Parasitic food-borne and water-borne zoonoses

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Summary
Estimates suggest that almost half of the population of the world is affected by water-borne and food-borne infections. Parasitic food-borne and water-borne zoonoses contribute to this statistic by inflicting a heavy toll on human health and causing serious direct and indirect losses to the agricultural industry. The inability of non-industrialised countries to keep pace with population growth, migration from rural to urban areas and the demand for clean, safe drinking water and proper sanitation means that water-borne zoonoses will continue to exact an increasing burden of ill health in these countries. The consumption of raw or undercooked meat, crustaceans, and fresh-water fish and vegetables facilitates transmission of large numbers of zoonotic infections. The burgeoning tourist industry, emigration and the importation of food from endemic regions has resulted in increasing diagnosis of these infections in non-endemic countries. The authors examine the epidemiology, medical and veterinary public health importance and recent developments in diagnosis, treatment and control of the most important parasitic food-borne and water-borne infections.

Keywords

Introduction

The insidious nature of most food-borne and water-borne parasitic zoonoses, combined with the lack of collaboration between policy makers in the fields of human and animal health has resulted in the under-reporting of the economic and public health importance of zoonotic infections. Spectacular advances have been made in the areas of epidemiology, diagnosis, treatment, mathematical models and cost-benefit analysis. However, to make a practical difference, these advances must be combined with a clear understanding of human behaviour, cultural differences and socio-economic status (education, occupation and financial status) of individuals in different parts of the world. The low socio-economic status of non-industrialised countries in terms of medical, veterinary and diagnostic institutions, trained personnel and financial status, provides conditions for the proliferation of parasitic zoonoses.

An overview of the distribution, clinical manifestations and public health importance of zoonotic protozoa and helminths is presented, along with current methods of diagnosis, treatment and control.

Protozoa

Toxoplasmosis
Distribution and public health importance
Toxoplasma gondii is possibly the most widespread and prevalent protozoan parasite on earth, infecting approximately half a billion people (26). The range of prevalence reported world-wide is great and may locally depend upon meat consumption habits and the population density of cats. In Europe, the seropositivity rate among adults varies from 10% to 80% and increases significantly with age. In most countries of central Europe, the seroprevalence for women of child-bearing age ranges between 30% and
Toxoplasma gondii is a parasite of domestic and wild cats that potentially is capable of infecting all vertebrates (21). Cats become infected from three sources, namely: by ingesting tissues from animals harbouring cysts of T. gondii that contain the slow-developing organisms called bradyzoites; by ingesting tissues from acutely infected animals with rapidly developing tachyzoites; and by ingesting oocysts shed in the faeces of other cats (17). After ingestion, T. gondii enters the feline intestinal epithelium in which the parasite develops, first through asexual stages or, under certain conditions, directly to the sexual stages. After fertilisation, zygotes develop into oocysts which enter the lumen of the intestine and are shed, unsporulated, in the faeces. The time from ingestion of cysts until shedding of oocysts is three to ten days and shedding usually lasts from seven to twenty-one days. Oocysts are not infectious immediately after shedding, but require exposure to air at room temperature for approximately two days. Sporulated oocysts contain two sporocysts, each of which contains four sporozoites. Cats can repeat oocyst shedding after reinfection, although the number shed is far less than during the primary infection (21).

Infection of a non-feline host with either oocysts or tissue cysts will allow tachyzoites to undergo repeated, rapid multiplication by a process called endodyogeny, until, influenced by the immune system of the host, the multiplication rate slows and the tachyzoites transform into bradyzoites. These become surrounded by a cyst wall and remain dormant but infectious in the tissue for long periods of time, sometimes for the life of the host. Bradyzoites transform back into tachyzoites when the cysts are ingested by another host or when the immune system of the current host is suppressed by malnutrition, disease, or medication.

Toxoplasmosis can be transmitted to humans via several routes. Although a major source of infection is thought to result from contamination of the environment with oocysts shed in cat faeces, the extent of human infection resulting from this route is not known. Faeces are deposited in gardens, fields, lawns, pastures, playgrounds and any other location available to cats. The oocysts measure only 10 µm to 12 µm in diameter and are dispersed easily by wind, water, shoes and feet of humans or animals and numerous other routes. Oocysts can remain infectious for a year or more if protected from temperature extremes, intense sunlight and desiccation.

Transmission of T. gondii by ingestion of tissue cysts in raw or undercooked meat from a variety of livestock and game animals has been documented as another major source of human infection (21). Specific cultural preferences for undercooked or raw meat inevitably result in a higher prevalence of infection. In France, 204 children became infected after being hospitalised and fed meals of very rare or raw meat (14). The risks presented by general association with meat are less clear; abattoir workers in Egypt and Ghana were not found to be at higher risk of acquiring T. gondii than the general population, whereas abattoir workers, butchers, and meat inspectors in Japan and Brazil were found to be at higher risk (26). Water-borne transmission of T. gondii oocysts has been documented rarely and may not be epidemiologically significant.

Pathogenesis and clinical features
Initial clinical signs of toxoplasmosis are usually characterised by non-specific and variable symptoms resembling those of influenza. Acute infections include dermatomyositis, encephalitis, enteritis, hepatitis, lymphadenitis, myocarditis, placentitis, pneumonitis, retinochoroiditis, skeletal myositis, tenosynovitis, tonsillitis, vasculitis, anaemia and fever (26). The period of incubation is quite variable; in most cases, clinical signs are manifested a few days to a few weeks after exposure. Duration and severity is very limited among immunocompetent persons. In patients with cancer or acquired immune deficiency syndrome (AIDS), infections of long duration, followed by death, may occur. A risk group of special interest is non-immune pregnant women. In Europe, congenital toxoplasmosis is reported in approximately 0.1% to 0.2% of pregnancies where the mother is seronegative prior to or during early pregnancy (23). Approximately 25% of the foetuses will exhibit pathologically distinct manifestations, for example, cerebral malformations or severe retinochoroiditis. The remaining 75% will exhibit sub-clinical forms of infection, which may exhibit post-natal manifestations such as chorioretinitis or mental retardation. In general, the earlier in pregnancy infection is acquired, the greater the extent of lesions in the foetus will be.

