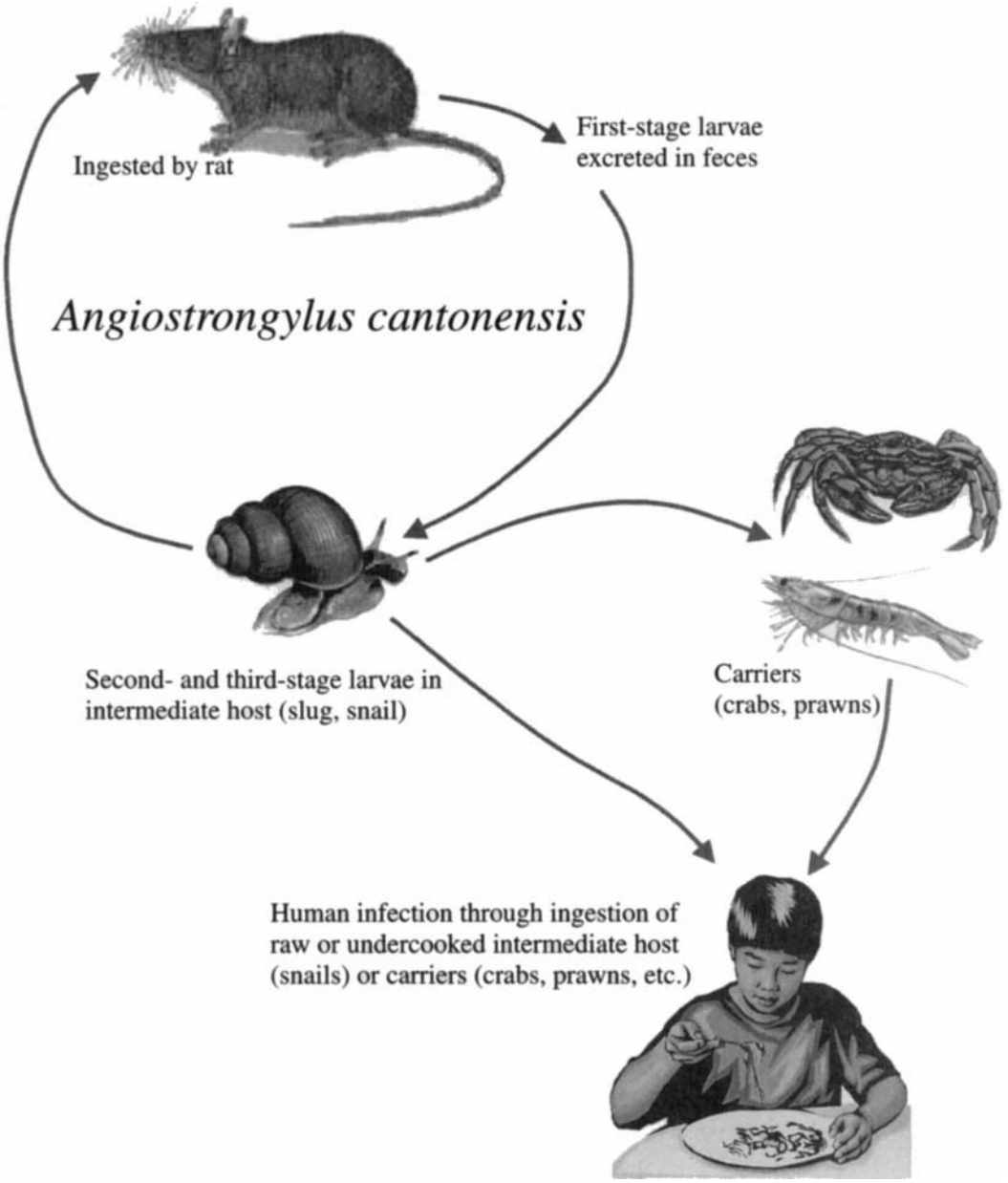

Figure 9–1 Life cycle of *Angiostrongylus cantonensis. Source:* © Crown Copyright.

Anisakiosis

Anisakiosis is a parasitic gastrointestinal disease of man that is caused by the larval stages of nematodes of the family Anisakidae. The adult worms are common parasites of marine mammals (Table 9–2), and the larval stages are found in marine fish and squid. Humans acquire infections by eating the raw or improperly cooked or preserved meat of these animals. There are many

Table 9–2 Food–Borne Helminths (Nematodes, Cestodes)

Parasite Class	*Parasite*	*Distribution*	*Main Hosts (final)*	*Source of Infection to Man*
Nematoda (Roundworms)	*Angiostrongylus*	Asia and Pacific Islands, Australia, India, Africa, Caribbean, parts of United States	Rodents (rats)	Molluscs (snails), shrimps, crabs, amphibians, contaminated vegetables and salads
	Anisakis simplex *Anisakis decipens*	North and South America, Pacific Islands, parts of northern Europe	Pinipeds (whales, dolphins, porpoises) Seals, sealions, walruses	Fish
	Capillaria phillipinensis	Phillipines, Thailand	Man (several species of birds)	Fish
	Dioctophyma renale	Worldwide (North and South America, southern Europe, Asia, Middle East)	Carnivores (mink, ferret, dogs, cats, jackals), man	Fish
	Gnathostoma spinigerum	Thailand, Japan, southeast Asia, China, Mexico (Middle East, Africa, Baltic States, Russia)	Carnivores (dogs and cats), man	Fish , frogs, chickens, ducks, snakes
	Gnathostoma hispidum		Pigs, man	
	Gongylonema pulchrum	United States, former USSR, parts of Europe, Middle East, China, North Africa, New Zealand	Ruminants, pigs, dogs, cats, horses, rodents, primates, man	Salads (insects)
	Trichinella spiralis	Worldwide (except Antartica)	Pigs, rodents, carnivores (mink, fox, badger, bears, walrus, seals), man	Meat
Cestoda (Tapeworms)	*Diphyllobothrium latum*	Northern Hemisphere (northern Europe, Russia, North America, South America, Asia, Africa)	Dog, fox, mink, cat, pig, bear, seals	Fish
	Taenia saginata (Cysticercus bovis)	Central Africa, Asia, South and West Africa, parts of Europe, southeast Asia, Central and South America; also reported in United States, Canada, Australia and Pacific Islands	Man	Meat (beef)
	Taenia solium (Cysticercus cellulosae)	Central and South America, central and east Africa, southeast Asia, southern Europe	Man	Meat (pork)

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species of anisakid nematodes, but those most often associated with human illness are *Anisakis simplex, Pseudoterranova decipiens, Phocanema,* and *Contracaecum* spp.

Public Health Significance

Anisakis causes acute or chronic gastrointestinal disease in man. Migrating larvae cause a foreign-body reaction and eventually necrosis and hemorrhage of the stomach, occasionally creating tunnels and burrows in the stomach mucosa,[139] causing pain, nausea, and vomiting. The acute symptoms subside in a few days, but a vague abdominal pain with intermittent nausea and vomiting persists for weeks, with symptoms resembling those of a peptic ulcer. The condition is often misdiagnosed because of its similarity to other acute gastrointestinal conditions (e.g., gastric ulcers or neoplasm, appendicitis, diverticulitis, Crohn's disease, gallstones, etc.). Diagnosis is normally only made following biopsy and confirmed on histopathology.

Life Cycle

Adult anisakid worms are located in the stomach of marine cetaceans and pinnipeds but do not develop in humans. The life cycle of these worms is shown in Figure 9–2. Humans become infected if an intermediate fish host containing infective third-stage larvae is eaten uncooked.

Distribution

Fish infections are found in most oceans and seas but are highest in areas in which there are high marine mammal populations, such as coastal Japan and Alaska. Many species of fish are naturally infected with anisakiosis, and the prevalence of infection can be very high. In Japanese waters, 123 species of marine fish have been found to harbor the parasite.[118] The global distribution of anisakiosis is summarized in Table 9–2. The highest levels of infection have been reported from Japan and the Netherlands.[88]

Epidemiology and Transmission

The main source of infection from anisakid worms for man is marine fish, many species of which are highly parasitized by anisakid larvae. Humans acquire *A. simplex* by eating raw or poorly salted, pickled, or smoked herring, cod, mackerel, salmon, or squid, and *P. decipiens* from cod, halibut, flatfish, and red snapper. Such traditional preparations as *green herring, lomi lomi salmon, seviche, sushi,* and *sashimi* (i.e., seasoned fish fillets), all of which use raw or uncooked fish, are major sources of infections.[34] In the Netherlands, the occurrence of the disease was due to the habit of consuming raw or lightly salted herring *(green herring).*[162] Although the habit persists, the incidence of human anisakiosis has been drastically reduced by freezing fish before marketing. In recent years, the highest incidence of the disease has been recorded in Japan, where many fish dishes are eaten raw (sashimi); pickled in vinegar (*sunomono*); or fermented in rice, rice bran, or *koji* (sushi and *zuke*). In the United States, at least two cases have been linked to eating *seviche* (i.e., pieces of raw fish seasoned in lemon juice for several hours), and others to eating Japanese raw fish dishes.

Prevention and Control

The risk of human infection with anisakiosis increases in countries where fish are eaten raw.[172] Anisakiosis is preventable by ensuring that only well-cooked marine fish, octopus, and squid are eaten. Larvae are killed by cooking at 60 °C or above. Freezing fish at –20 °C for 24 hours will kill the larvae, with the exception of some North American species that can survive freezing at that temperature for 52 hours. Cleaning and eviscerating fish immediately after they are caught prevents larvae migrating from the intestine to the muscles. Salt curing, marinating, microwaving, and smoking temperatures are insufficient to kill the parasite.[34] Marination of herring has been a long tradition in parts of northern Europe,[85,106] involving the preservation of herring fillets in salt and acetic acid. The salt/acetic acid marination process produces the typical flavor as a result of denaturing of the fish proteins, lowering of the pH, and addition of sugar and spices.[158] The salt/acid treatment may take up to 42 days to kill *Anisakis* larvae, and at low concentrations may not kill larvae at all.[85] Larvae have also been shown to survive in *izushi*

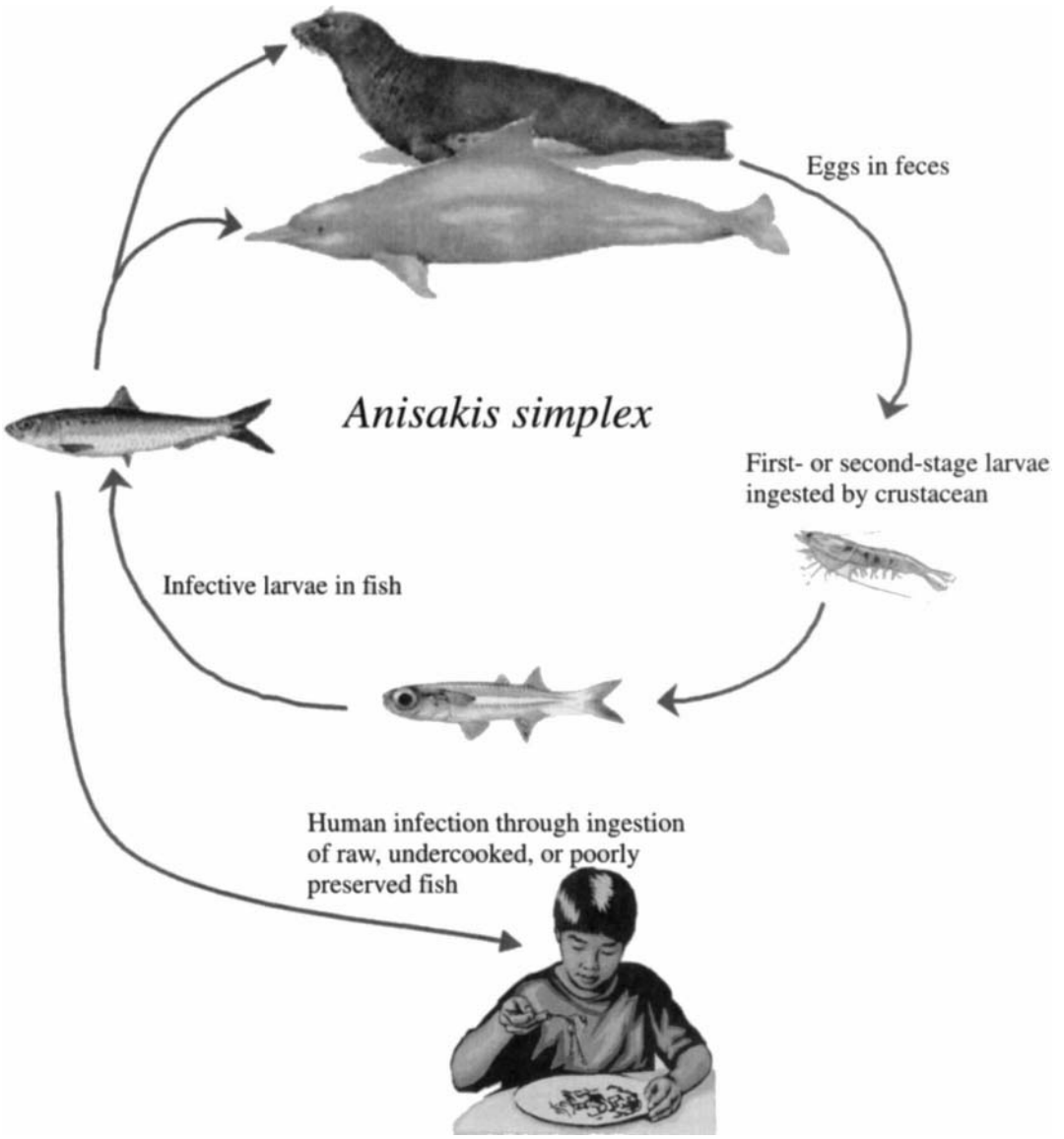

Figure 9–2 Life cycle of *Anisakis simplex. Source:* © Crown Copyright.