Diagnosis
In humans and animals, direct diagnosis is based on medical history, tissue sections, tissue biopsies, fluid aspirates, or other diagnostic substrates that may contain T. gondii organisms. The detection of parasites can be performed using microscopy, histological or immunohistochemical procedures. As parasites can be few in number, these approaches have low sensitivity. Alternatively, diagnostic amplification of T. gondii deoxyribonucleic acid (DNA) by the polymerase chain reaction (PCR) has been used successfully in investigations of the parasite in both humans and animals (5, 58).
Serological tests include, among others, direct agglutination tests, the Sabin-Feldmann dye test, the indirect fluorescent antibody test and the enzyme-linked immunosorbent assay (ELISA). Agglutination tests and ELISA are available commercially, the latter is offered to detect immunoglobulin (Ig) M, IgG and IgA and even to assess the avidity of the antibody binding reactivity in order to discriminate between recent (acute) and old infections. In veterinary parasitology, serological tests can only indicate that an animal has been exposed to T. gondii or is currently infected. Avidity tests to determine recent infections are under development.

Serology is unreliable for diagnosis of infection in animals or meat. Diagnosis is possible if the diagnostic material is inoculated into mice or fed to cats, with a subsequent demonstration of infection in these animals. To confirm transmission of organisms from suspect tissues, tachyzoites can be detected in mouse peritoneal exudate after four to six days and possibly only after four weeks post inoculation. Toxoplasma gondii antibodies can be found in the mice two to three weeks after inoculation, and cysts will be present in the brain one month after inoculation. Oocysts can be shed in cat faeces a few days or later after potential infection.

**Treatment, prevention and control**

Chemotherapeutic treatment for toxoplasmosis in humans has been reviewed (36). Pyrimethamine with sulphonamides acts synergistically against the rapidly dividing tachyzoite stage and is the treatment of choice in many countries. Spiramycin and clindamycin, macrolide antibiotics, are also reported to be effective treatments. All these compounds have serious side-effects and must be used with caution. In cats, monensin and toltrazuril appeared effective against the intestinal developmental stages of T. gondii, the latter drug also affects the extraintestinal stages.

Measures that reduce or eliminate contamination of the environment with oocysts from cat faeces will help prevent toxoplasmosis (26). Cats should be prevented from hunting birds and rodents, and should be fed thoroughly cooked, dry or canned food. Litter pans should be used in the home and emptied daily. Sandboxes for children should be covered when not in use and gardeners handling soil should wear gloves and wash their hands thoroughly before eating or handling food. On the farm, barns, stalls, feed bunkers, waterers and other areas should be kept free of cat faeces.

All meat should be cooked thoroughly before eating. Extensive studies have been conducted that demonstrate thermal death curves for cooking meat, and indicate the necessary combination of time versus temperature for rendering T. gondii non-infectious; 60°C or higher as minimal core temperature in meat; freezing (−15°C or lower) or gamma-irradiation (0.5 kGy) are other effective measures.

Vaccination of cats has exhibited 85% efficacy using the mutant strain T-263 (19), and vaccination of sheep with the commercial live vaccine strain S-48 inhibits abortion but does not completely prevent cyst formation in infection-challenged animals.

**Sarcocystosis**

Sarcocystis spp., like T. gondii, are coccidian protozoans which have a global distribution. The life-cycle is heteroxenous with herbivores (domestic and wild) primarily acting as intermediate hosts, containing zoitocysts (formerly known as sarcocysts), and carnivores (domestic and wild), including humans, serving as definitive hosts. Numerous species of Sarcocystis infect cattle, sheep, pigs, horses, camels, buffalo and wild game animals. Heavy infections in these intermediate hosts may cause abortion, anorexia, fever, anaemia and reduced live weight gain. Two species are recognised as zoonotic, namely: S. hominis and S. suihominis, although zoitocysts of unknown origin have also been found in humans (87). The public health implications of this are unknown but may indicate that the genus is a much more important zoonosis than is currently appreciated. Humans acquire S. hominis by consumption of uncooked beef containing zoitocysts. Sarcocystis hominis is only mildly pathogenic in humans, causing stomach pains, nausea and diarrhoea. Sporocysts begin to be passed in the faeces after 14 to 18 days (11 to 13 days after infection with S. suihominis).

Sarcocystis suihominis is acquired by eating zoitocysts in undercooked pork. Sarcocystis suihominis is more pathogenic than S. hominis, causing stomach pains, nausea, diarrhoea and dyspnoea within 24 hours of infection. No effective treatment is available for either intermediate or definitive hosts. Control is possible by avoiding eating undercooked meat.

**Giardiosis**

**Distribution and public health importance**

Various genetic variants of *Giardia* infect humans and animals world-wide. In 1976, a survey in the USA reported *Giardia* in 3.8% of nearly 415,000 people. In 1980, the parasite was found to infect from 2% to 20% of people in the USA (depending on the population sampled) (11). Transmission of giardiosis from animals to humans remains controversial. The close association between humans and companion animals provides opportunities for transmission. In central Europe, high rates of cyst excretion have been reported in pet animals, including dogs (0.5%-18%) and cats (2%-5%) and in livestock, including calves (27%) and lambs (30%) (79). Untreated surface water in unpopulated areas may be contaminated through reservoir hosts, including beavers (Castor fiber), muskrats (*Procyon lotor*), muskrats (*Ondatra zibethica*), moufflon (*Ovis musimon*) and other species (26). Evidence for direct zoonotic transmission and the ability to attribute outbreaks to specific host species depend upon markers to identify and distinguish *Giardia* from wild animal, domesticated animal, and human sources (41).

**Parasite biology, life-cycle and epidemiology**

*Giardia intestinalis* (synonyms: *Giardia duodenalis*, *Giardia lamblia*) is a flagellate exhibiting a very simple and direct
life-cycle. After ingestion of GIardia cysts, each of which harbour two identical parasite trophozoites, the cysts pass through the duodenum and then the organisms leave the cyst and undergo binary fission to form new trophozoites that continue to proliferate and establish infection in the host. The bi-nucleate, motile feeding stage, the trophozoite, attaches to the epithelium in the upper part of the small intestine by a ventral, disk-like organelle. Trophozoites swept into the lumen undergo mitotic division or transform into the cyst stage that passes from the host in faeces. Morphologically, the trophozoite has a face-like or pear-shaped appearance and, when viewed with the narrow end down, the paired nuclei look like eyes, the anterior flagella loop above the nuclei appears like eyebrows, and the median body resembles a down-turned mouth (26). Trophozoites measure from 9 µm to 21 µm in length and from 5 µm to 15 µm in width. GIardia cysts have a visible but not prominent wall, are ellipsoidal, contain four nuclei and paired axonemes, and measure approximately 8 µm to 12 µm in length by 7 µm to 10 µm in width. Transmission of the dormant, environmentally resistant cyst stage is via the faecal-oral route, indirectly through contaminated water or food, or by direct person-to-person contact. Cysts can remain infectious for several months under moist and cool conditions, but lose infectivity rapidly under dry, hot conditions. Conventional decontamination of drinking water using chlorine is ineffective against GIardia cysts. GIardia has been identified more often than any other pathogen in water-borne disease outbreaks in the USA (26). Most outbreaks have occurred in water systems of small communities. Infrastructures at risk include water supplies in campsites, parks, resorts and institutions, or individual water systems, including non-potable sources. Infection can also follow ingestion of water while swimming or diving. A seasonal trend, especially during the summer, implies either increased contamination of non-community water supplies or use by greater numbers of susceptible persons. Most cases have been attributed to contaminated surface water but a few represent contamination by groundwater. Food-borne transmission of GIardia due to faecal contamination may occur through contaminated vegetables or salads, although this seems to play a minor role in the epidemiology of giardiosis in humans (26).

Pathogenesis and clinical features

Initial signs of illness associated with giardiosis include nausea, anorexia, discomfort in the upper intestine and fatigue. This is followed by bursts of foul-smelling watery diarrhoea, flatulence and abdominal distension, usually lasting only a few days. Occasionally, this acute stage can last for months, causing malabsorption, weight loss, and dehydration (26). Chronic infection is marked by recurrent brief episodes, or to a lesser extent, persistent episodes of foul-smelling loose stools, flatulence and abdominal distension. Lactose intolerance, common during active infection, may persist for a period thereafter. Mortality has been reported very rarely.

Diagnosis

Diarrhoea caused by giardiosis must be differentiated from other entero-pathogenic agents by diagnosis. Some clinical indications for giardiosis are provided by the presence of upper-abdominal cramps, abdominal distension, flatulence, steatorrhoea and foul-smelling faeces and by the absence of blood and mucus in the faeces. Traditionally, diagnosis is based on identification of cysts or, less frequently, trophozoites in faeces, or trophozoites in duodenal aspirates or biopsies. Most diagnoses can be performed by stool examination. Fresh stools must be examined immediately by wet smear or preserved in buffered formalin solutions such as sodium-acetate-formalin (SAF) or merthiolate-iodine-formalin (MIF). At least three stools collected on alternate days should be examined before other diagnostic procedures are attempted. When organisms in faecal smears are absent, zinc sulphate solution should be used for flotation and concentration; sugar and other salts should not be used because these distort the parasite, rendering it unrecognisable (26). When GIardia cannot be detected in stools of suspected cases, duodenal or jejunal fluid should be obtained and examined by duodenal tube, endoscope, or duodenal content sampling by the duodenal string-capsule-technique (Entero-Test). These traditional diagnostic methods either lack methodical sensitivity, are difficult to perform, or involve invasive procedures, and hence complementary immunological methods have been developed to support diagnosis. Serodiagnosis, by detection of anti-Giardia antibodies is not appropriate. Conversely, immunodiagnostic detection of GIardia-antigen, including immunodiffusion, immunofluorescence, counterimmunoelectrophoresis and ELISA, has shown great value and has resulted in a large commercial market for rapid and reliable tests (80). In endemic non-industrialised countries where stool microscopy may provide the only diagnostic option, a therapeutic trial may be justified when clinical symptoms suggest GIardia infection but repeated stool samples remain negative.

Detection of GIardia cysts in water presents special logistical difficulties, as samples of 100 to 1,000 litres are usually used. Methodically highly sensitive techniques, such as PCR or fluorescence-activated-cell-sorting (FACS), are used for this application.

Treatment, prevention and control

The treatment of choice for humans varies according to country, due to differences in approved drugs. Generally, giardiosis is treated with nitroimidazoles (such as metronidazole, ornidazole or tinidazole) or albendazole. Furazolidone has been recommended for children. Paromomycin has been proposed for treatment of pregnant women. In domestic animals, especially in dogs, the drugs used are the same as for humans, except that fenbendazole has been demonstrated to be highly effective in dogs (but not other animals). Indication for treatment is usually restricted to
Cryptosporidiosis

Of the eight recognised species of *Cryptosporidium*, all of which infect vertebrates, only one, *C. parvum*, is zoonotic. This species is remarkable within the genus for a lack of host specificity; in addition to humans, infection has been reported in seventy-nine species of mammals. Discovered by Tyzzer in 1907 in asymptomatic laboratory mice, the parasite was thought to be non-pathogenic for three-quarters of a century. The economic importance of the parasite became apparent to the agricultural world when an outbreak of severe diarrhoea was reported in 1935 in turkeys and a similar problem was reported in calves in 1971. Since then, the parasite has been associated with outbreaks of diarrhoea in the young of cattle, sheep, goats, deer, horses, cats and turkeys. The first case of *C. parvum* in a human was reported in 1976, and only seven cases were reported prior to 1982. An increasing incidence has since been reported, mainly in immunocompromised patients with AIDS, in whom the infection is life threatening. *Cryptosporidium parvum* has been demonstrated to be responsible for sporadic outbreaks of water-borne illness in immunocompetent individuals, some of which have involved many thousands of people.