(i.e., pickled rice with cod roe, fillets of salmon, and cod) and in sashimi.[118]

Capillariosis

Intestinal capillariosis is caused by a tiny nematode, *Capillaria philippinensis.* The disease was first recognized in the Philippines in the 1960s and has subsequently been reported in other countries.[32,34,93] Man is the main definitive host for the parasite, but several species of birds are now believed to be a natural host and are able to transmit the infection.[35]

Public Health Significance

Infections with *C. philippinensis* can cause diarrhea, anorexia, weight loss, and, if left untreated, death. The parasites cause damage to the

mucosa of the small intestine, leading to fluid, protein, and electrolyte loss. Clinical symptoms include abdominal pain and diarrhea. If treatment is not initiated rapidly, patients die because of the irreversible effects of the electrolyte loss, heart failure, or septicemia. In endemic areas, a diagnosis can be made on patients based on clinical signs. In chronic infections, there is weight loss, wasting, and intractable diarrhea. Infection is confirmed by identifying eggs, larvae, and adults microscopically in the feces. Serological tests are not sufficiently specific for routine use.

Life Cycle

C. philippinensis is a small nematode that is found in the small intestines of man. Further development occurs in fish. A number of species of freshwater fish are suspected to serve as intermediate hosts for the parasite. The fish are usually small and are eaten whole in the Philippines and Thailand, leading to human infection.

Distribution

The distribution of intestinal capillariosis is summarized in Table 9–2. Nearly 2,000 cases of capillariosis have been recorded in the Philippines, with more than 100 deaths. In Thailand, there have been only a few hundred cases, with an unknown number of deaths recorded.[36]

Epidemiology and Transmission

Sanitation facilities are poor in many rural areas of southeast Asia and defecation in the fields is a common practice. During the monsoon rains, the feces are broken down and washed away to streams and ponds, resulting in infection of freshwater fish. These and many other foods are eaten uncooked, especially in the endemic areas of the Philippines and in Thailand.

Prevention and Control

Educating both the local population and visitors of the dangers of eating uncooked freshwater fish can help prevent intestinal capillariosis. Improvement of sanitation and the control of indiscriminate disposal of feces would also be beneficial. No information is available on the conditions that kill the parasite in fish and whether they are known to survive in fermented fish products.

Dioctophymosis

Dioctophyma (Dioctophyme) renale is a large kidney-dwelling nematode of carnivores. Infection is acquired by ingesting raw or undercooked fish or frogs. It has only rarely been reported in man.

Public Health Significance

Infection in man can cause renal damage and associated symptoms of renal colic, hematuria, or urinary obstruction. In humans and dogs, *Dioctophyma* usually locates in only one kidney, most often the right one, and in most cases only one parasite is found, causing little or no clinical symptoms. Infection is diagnosed by the presence of the characteristic thick, bipolar eggs in urine (only if female worms are present).

Life Cycle

D. renale is a large, blood-red nematode that is found in the kidneys of carnivores (Table 9–2). The size of the parasite depends on the size of the host species; in dogs, the adult female of the parasite can reach up to 1 m in length. The intermediate host is a free-living, aquatic segmented worm (oligochaete) in which further development to an infective larva occurs. Transmission to a final host occurs following ingestion of the annelid intermediate host, or more usually following ingestion of a fish or a frog, which act as transport hosts. The prepatent period is from 3½ to 6 months.

Distribution

D. renale is found on all continents with the possible exception of Africa and Oceania (Table 9–2). The most frequently reported form of infection is canine dioctophymosis, with the highest prevalence of infection in Canadian wild mink *(Mustela vison),* where 18% of the animals are infected. The disease is very rare in man, with only a few reports worldwide.

Epidemiology and Transmission

In North America, mustelids, especially mink, appear to be the main reservoir. In other areas, it

is likely that other species of mustelids or wild canids serve as main definitive hosts. These hosts are infected by ingesting frogs or fish (paratenic hosts) and aquatic oligochaetes (intermediate hosts) that contain the third-stage larvae. Dogs and humans are accidental hosts and are infected by ingesting raw fish and frogs, and almost always harbor only one parasite. The rarity of human infection can be explained by the fact that larvae are located in the mesentery and liver of fish and frogs, which generally are not eaten by man.

Prevention and Control

Infection can be prevented, both in humans and dogs, by avoiding the consumption of raw or undercooked fish and frogs. It is not known what conditions result in larval death.

Gnathostomosis

Gnathostomosis is caused by infection with the larval or immature adult stages of nematodes of the genus *Gnathostoma.* Adult parasites are reported in dogs, cats, and other carnivorous animals worldwide. In Thailand, more than 40 species of vertebrates have been reported to be naturally infected. These include freshwater fish, frogs, snakes, chickens, ducks and other birds, rats, mongooses, and tree shrews.[38] Four species, *G. spinigerum* and *G. hispidum,* and more recently, *G. doloresi* and *G. nipponicum,* have been reported in humans in Japan.[111,152]

Public Health Significance

Man is an abnormal host, with infection resulting in a larval migrans causing red, itchy, and edematous subcutaneous swellings that usually last approximately one week but can recur weeks or months later. More rarely, the parasite may enter the eye, causing subconjunctival edema, exopthalmus, impaired vision or blindness through hemorrhage, and retinal damage. Invasion of the central nervous system (CNS) can produce headaches, neck stiffness, drowsiness, or coma and death. Brain hemorrhage and transitory obstructive hydrocephalus have also been reported.[140] Diagnosis in endemic areas is based on history, symptoms, or serology and can be confirmed following the recovery and identification of parasitic larvae.[114]

Life Cycle

Adult worms of *G. spinigerum* are found in tumor-like masses in the stomach wall of fish-eating mammals. The life cycle of *G. spinigerum* is shown in Figure 9–3. The prepatent period is approximately six months.

Distribution

The distribution of human gnathostomiosis is summarized in Table 9–2.

Epidemiology and Transmission

The main source of human infection of gnathostomosis in Thailand is the snake-headed fish, *Ophicephalus* spp., which is one of the fishes used in *som-fak,* a rice-fermented fish dish with widespread popularity. In Japan, freshwater *Ophicephalus* species are eaten raw as sashimi. The ingestion of raw or inadequately cooked fish is the major source of infection in other areas reporting the disease. Infections in Mexico are attributed to eating raw cycloid fish as ceviche.[99] Human infections are also reported from eating raw or poorly cooked catfish, eels, frogs, chickens, ducks, and snakes.[39] Dogs, cats, and several species of wild mammals are reservoirs of the parasite. These definitive hosts become infected primarily through eating infected fish or other animals that serve as paratenic hosts.