Distribution, public health importance and epidemiology

In the 1990s, the number of reports of *C. parvum* infections has increased dramatically, including infection in immunocompromised individuals and immunocompetent children and adults from all over the world, thereby reaffirming the global distribution of the parasite. During this period, over twenty water-borne epidemics have been reported from a number of developed countries, including the USA, Canada, England, Scotland and Japan (77). Many of the outbreaks involved small numbers of people infected after contamination of swimming pools. Four epidemics involved many thousands of individuals and resulted from contamination of municipal water supplies. The largest of these occurred in Milwaukee, in the USA, in the spring of 1993, when 403,000 cases were reported (56). The epidemic completely overwhelmed the public health system: 44,000 people sought medical care and over 4,000 were hospitalised. Oocyst densities of 0.13 per litre were found in water supplied by the Milwaukee treatment plant, although the source of the parasite remains speculative. Cattle, a slaughterhouse and human sewage were all suspected. Genetic analysis of recovered isolates has traced most outbreaks among humans to human infection sources; animals have rarely been determined as infection sources for humans.

In immunocompetent individuals, the parasite is an important contributor to diarrhoea in children, with a reported prevalence of between 1% and 3% in industrialised countries and between 4% and 17% in developing countries. Diarrhoea due to *C. parvum* has been reported to cause mortality in infants less than one year of age, at a rate of 2.9% in Guinea-Bissau. Traveller’s diarrhoea may also result from infection with this organism.

The average prevalence of *C. parvum* in patients with human immunodeficiency virus (HIV) has been reported to be 27% in developing countries and 12% in industrialised countries (25). The life-threatening potential of *C. parvum* infections in immunocompromised and immunosuppressed individuals has greatly enhanced the importance of cryptosporidiosis as a global public health problem, although recently, the incidence of the disease seems to have decreased in industrialised countries, due to the introduction of triple-therapy.

Domestic animals, particularly young animals, are frequently infected and the associated symptoms cause economic losses to farmers. The role of animals in the infection of humans, and vice versa, remains unclear, but, according to genetic analyses of recovered isolates, should not be overestimated. Sewage waste and agricultural and urban run-off have been recognised as sources of water contamination. Veterinarians and animal handlers have an increased risk of contracting cryptosporidiosis.

Parasite biology and life-cycle

Transmission of *C. parvum* occurs via oocysts which are immediately infective when passed, and may be transmitted by water-borne or faeco-oral routes. Water-borne epidemics are facilitated by the ability of the oocyst to withstand standard water treatments (chlorination and sand filtration) and to remain viable for long periods in the environment. Infected hosts may shed as many as $10^{10}$ oocysts daily. In an infected individual, both thick and thin walled oocysts may be produced. The former are thought to be responsible for transmission between hosts and the latter hatch in the same host and become trophozoites in this intracellular but extracytoplasmic location. The trophozoites become schizonts containing merozoites. On release, merozoites may become micro- or macro-gametocytes, the union of which produces a zygote which transforms into an unsporulated oocyst. In immunocompromised hosts, the cycle is repeated.
continuously, whilst in immunocompetent individuals, the cycle is self-limiting.

Pathogenesis and clinical features
Approximately one week after ingestion of oocysts by humans, a wide range of clinical manifestations of cryptosporidiosis are experienced, depending on the age and immune status of the host. Infection with C. parvum may result in malabsorptive or secretory diarrhoea. Immunocompetent individuals present with a range of symptoms which can start with abdominal cramps, nausea, low-grade fever and anorexia. Stools are offensive, loose to watery and are typically a brown-green colour with mucus but no blood or pus. The duration of symptoms is from one day to eight weeks. Stool frequency is from two to ten times per day. In immunocompromised individuals, the clinical manifestations are variable: from asymptomatic transient infections to fulminating diarrhoea, up to three litres a day, with vomiting and abdominal cramps. In patients with AIDS, oocysts have also been found in the biliary tract which may cause a sclerosing cholangitis which may present clinically as a progressive right upper quadrant abdominal pain.

Diagnosis
Despite being relatively insensitive, detection of oocysts in stools by microscopy remains the principal method of diagnosis. Various staining techniques can be employed, the most widely used being the modified Ziehl-Neelsen technique. Detection of antigen in faeces using ELISA has provided good sensitivity and specificity. Polymerase chain reaction assays to detect DNA in stool samples or biopsies have not yet been applied in a routine clinical setting. Tools to detect C. parvum in water samples are similar to those offered for G. intestinalis (see above), and include mainly FACS and PCR.

Treatment, prevention and control
No effective treatment or vaccine is available. Patients at high risk of severe cryptosporidiosis are advised to boil and/or filter (<2 µm pore size) all drinking water and not to swim in public baths. Where companion animal programmes are used for AIDS patients, the animals should also be provided boiled or filtered drinking water. The inability of water treatment systems to control the parasite will contribute to the public health importance of cryptosporidiosis until modifications render water treatment systems more effective. In Milwaukee, and in other large cities in the USA, municipal water treatment now includes ozonation of the water which destroys C. parvum oocysts.

Trematodes
Fasciolosis (distomatosis)
Distribution and public health importance
Fasciola hepatica, the common liver fluke, affects predominantly ruminants and occurs throughout most temperate regions of the world. In veterinary medicine, the organism may be a significant health problem and can cause high economic losses through disease and diminution of production. Humans are rarely affected, although the World Health Organization estimates that 2.4 million people are infected world-wide (89). The annual incidence in Europe is estimated to be a few cases per year and per country. While most infected people have eaten wild watercress or other freshwater-raised plants, infective metacercariae may, in some cases, be acquired directly through drinking water. Other fasciolid flukes may also occasionally infect humans, but are considered to be of minor importance.

Parasite biology, life-cycle and epidemiology
Fasciola hepatica is a flatworm of 2 cm to 5 cm in length which, as an adult fluke, parasitises the bile ducts. Immature eggs are shed in faeces and under optimal conditions, a miracidium will develop in, and then subsequently be released from, the egg. This larva will develop and multiply asexually in molluscan intermediate hosts (e.g. Lymnaea truncatula in Europe). Released cercariae adhere predominantly to water plants where they mature to infective metacercariae. Ingestion of metacercariae will be followed by the release of juvenile flukes which penetrate through the intestine to reach the liver, via the peritoneal cavity. The juvenile flukes migrate through the liver parenchyma for six or seven weeks to finally reach the bile ducts. Here the flukes mature and egg production commences as early as two or three months post infection.

Pathogenesis and clinical features
Disease presentation is related to the intensity of exposure and stage and duration of infection. Most cases remain sub-clinical, but when symptoms occur, these usually are related to the hepatobiliary system. Occasionally, aberrant migration of immature flukes leads to unusual ectopic manifestations. Heavy infections may result in traumatic hepatitis when juveniles occur in the liver parenchyma.

Diagnosis
In established infections, fasciolosis can be diagnosed by detecting parasite eggs in the faeces. If eggs are absent, such as in the early, tissue-invasive stage, or in exclusively ectopic disease, serology may be useful (71). Blood eosinophilia supports the diagnosis, but is not always present. Non-invasive imaging techniques may help to establish the extent of liver damage, but do not specifically confirm the diagnosis (37). Biopsy of ectopic lesions provides a definitive diagnosis. Very occasionally, eggs appear in faeces as a result of gastro-intestinal passage in individuals who have consumed infected sheep liver.

Treatment, prevention and control
According to preliminary veterinary clinical data and studies in ruminants, the most effective and least toxic drug for the treatment of fasciolosis is triclabendazole, given in a single dose of 10 mg/kg body weight (91). Praziquantel has not
proved effective in treating fasciolosis. In ectopic disease, surgery, if indicated, is both diagnostic and curative; chemotherapy is not useful. In terms of prophylactic control, consumption of raw leaf vegetables and possibly contaminated water should be avoided, especially if obtained from ponds or streams in fields exposed to sheep and cattle faeces.

**Clonorchiosis and opisthorchiosis**

*Clonorchis sinensis*, *Opisthorchis viverrini* and *O. felineus*, the human liver flukes, are parasites of fish-eating mammals, particularly in Asia and Europe where more than 20 million people are infected. In highly endemic areas, such as north-east Thailand, the prevalence of *O. viverrini* may reach up to 90% (6). *Clonorchis sinensis* is highly prevalent in the People's Republic of China, Taipei China and Vietnam and still occurs in Japan and the Korean peninsula. The main animal hosts are cats, dogs, pigs, rats and camels. *Opisthorchis felineus* is prevalent in Poland, eastern Germany and in parts of the former Union of Soviet Socialist Republics. The adult flukes live in the bile ducts and may occur in large numbers. Large flask-shaped operculated eggs are shed in faeces and hatch if ingested by the appropriate intermediate snail host. Cercariae are shed which penetrate the skin of fish of the family Cyprinidae, and eventually encyst in the muscles of these fish. Infection occurs through eating undercooked or raw fish and the metacercariae reach the liver by direct migration up the bile duct. Raw fish dishes are a dietary habit still occurs in Japan and the Korean peninsula. The main animal hosts are cats, dogs, pigs, rats and camels. *Opisthorchis felineus* is prevalent in Poland, eastern Germany and in parts of the former Union of Soviet Socialist Republics. The adult flukes live in the bile ducts and may occur in large numbers. Large flask-shaped operculated eggs are shed in faeces and hatch if ingested by the appropriate intermediate snail host. Cercariae are shed which penetrate the skin of fish of the family Cyprinidae, and eventually encyst in the muscles of these fish. Infection occurs through eating undercooked or raw fish and the metacercariae reach the liver by direct migration up the bile duct. Raw fish dishes are a dietary habit in all countries where these flukes are commonly found. Clinical manifestations are rare, but infection increases the risk of cholangiocarcinoma (39). Control is possible through treatment with praziquantel, sanitation measures and education to discourage consumption of raw fish.

**Heterophyosis**

*Heterophyes heterophyes* and *Metagonimus yokogawai* are probably the two most important of numerous different species of small (usually under 2.5 mm in length), zoonotic intestinal flukes found in mammals and birds which ingest encysted metacercariae in raw or undercooked fish. These flukes commonly occur in Japan, Laos, Thailand, the Republic of Korea, Hawaii, the Balkans, the Philippines, the People's Republic of China, Taipei China, Turkey and Siberia. The life-cycle is similar to that of *Clonorchis* and *Opisthorchis* spp. and the operculated eggs passed in faeces are morphologically very similar. Clinical manifestations are rare and, if present, are usually due to eggs trapped in various tissues (84). Treatment and control are similar to other fish-borne trematodes.

**Paragonimosis**

Paragonimosis results from infection by numerous species of lung-dwelling flukes. Over 20 million people are infected worldwide. The species involved include *Paragonimus westermani* (the main species in the Far East), *P. miyazakii*, *P. skrjabini* and *P. heterotremus* in Asia, *P. africanaus* and *P. uterobilateralis* in Africa and *P. mexicanus* and other species in Latin America. Countries with significant numbers of cases include the People's Republic of China, Taipei China, Thailand, Japan, Nigeria, Cameroon, Peru and Ecuador. Numerous species of mammals may act as definitive hosts, including dogs, cats and wild carnivores. Aquatic snails are the first intermediate host from which cercariae are released, subsequently infecting crabs, crayfish or shrimp. Definitive hosts are infected by eating raw or undercooked encysted metacercariae which occur in these species. Infection may also occur when paratenic hosts, such as wild boar are consumed. Pulmonary infection is characterised by a chronic productive cough and chest pain. The clinical signs, when combined with an appropriate history, are relatively pathognomonic; other diagnostic measures may include detection of eggs in sputum or faeces and dot-ELISA tests. Plain radiographs are useful for detecting pulmonary masses. In addition to the lung, these flukes can be found in the brain, giving rise to serious neurological symptoms. Most neurological infections have been reported from the Far East, especially the Republic of Korea. Computed tomography (CT) scans are useful for disclosing brain lesions. Control measures include education and treatment using praziquantel.