Prevention and Control

Health education programs in endemic areas of Asia are required to control this type of infection. Ensuring that people eat only well-cooked fish, eels, or other intermediate hosts such as snakes, frogs, and poultry can prevent infections. Potentially copepod-infested water should be boiled or treated.

Gongylonemosis

Gongylonema pulchrum is a spiruroid nematode of the Thelaziidae family (Table 9–1). It is found in all domesticated mammals, but is most

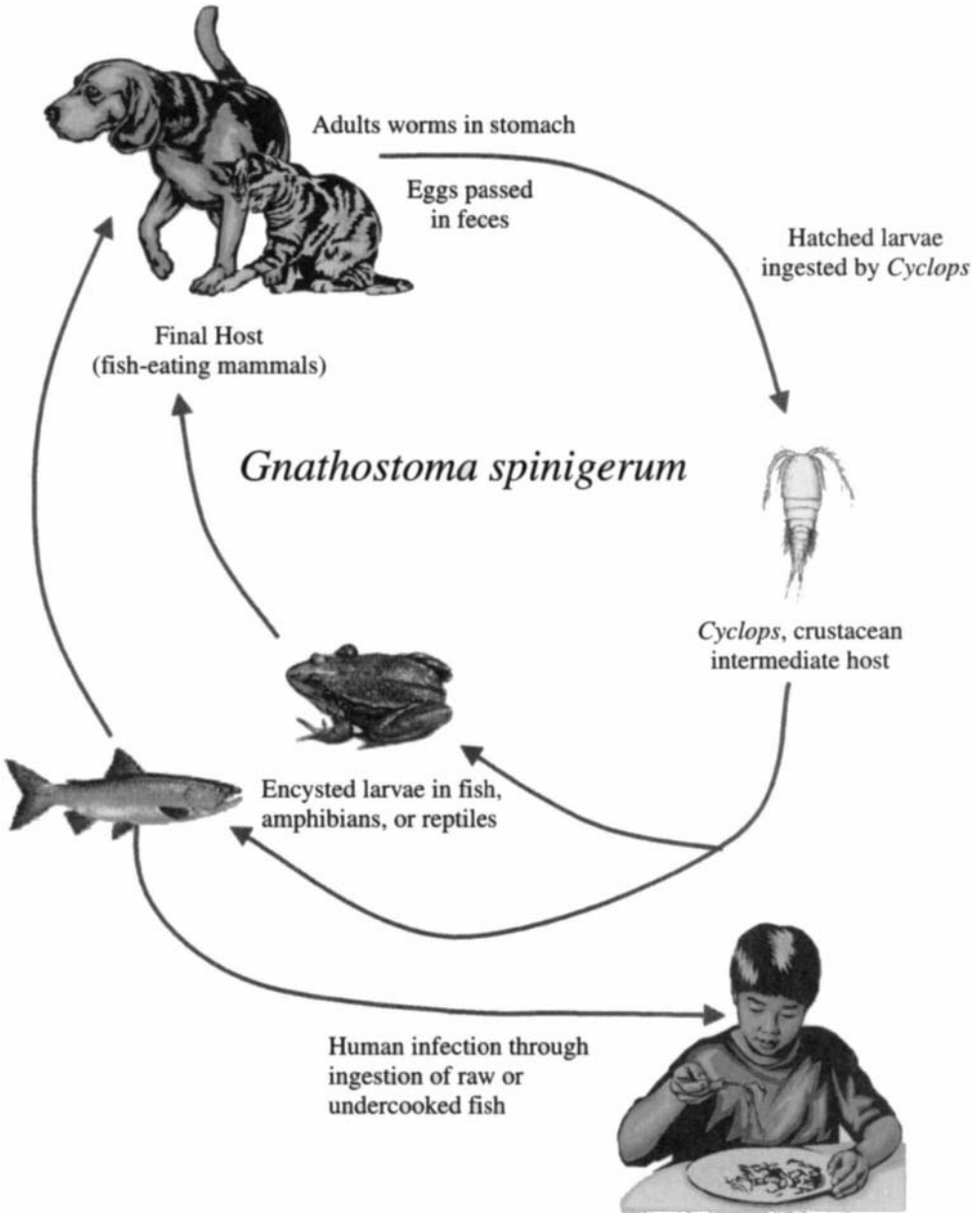

Figure 9–3 Life cycle of *Gnathostoma spinigerum. Source:* © Crown Copyright.

prevalent in ruminants (Table 9–2). Cases of human infection are rare.

Public Health Significance

In humans, gongylonemosis parasites have been found in the submucosa of lips, gums, hard palate, soft palate, and tonsils, with pharyngitis and stomatitis reported. Diagnosis is based on history, clinical signs of mouth irritation, and microscopic identification of the parasite. Occasionally, the parasite has been found emerging from the mouth. Infection in animals is usually

asymptomatic, but may sometimes cause lesions of the mouth or pharynx.[29] In pigs, the parasite is found in the tongue mucosa and may cause occlusion of the esophagus.[179]

Life Cycle

Adult *Gongylonemosis* worms live in the mouth, esophagus, or rumen of the final hosts. The life cycle of *G. pulchrum* involves coprophagic beetles of the genera *Aphodius, Ontophagus,* and *Blaps* as intermediate hosts. Ruminants become infected by ingestion of the beetles with grass or other infested food.

Distribution

Although *G. pulchrum* is widely distributed geographically, human infection is rare. The distribution of *G. pulchrum* is summarized in Table 9–2. Infection in domestic ruminants varies considerably, with high levels of infection reported in the Ukraine (e.g., 32–94% of adult cattle, 39–95% of sheep, and 0–37% of pigs infected),[29] and Iran (e.g., 49.7% of the cattle).[4] In the United States, the parasite was found in 5.9% of pigs, varying from 0 to 21% according to geographic origin.[179]

Epidemiology and Transmission

Man is an accidental host and is probably infected by ingesting beetles on salads and raw vegetables.

Prevention and Control

Because the *Gongylonemosis* parasite is rare in humans and causes only mild symptoms, special control measures are usually not recommended. Individual protection can be obtained by observing the rules of personal, food, and environmental hygiene.

Trichinellosis (Trichinosis)

Trichinellosis (trichinosis) is a food-borne disease that is caused by infection with parasitic nematodes of the genus, *Trichinella.* Infection results from ingesting meat harboring infective larvae. Until recently, *T. spiralis* was accepted as the sole representative of the genus *Trichinella.* It has now become clear that not all populations of the parasite are the same, and five species have recently been proposed.[24] *T. spiralis* is the most important species, with widespread distribution in domestic pigs.

Public Health Significance

Trichinellosis is a cosmopolitan zoonotic, food-borne, parasitic disease resulting from the ingestion of meat harboring the infective larvae of *Trichinella.* Intestinal trichinellosis is usually mild and therefore not often diagnosed, but may cause diarrhea and abdominal discomfort, sometimes accompanied by nausea and vomiting. Ieavy infections can be severe, causing extremely painful muscles, and even fatalities in man. The illness typically begins one to four weeks after ingestion of infective meat, and is characterized by muscle aches and fever. Muscle pain, which may be severe and incapacitating, is an outstanding feature, with the jaw muscles frequently involved. The infection of heart muscle may induce severe, even fatal, myocarditis. Death may also result from encephalitis or pneumonitis. In most parts of the world, the probability of contracting the disease is now low, and its decline, certainly throughout the western world, can be attributed to the introduction of a number of control measures discussed later. Diagnosis may be based on a clinical history of prior consumption of raw or undercooked meat, but this aspect may be missed, particularly in countries where the disease rarely occurs. Clinical signs of muscle aches, fever, and periorbital edema are indicative of the disease. Infection is usually diagnosed by demonstrating larvae in muscle biopsy specimens.

Life Cycle

T. spiralis is a small, nematode parasite that is found in the small intestine of man, pig, rat, and other mammals (Table 9–2). The life cycle of *T. spiralis* is shown in Figure 9–4. Encysted larvae remain infective for months, even years. In some hosts, especially man, they eventually die and become calcified. *Trichinella* is remarkable among parasitic nematodes in having neither a free-living stage between individual hosts nor an intermediate host. The spread of larvae throughout the host musculature permits transmission to

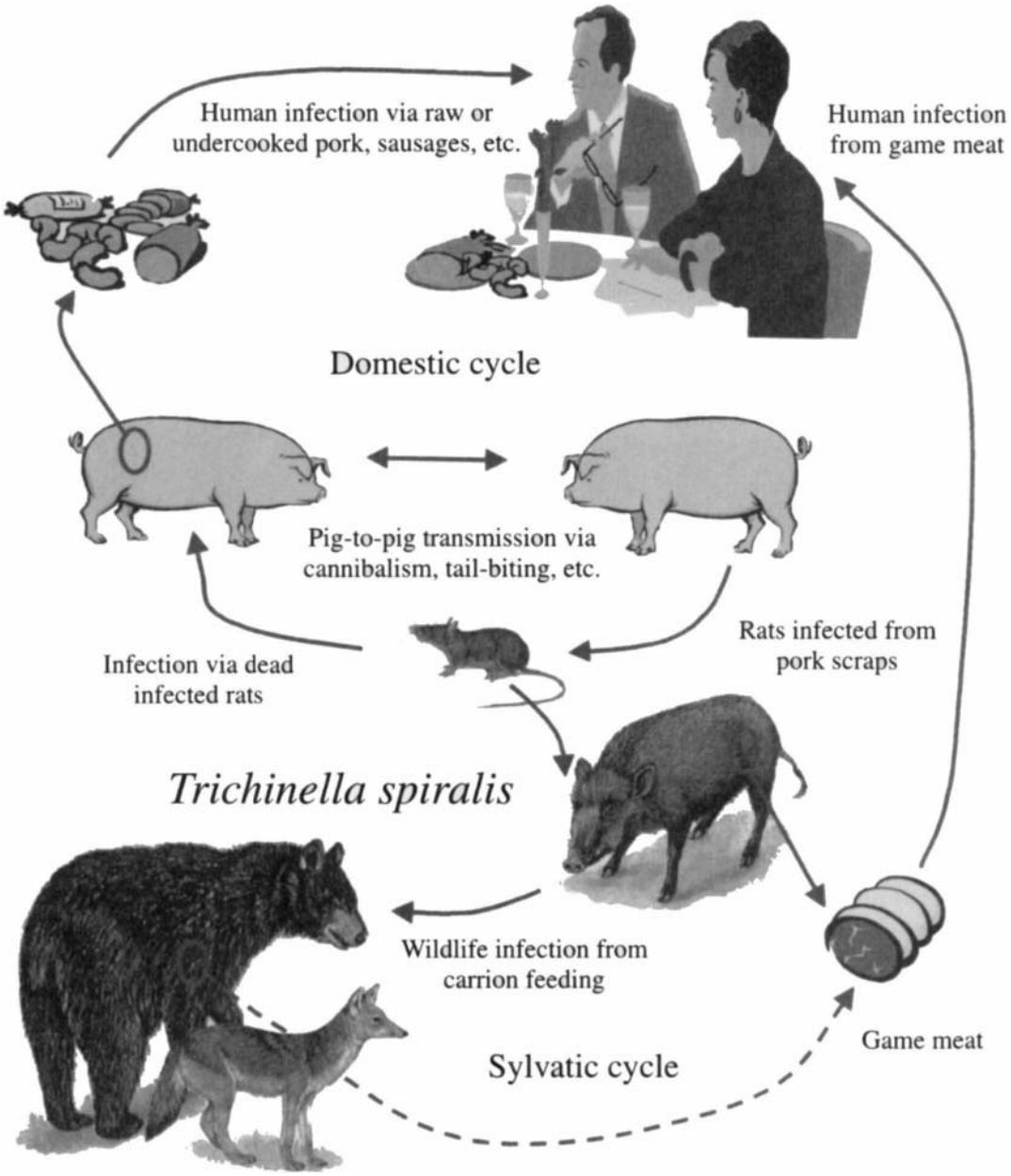

Figure 9–4 Life cycle of *Trichinella spiralis. Source:* © Crown Copyright.

another individual host, but only after the death of the first host.

Distribution

Trichinella has been recorded on every continent except Antarctica (Table 9–2). In many areas, its prevalence in man and pigs has been reduced to a low level, but persists at higher levels in wildlife. Prevalence rates are higher in large carnivorous or scavenging species such as bears, mink, fox, badger, wild boar, and rodents. Information on the global incidence of clinical

trichinellosis in man is not readily available, but it is evident that there has been a striking reduction in western Europe and the United States. Several outbreaks in France and Italy have been associated with eating horse meat that was thought to have become infected by intentionally or inadvertently eating fodder that was contaminated with the bodies of dead rats or mice. Outbreaks of varying severity continue to occur in eastern Europe, the former Soviet Union, Asia, and occasionally elsewhere.

Epidemiology and Transmission

Two distinctive epidemiological cycles of *T. spiralis* are recognized, domestic and sylvatic. The domestic cycle involves pigs and rats, through either the feeding of uncooked pork scraps (e.g., in waste feed) to pigs, cannibalism among pigs (e.g., scavenging of dead carcasses and possibly tail biting of live pigs), or infection of rats by disposal of uncooked pork and the subsequent infection of pigs by the ingestion of infected rats. Human infection occurs when undercooked or raw pig meat is eaten.

In the sylvatic cycle, *Trichinella* is transmitted among species of wildlife. Man becomes infected by consuming game meat. The two cycles may be interrelated by the fact that domestic pigs may scavenge on dead wild animals and vice versa. Rats can also be of significance in this respect in that they may become infected either through eating pork scraps or by scavenging wildlife carcasses. Rats may in turn be hunted and eaten by wildlife predators, or when they die, be eaten by wild carrion feeders or pigs. Crossover of *Trichinella* from one transmission cycle to another may occur, with domestic to sylvatic cycle the more likely[109] as wildlife strains may have low infectivity for rats or pigs.