**Echinostomosis**

These trematodes are of minor zoonotic importance but a high prevalence has been reported in endemic countries, such as the Republic of Korea, the Philippines, Indonesia, Malaysia and Thailand. The most prevalent species include *Echinostoma ilocanum*, *E. revolutum*, *E. malayanum*, *E. echinatum* and *E. hortense* (42). Human infection is by ingestion of metacercariae encysted in freshwater snails and fish. Heavy infections may result in diarrhoea, anorexia and abdominal discomfort. The eggs are similar to *Fasciola* and *Fasciolopsis*. For control, recourse is made to education and treatment using praziquantel.

**Cestodes**

**Taeniosis and cysticercosis**

**Distribution and public health importance**

*Taenia solium* and *T. saginata* have cosmopolitan distributions with the former being more widespread in the rural areas of Latin America, Africa and Asia. Prevalence and incidence data among humans is lacking, as the species are often not identified. In general, the prevalence of *Taenia* spp. is low, even in (hyper) endemic areas in Latin America (0.2% to 2.8%) (76).

Bovine and porcine cysticercosis are reported worldwide. Although the official figures for *T. saginata* cysticercosis in Western Europe vary between 0.2% and 2%, detailed examination of the heads and hearts of cattle revealed that approximately 10% are infected with cysticerci (30). Bovine cysticercosis remains very common in Eastern Africa, whereas high prevalences of porcine cysticercosis are reported from Latin America and some regions of Africa and Asia (30, 76).
The public health importance of *T. solium* cysticercosis has been seriously underestimated in many regions of the world (82). World-wide, the number of deaths due to neurocysticercosis is estimated at approximately 50,000 (75). The epidemic of cysticercosis in a community of orthodox Jews in Los Angeles has highlighted the risk of *T. solium* for those living in non-endemic areas (76).

### Parasite biology, life-cycle and epidemiology

In addition to *Taenia saginata* and *Taenia solium*, a new species of *Taenia* has been discovered in Asia which is considered by some as a separate species, *Taenia asiatica*, and by others as a subspecies of *T. saginata*, *T. saginata asiatica* (24). The cysticerci of this *Taenia* are not present in the muscles, but develop essentially in the liver. The pig is the principal intermediate host, but cattle, goats and monkeys can also harbour the cysticerci. People become infected by eating raw or undercooked pork liver, which seems to be a fairly widespread habit in some areas of the region. Whether or not the eggs of the Asian *Taenia* are also infective for humans is still unclear, but available circumstantial evidence, and the fact that the eggs did not develop in baboons, rather suggest that human cysticercosis due to this *Taenia* sp. is probably not a concern. Molecular analyses have shown that the Asian *Taenia* is distinct, but very closely related to *T. saginata* (55).

In Latin America, the epidemiology of *T. solium* has been studied intensively. Risk factors associated with higher levels of seropositivity for cysticercosis in humans included low levels of sanitary infrastructure, personal hygiene, a history of taeniosis, and an age of over twenty years (76). Clustering of seropositive cases of cysticercosis in households of people with a history of, or current taeniosis, has also been reported.

The epidemiology of *T. saginata* has received much less attention than *T. solium*. In Denmark, case control studies of cattle with cysticercosis from lightly or heavily infected farms were performed to examine sources of infection. The most important source of *T. saginata* eggs for lightly infected farms appeared to be the use of effluent from sewage treatment plants as drinking water for the cattle, whereas the origin of infection in heavily infected farms was related to the use of sludge from septic tanks (47).

### Pathogenesis and clinical features

*Taenia saginata* carriers may suffer from abdominal pain, nausea, weakness, loss of appetite or increased appetite, headache, constipation, dizziness, diarrhoea, anal pruritus and hyperexcitability. Similar symptoms have been reported for *T. solium*. *Taenia saginata* proglottids are usually passed in or outside stools whereas *T. solium* proglottids are generally eliminated with the faeces. Thus, *T. solium* infections may go unnoticed.

In pigs and cattle, infection with cysticerci is generally asymptomatic. Only in massive infections have some clinical symptoms been described. Symptoms due to neurocysticercosis in humans vary considerably according to the number and location of cysticerci, the status of the cysticercus (living or dead) and the immune response of the host (86). In many patients, infection may remain asymptomatic despite long-term and even severe infections. The development of subcutaneous cysticerci seems to be less common in Latin America than elsewhere. Neurocysticercosis is considered to be one of the most important causes of epilepsy, especially late-onset seizures, in developing countries. In severe cases it is an acute life-threatening disease, but more often it is a long-lasting infection affecting the quality of life of the patient.

### Diagnosis

#### Taeniosis

Important progress has been achieved in the field of diagnosis, both of taeniosis and cysticercosis in the 1990s. The classical coprological techniques are recognised to lack sensitivity for the detection of tapeworm ova in the faeces, unless repeated several times. The perianal swab technique is more sensitive, certainly for *T. saginata*, but patients are often reluctant to undergo this kind of sampling. A commercially available ELISA test allowing the detection of parasite antigens in stool samples has a high sensitivity and specificity, but is not able to distinguish between *T. saginata* and *T. solium* (1). Differentiation between the species is possible, however, using DNA probes or PCR assays (33).

#### Bovine cysticercosis

Comparison of the efficacy of the classical meat inspection (incisions in the so-called predilection sites) with detailed examination of the carcass has shown that only 10% to 20% of cysticercosis cases are detected at the abattoir (30). As an alternative to these methods, antibody detection techniques were developed. However, these serological tests were not able to reliably identify naturally infected animals, or to distinguish animals carrying living cysts from those harbouring dead ones. The latter could be achieved by monoclonal antibody-based antigen detection ELISAs (4, 38). These tests are highly specific and allow the detection of cattle harbouring a minimum of thirty to fifty cysts.

#### Porcine cysticercosis

Classical meat or tongue inspection lacks sensitivity for the diagnosis of *T. solium* cysticercosis in pigs. The immunoblot assay using purified glycoproteins of *T. solium* cysticerci has been demonstrated to be very sensitive and specific. Promising results have also been obtained in ELISA using purified fractions of the cyst fluid or excretory-secretory products of *T. solium* cysticerci. The antigen detection ELISAs are also useful to detect pigs harbouring living cysticerci of *T. solium* or the Asian *Taenia* (4, 38).

#### Human cysticercosis

Contrasted CT and magnetic resonance imaging (MRI) are the techniques of choice to confirm neurocysticercosis. For most forms of the disease (with the exception of micro-calcifications), the latter is more sensitive and specific (76).
However, these sophisticated techniques are usually not available in rural areas where most cases of neurocysticercosis occur. Using purified glycoproteins of T. solium, a highly sensitive and specific immunoblotting technique has been developed (81). The test detects 98% of the proven cases with two or more cysts and is able to identify 60% to 80% of the patients with only a single cyst. An ELISA using these antigens was shown to be as sensitive and specific as the immunoblotting (45). A monoclonal antibody-based ELISA was able to detect circulating antigen in a high percentage of patients with neurocysticercosis on the basis of serum or classical swine fever samples (4). The advantage of this test is that only active infections (with living cysts) are detected.

**Treatment, prevention and control**

The eradication of taeniosis/cysticercosis, especially due to T. solium, is possible for the following reasons:

- tapeworm infections in humans are the only source of infection for intermediate hosts
- domestic animal intermediate host populations can be managed to avoid infection
- no significant wildlife reservoir exists
- effective treatment is available for tapeworms (75).

Praziquantel or niclosamide remain the drugs of choice for all intestinal Taenia infections. The possible exacerbation of symptoms in persons with concomitant neurocysticercosis suggests that use of niclosamide might be preferable in endemic areas of cysticercosis.

Treatment of bovine or porcine cysticercosis is possible using anthelmintics at a higher dosage. The treatment of choice for T. saginata cysticercosis in cattle is praziquantel at 50 mg/kg (preferably repeated twice). This dosage kills all cysterci, but several months are required for the cysts to be resorbed and disappear. Porcine cysticercosis can be treated reliably with a single dose of oxendazole (30 mg/kg), which offers the opportunity of including the treatment of cysticercotic pigs as a possible intervention in any cysticercosis control programme.

Albendazole and to a lesser extent, praziquantel, are considered the treatment of choice for cysticercosis in humans, especially when steroid drugs are used simultaneously (86). While a general decrease in the frequency of seizures was recorded in patients who received anthelmintic therapy, many studies cannot be interpreted correctly due to the lack of appropriate controls and patient selection bias (86). Doubt still remains as to whether the course of neurocysticercosis is modified by anthelmintic treatment.

A recombinant vaccine has been developed which provides protection against T. saginata cysticercosis in more than 99% of the immunised animals (51). Since T. solium oncospheres contain a protein, which is homologous to the host-protective 18 kDa antigens in T. ovis and T. saginata, a vaccine against T. solium cysticercosis in pigs (and possibly humans) can be expected in the near future.

**Echinococcosis**

Echinococcosis is a group of infectious diseases caused by the tapeworms of the genus Echinococcus. Two species, E. granulosus, the causative organism of cystic echinococcosis (CE), and E. multilocularis, which causes alveolar echinococcosis (AE) are of significant public health importance. Two additional species, E. vogeli and E. oligarthrus, rarely infect humans and are geographically limited to Central America and the northern region of South America.

**Cystic echinococcosis**

**Distribution and public health importance**

Infections with E. granulosus occur world-wide. A so-called European form, primarily involving synanthropic hosts in the life-cycle, has a nearly cosmopolitan distribution (67). This form is related to major public health or economic problems in many rural areas of the world. Another form is prevalent in northern parts of the North American continent and Eurasia (67). Globally, little data exist on the overall prevalence of CE. Regions with good documentation where a relatively high prevalence in defined geographical areas has been reported include the entire Mediterranean area, the semi-arid areas of East Africa (Kenya, Sudan, Ethiopia, Tanzania); large foci also exist in many countries in South America and parts of the People’s Republic of China.

The main economic losses in livestock occur in the families Bovidae, Suidae, Equidae and Camelidae and are due to condemnation of infected viscera, decreased live weight gain and milk and wool production. Unfortunately, reliable data on the economic repercussions for livestock production are lacking for all countries.

**Parasite biology, life-cycle and epidemiology**

*Echinococcus granulosus* is a small tapeworm (7 mm in length), found in the small intestine of carnivores, predominantly dogs. Ungulates, and rarely some other animals, and humans are intermediate hosts. In definitive hosts, sexual maturity of adult tapeworms is reached within five to six weeks. Gravid proglottids, each containing several hundred eggs, and eggs liberated from disrupted proglottids are shed in faeces. Following ingestion of E. granulosus eggs by susceptible intermediate hosts, a primary larva (the oncosphere) hatches from the egg and penetrates the intestinal epithelium into the lamina propria. The oncosphere is subsequently transported to primary target organs, such as the liver and lungs, and less frequently to other organs. At these sites, hydatid cyst maturation occurs, which may result in the formation of protoscoleces. Once ingested by a definitive host, such protoscoleces grow into adult tapeworms.
The route of transmission of eggs to humans is diverse; taenid eggs in general are known to adhere to the fur of the definitive host. Close contact with infected dogs creates risk of infection (85). Defaecation sites of dogs in areas in which E. granulosus is prevalent are high risk, especially for children or any people in contact with the contaminated soil. Secondary contamination of food produced on soil or which has been putatively contaminated by faeces of carnivores may be a significant source of infection. Faecal contamination of drinking water may occur in areas where dogs have access to drinking water sources.