Prevention and Control

Human infection by trichinae is linked to the consumption of undercooked pork or game meat. A number of measures can therefore be taken to control infection. These involve a combination of consumer education and control of infection in pigs. Pig herds can be kept free of infection by ensuring that pork scraps are not fed to pigs. In some countries, laws requiring waste food (swill) to be cooked before being fed to pigs have been introduced to help control a number of important viral pig diseases. Good husbandry and rat-proofing piggeries also help control infection. In many countries, meat inspection procedures have been introduced to identify infection.

Ethnic or cultural practices in which meat is eaten undercooked or raw are a particular risk area and may call for special educational measures. Traditional types of sausage (including fermentated sausage) that receive little cooking have long been associated with human disease. Education draws attention to the need to freeze or cook such foodstuffs. Freezing may be more acceptable because it has less effect on flavor and taste than cooking. To be effective, meat must be frozen throughout and stored for sufficient time to ensure death of encysted larvae. The thermal death point of *T. spiralis* is approximately 57 °C, and cooking pork so that it reaches a temperature of 77 °C gives a margin of safety without destroying the taste of the meat. Slightly lower temperatures may be adequate provided the temperature is achieved uniformly throughout the meat. It can be assumed that pork will be safe if it is cooked until there is no red or pink coloration throughout. In the United States, fermented pork sausages must either originate from *Trichinella*-certified meat or be heated to 58.3 °C at the end of the fermentation process.[89] Although certain factors such as pH may affect survivability of trichinae in fermented sausage, prescribed heat treatment is considered necessary.[31]

CESTODES (TAPEWORMS)

There are a number of food-borne tapeworms that infect humans, of which a few are acquired by eating meat or fish. A general description and classification of food-borne tapeworm species is provided in Table 9–1.

Diphyllobothriosis

Although there are various species of fish tapeworm reported in humans, the most important is *Diphyllobothrium latum.*

Public Health Significance

Diphyllobothriosis is usually asymptomatic, but long-term infection with the tapeworm may produce vitamin B_{12} deficiency leading to anemia. The presence of several worms may cause intestinal obstruction. CNS signs of peripheral and spinal nerve degeneration have been reported. Diagnosis is based on identifying the presence of the characteristic eggs in human feces.

Life Cycle

The fish tapeworms are among the largest worms to infect humans. Adult tapeworms are found in the small intestine, ranging from 2 m to 15 m in length and living as long as 10 years. Many species of fish such as pike, perch, turbot, salmon, and trout serve as second intermediate hosts. The life cycle of *D. latum* is shown in Figure 9–5.

Distribution

The distribution of *D. latum* is widespread in the temperate and subarctic regions of the Northern Hemisphere where freshwater fish are eaten. Distribution is summarized in Table 9–2.

Epidemiology and Transmission

Diphyllobothriosis is transmitted by the ingestion of infected, raw, or improperly cooked freshwater fish. Human cultures with preferences for smoked, pickled, or raw fish (such as sashimi or sushi) are at particular risk.

Endemnicity is maintained where there is poor sanitation, or, due to the practice of lakeside hotels, pumping of raw sewage into freshwater lakes. The parasite may have been spread by the emigration of infected people from endemic areas into lake regions in which susceptible copepods and fish were present. Scandinavian and Russian immigrants are thought to have introduced the parasite into the Great Lakes region of North America and Alaska.

Prevention and Control

Human infection is easily prevented by ensuring that freshwater fish is well cooked or by changing dietary habits through education. If fish is to be eaten raw, smoked, pickled, or fermented, then freezing at –10 °C for 1–3 days should kill pleurocercoid larvae in the fish tissue. Sewage from lakeside hotels and from leisure boats should be treated before release into the lakes.

Taeniosis (Cysticercosis)

Taeniosis is intestinal infection with a preadult or adult stage of a tapeworm of the genus *Taenia*. Only two species, *T. saginata* and *T. solium,* infect human intestines as adult tapeworms, and man is the only known final host. Intermediate stages of these human tapeworms infect the tissues of meat-producing animals. Tissue infection with a metacestode stage of *Taenia* is referred to as cysticercosis. The intermediate hosts of *T. saginata* and *T. solium* are domesticated cattle and pigs, respectively, but several other ruminants, including sheep, goats, and llamas, have been recorded as carriers of *C. bovis,* although the validity of these hosts has been questioned. The reindeer, *Rangifer tarandus*, has been shown to act as an intermediate host in Russia. Cysticerci thought to be *C. cellulosae* have been reported in monkeys, wild pigs, bush babies, camels, rabbits, hares, bears, dogs, foxes, cats, rats, and mice. Four species (i.e., *T. solium, T. saginata, T. multiceps*, and *T. hydatigena*) parasitize human organs as cysticerci; the last three species invading man only exceptionally.[163] Other species, *T. serialis, T. longihamatus, T. crassiceps,* and *T. taeniaeformis,* have occasionally been diagnosed as a cause of cysticercosis in man.[12,14,92]

Public Health Significance

Taeniosis itself causes little if any disability and morbidity. Conversely, human cysticercosis has a definite public health significance, causing disability and death in infected people. Cysticerci may be found in every organ of the body of man, but are most common in the subcutaneous tissue, eye, and brain. In the brain (neurocysticercosis), the tissue reaction that occurs may cause a variety of CNS disorders, some of which may be fatal. In endemic areas, neurocysticercosis may be responsible for 30–60% of cases of epilepsy, and mortality may

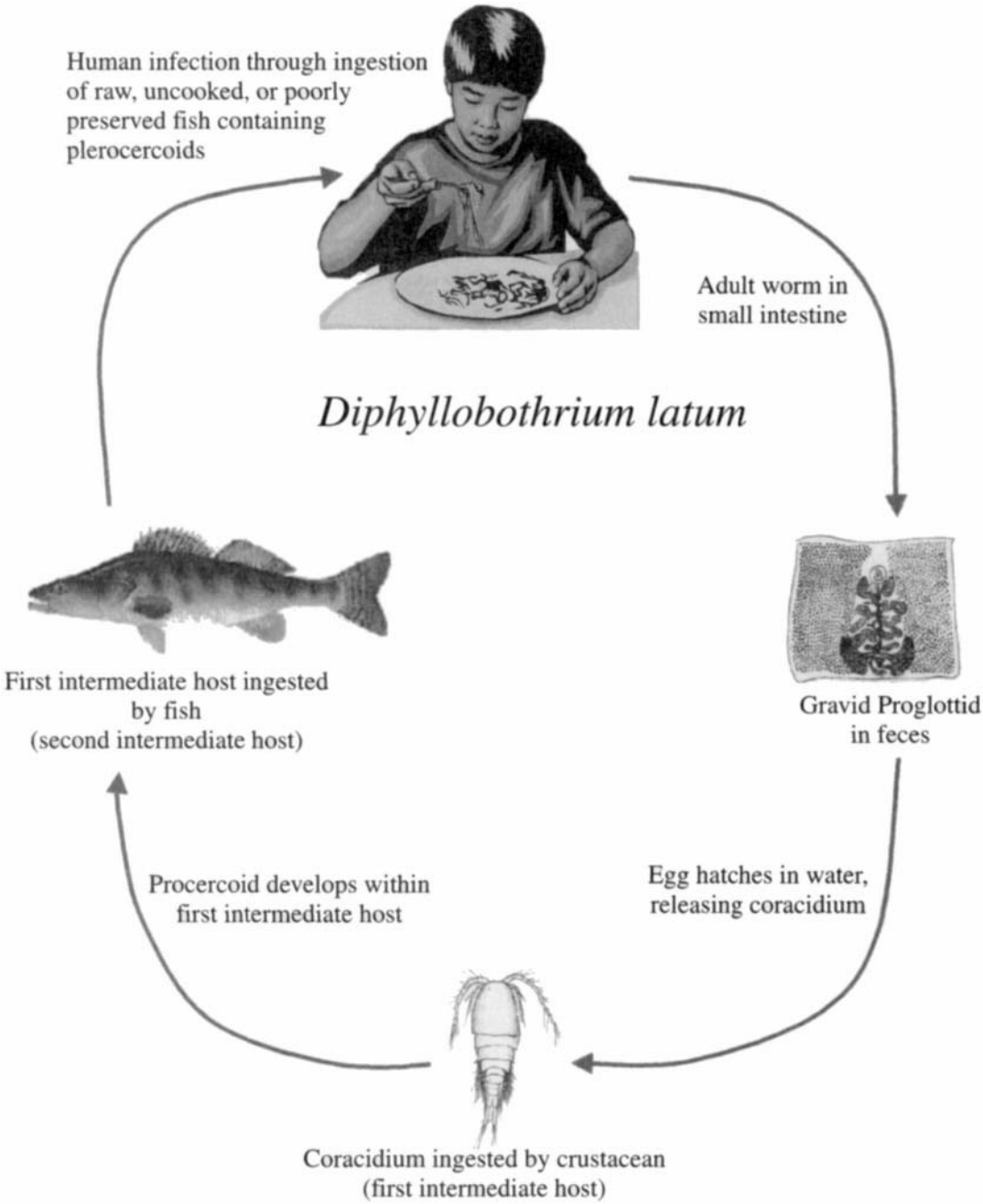

Figure 9–5 Life cycle of *Diphyllobothrium latum*. *Source:* © Crown Copyright.

range from 1% to 2% of all causes of death. For a long time, treatment of taeniosis was neither safe nor satisfactorily effective; however, the introduction of effective taenicides has seen a dramatic improvement in therapy. Diagnosis of human taeniosis is not always straightforward and is based on clinical symptoms and the identification of tapeworm proglottids or eggs during

stool or anal swab examination.[72] Repeated fecal examinations increase the chances of finding eggs, and diagnosis can be improved by taking perianal swabs using sticky cellophane tape. A fecal antigen test has also been reported.[3,41]

Life Cycle

Adult tapeworms of *T. saginata* measure 4–12 m in length and take approximately three months to become fully grown. *T. solium* is shorter, 1.5 m to 8 m, and takes 62–72 days to mature. Both tapeworms are found in the small intestine of man and may live for up to 25 years. The life cycles are similar, involving cattle and pigs respectively (Figure 9–6).

Distribution

T. saginata (*C. bovis)* occurs in many cattle-breeding regions and especially where beef is eaten raw or undercooked. Distribution of *T. solium* (*C. cellulosae*) is usually confined to poor countries because it is mainly related to the low sanitation in pigs' breeding areas. Human migration and increased consumption of pork increases the spread of taeniosis/cysticercosis from the endemic rural areas into urban areas. Bovine cysticercosis has a high prevalence in western and eastern Central Africa and some Asian countries.[60] Moderate infections are seen in other countries[125,173] and are summarized in Table 9–2. The prevalence of bovine cysticercosis in Europe and the United States has decreased throughout the twentieth century, through the introduction of meat inspection procedures in these countries. Fluctuations in prevalence in Europe have occurred as a result of the migration of people following World War II and increased tourism,[124] and in the United States, occasional outbreaks have been attributed to Mexican immigrant workers.[141]

The distribution of pig cysticercosis is also summarized in Table 9–2. In countries that are supposed to be free of *T. solium* infections, human cysticercosis may occur sporadically, mainly due to contact with infected migrants or tourists.[76]

Epidemiology and Transmission

Man becomes infected with taeniosis by eating raw or undercooked meat containing viable cystercerci. The life span of cysticerci varies, probably due to parasite or host strain variations, different infection doses, and host immunological responses. *C. bovis* in cattle, for example, remain viable for nine months to three years. Numbers of cysticerci depend not just on the degree of exposure to infective and viable tapeworm eggs, but also on the level of host immunity that can effectively reduce the number of developing cysticerci.

Adult tapeworms have a high biotic potential. Within infected human populations, the total production of eggs can be enormous. The eggs are sensitive to temperatures higher than 38 °C and to desiccation, but are capable of surviving European winters for 35 days[58] and of surviving in sea or brackish waters for some time. The eggs are also relatively resistant to chemicals. *T. saginata* eggs remain infective for calves after 16 days in sewage, up to 71 days in sludge, and for several months in pastures.[110]

Animal husbandry practices, human eating habits, sanitary education, and willingness to cooperate in control programs are all factors that may further influence the transmission of taeniosis. Poverty, ignorance, and some local customs of eating raw pork or raw meat or viscera may also play an important transmission role. The habit of eating raw meat or semi-raw sausages is strongly rooted in some cultures.

Prevention and Control

Control measures include improved diagnosis and treatment of human taeniosis as well as proper pig and cattle husbandry and the instigation of meat inspection procedures. However, routine meat inspection may be inadequate for light infections and may miss more than half of the infected animals.[165] In cattle, the heart is most frequently infected; in pigs, the tongue is the most commonly infected organ.[125] Poor local sanitation is largely responsible for the ease of transmission in rural endemic areas.

Food transmission can be controlled by avoiding the consumption of raw pork or beef or semi-raw meat products. Freezing infected pork or beef can kill the cysticerci when the internal temperature of meat or a carcass is less than –5

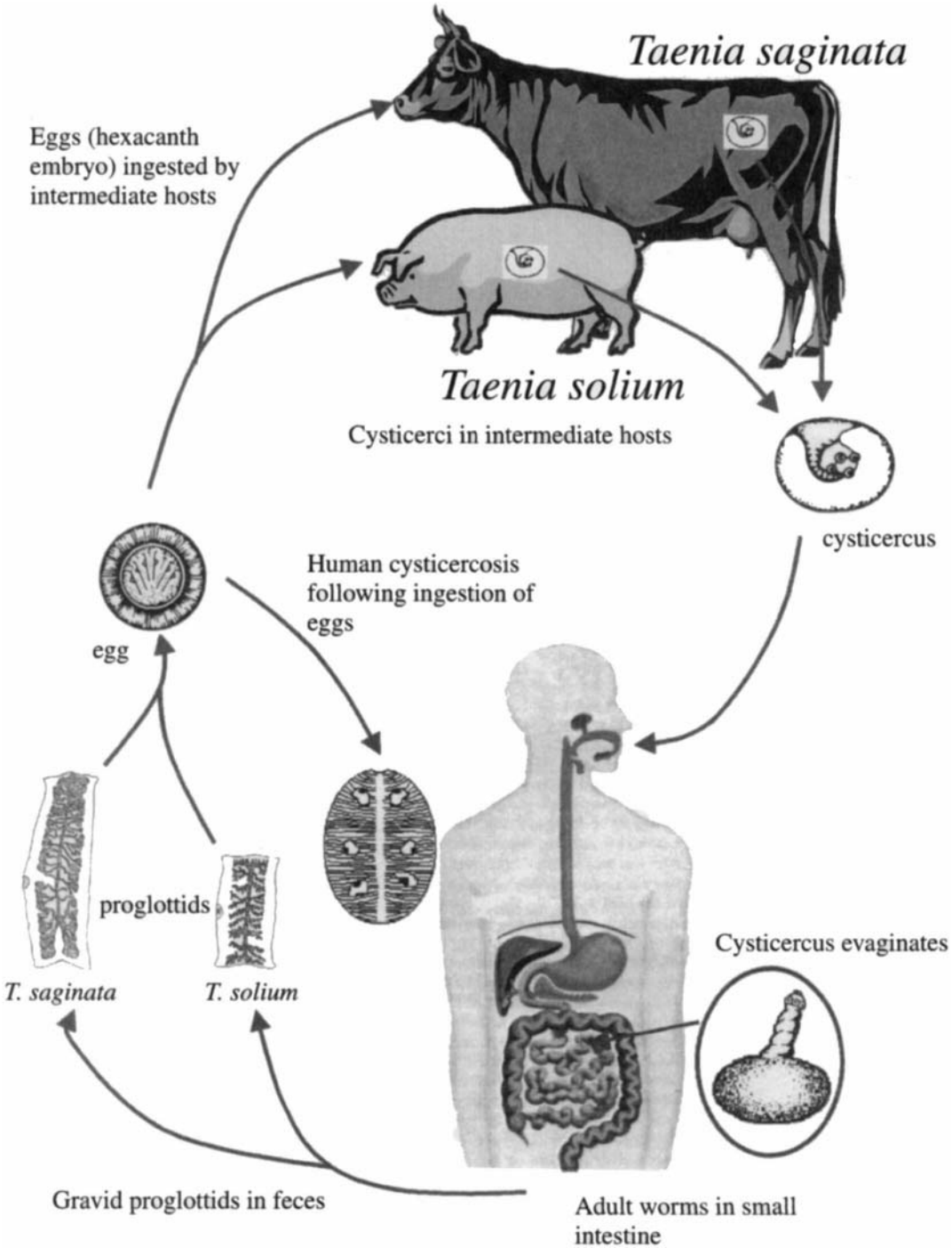

Figure 9–6 Life cycle of *Taenia solium* and *Taenia saginata*. *Source:* © Crown Copyright.

°C for at least four days or around –20 °C for at least 12 hours. It is not known if cysterci can survive meat fermentation conditions, but it would seem sensible to freeze or heat treat flesh ingredients wherever possible.

TREMATODES (FLUKES)

Trematodes or flukes are unsegmented, dorso-ventrally flattened, leaf- or lancet-shaped parasitic worms. The life cycles of the parasitic flukes discussed in the text are indirect, involving a variety of intermediate hosts. A general description of food-borne flukes and their classification is provided in Table 9–1.

Clonorchiosis

Clonorchis sinensis (*Opisthorchis sinensis*), the Chinese liver fluke, is a trematode infection that is found throughout southeast Asia. The parasite is acquired by eating raw or poorly cooked or preserved freshwater fish, particularly carp, and can infect a range of mammals, including man.

Public Health Significance

Human infections may be present for many years without causing overt signs of clinical disease. The development of clinical signs depends on the number of worms present, which can number several thousands in heavy infections. Large numbers of flukes in the bile ducts can cause cholangitis (inflammation of the bile ducts) and gallstones in man,[115] and may possibly predispose to cholangiocarcinoma.[143] The parasite may on occasions enter the pancreatic ducts, causing dilatation, fibrosis, and pancreatic stones.

Life Cycle

Adult flukes, which may live as long as 30 years, inhabit the bile ducts of man and other fish-eating mammals. More than 100 species of fish are reported hosts for the parasite in Asia. The life cycle of adult fluke is shown in Figure 9–7.

Distribution

The parasite distribution of flukes is shown in Table 9–3. Infection rates have decreased in Japan in recent years, but infections remain widespread in China, Taiwan, and Korea. The prevalence and distribution of infection is associated with the presence of susceptible snail and fish intermediate hosts and habits of the indigenous populations. It has been suggested that close to 25 million people are infected in Asia, mostly in southern China and North Korea.

Epidemiology and Transmission

Infection by flukes in man occurs by eating raw, undercooked, or poorly preserved infected fish. In some areas where the parasite occurs, fish is eaten raw in thin slices with rice (*congee*). The eating of raw freshwater fish has become increasingly popular in several Far Eastern countries, and consequently the prevalence of human infection is increasing. Infections outside of Asia are usually imported. In most endemic areas, cats and dogs are infected in high numbers. Levels of infection are maintained by the practice of fertilizing ponds used to raise fish with human excrement.

Diagnosis is based on the identification of the characteristic eggs in fecal samples, which have to be differentiated from other trematode eggs such as *Heterophyes heterophyes, Metagonimus yokogawi, Haplorchis taichui,* and *Opisthorchis* species (Table 9–4). Several serologic tests have been developed, but most are nonspecific. A reported enzyme-linked immunosorbent assay (ELISA) may be of value.[30]

Prevention and Control

In endemic areas, treatment of all infected persons and improved sanitation would help control infection by flukes. In areas where fish are raised in ponds, human and animal feces should be composted or sterilized before they are applied as fertilizer to ponds.

Thorough cooking of all freshwater fish is the most effective means of controlling infection by flukes. Clonorchiosis can be prevented by avoiding eating raw, undercooked or improperly pickled, salted, dried, smoked, or fermented fish in endemic areas. There is little or no information on conditions affecting the survivability of the encysted infective stages in fish flesh. Education projects are of some benefit, but the eating of raw or fermented freshwater fish has been a

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