Pathogenesis and clinical features
Cases of CE usually present with well-delineated spherical primary cysts (35). Although variations occur geographically, approximately 65% of cysts occur in the liver, 25% in the lungs and the remainder can occur in almost any location (35). Cysts cause pathological damages in, or dysfunction of, infected organs mainly by the gradual process of space-occupying repression or displacement of vital organs, tissues or vessels. Cyst rupture may be a cause of anaphylactic or acute inflammatory pathology. Clinical manifestations are primarily determined by the site, size and number of cysts. Success of surgical removal of hydatid cysts is variable, depending on the facilities available. In countries with modern medical facilities, case-fatality rates are low, varying between 1% and 4% for first surgical intervention cases (35). This mortality rate is much higher in countries where operating and post-operative care facilities are not optimal. Under non-optimal conditions, recurrence rates of over 15% have been reported (due to the growth of protoscoleces or other larval material being left in the patient during surgery and subsequently developing into multiple cysts) (56). Secondary infections are usually multiple and result in a higher mortality rate. The public health importance is reflected mainly by the number of infected persons and their diminished functional capacity, the direct and indirect costs of hospitalisation and recovery from surgery, and any residual disability or clinical sequelae (74). In highly endemic regions, fear of becoming infected causes an immeasurable socio-economic cost.

Diagnosis
Diagnosis of E. granulosus infections in definitive hosts is based on the recovery and identification of proglottids and the detection of the characteristic eggs. An important feature is that morphological speciation of Taenia spp. and E. granulosus eggs is not possible. More specific and sensitive diagnostic approaches for E. granulosus in carnivores include copro-antigen detection (13), and species-specific egg identification by monoclonal antibodies (9), or more recently by PCR (12, 13, 16). For the diagnosis of larval infections in humans, imaging procedures together with serology will yield the diagnosis. Ultrasonography (US) is the primary diagnostic procedure of choice (57). False positive results can occur in up to 10% of cases due to misidentification of benign serous cysts and abscesses (35). For the detection of extrahepatic disease and volumetric follow-up assessment, CT is the superior technique whilst MRI adds diagnostic benefit by identifying changes of the intra- and extra-hepatic venous system. Ultrasonography is also useful in longitudinal studies, such as following up treated patients where successfully treated cysts become hyperchochogenic. Aspiration cytology appears particularly helpful in detecting pulmonary, renal and other non-hepatic lesions for which imaging techniques and serology do not provide appropriate diagnostic support.

Immunodiagnostic tests for the detection of serum antibodies are used to support the clinical diagnosis of CE (35, 49). The indirect haemagglutination tests and ELISA using E. granulosus hydatid fluid antigen are relatively sensitive for hepatic cases (85%-98%). For pulmonary cyst localisation, the diagnostic sensitivity is markedly lower (50%-60%), for multiple organs, localisation is very high (90%-100%). These tests are usually used for a primary serological screening. Specificity is low with regard to other cestode infection and relatively low for non-cestode parasitoses. In order to increase specificity, primary seropositive sera are retested in a confirmation test such as antigen-5-precipitation (arc-5-test) or immunoblotting for a relatively specific 8kDa/12kDa hydatid fluid polypeptide antigen (40, 43, 48, 60).

Treatment, prevention and control
Surgery and puncture-aspiration-injection-reaspiration (PAIR), sometimes complemented or replaced by chemotherapy, represent the principal treatment (90). Perioperative chemotherapy with albendazole or mebendazole is indicated for reducing the risk of secondary echinococcosis. Treatment should commence at latest four days prior to surgery and continue for one or more months. Treatment of non-resectable cysts with albendazole or mebendazole results in cyst disappearance in 30% of cases, another 30%-50% of patients demonstrate degeneration of cysts or significant size reductions, and the cysts of between 20% and 40% of patients under chemotherapy show no morphological change (35).

Prevention of CE focuses primarily on veterinary aspects to control the intensity and extensity of infection in definitive host populations. This includes regular treatment of definitive hosts with praziquantel and meat inspection to prevent access of dogs to cysts (88). A vaccine for ruminant intermediate hosts is being developed (50, 51).

Alveolar echinococcosis
Distribution and public health importance
The geographical distribution of E. multilocularis is limited to the northern hemisphere. In North America, the cestode is mainly present in sub-arctic regions of Alaska and Canada (35). In Europe, areas with relatively frequent reports of alveolar echinococcosis in humans are central and eastern France, Switzerland, Austria and Germany (2). More recent data suggest that neighbouring countries, such as the Netherlands, Belgium, Poland and Chechenya, are also
infected relatively frequently. Areas of Asia with a high prevalence of *E. multilocularis* include the entire zone of tundra from the White Sea eastwards to the Bering Strait, covering large areas of the former Union of Socialist Soviet Republics, the north of the People's Republic of China and parts of other countries. Similarly to CE, little data exists on the overall prevalence of AE in humans. In Switzerland, France, Germany and Austria, the annual morbidity rates range between 0.2-1.0 case per 100,000 inhabitants (2). The importance of the disease is not due to the large number of cases reported but rather to the severity of the clinical disease in the individual patient, with a frequently lethal outcome for non-treated cases. Mortality reached 92% within ten years of infection in rodent hosts, lesions in humans rarely exhibit the peripheral zones of calcification. In contrast to the CE, AE is characterised by a hepatic lesion consisting of a dispersed, firm, pale tissue, subsegmented by scattered small cysts and vesicles. The lesions may have focal, non-peripheral zones of calcification. In contrast to the infection in rodent hosts, lesions in humans rarely exhibit the formation of protoscoleces and brood capsules within vesicles.

Clinical symptoms are usually non-specific with mild upper quadrant and epigastric pain. Hepatomegaly linked with obstructive jaundice has been reported.

**Parasite biology, life-cycle and epidemiology**

The life-cycle of *E. multilocularis* is similar to that of *E. granulosus*. *Echinococcus multilocularis* occurs as adult tapeworms mainly in red and arctic foxes (*Vulpes* spp.), but dogs and cats can also be involved incidentally as definitive hosts. Dogs and cats may play a significant role in the transmission of parasites to humans, due to close contact. Small mammals (microtine and arvicolid rodents and occasionally other species) are intermediate hosts for *E. multilocularis*. In contrast to *E. granulosus*, *E. multilocularis* is predominantly maintained by a wildlife cycle. Fox and dog fur contaminated with *E. multilocularis* eggs is considered to be an important health hazard to fox hunters and dog owners and to their family members. Vegetables grown outdoors, forest fruits, and windfall fruit contaminated by fox or dog faeces or eggs stripped from fox fur are considered to be the major source of infection for humans. Exact data are still unavailable and are very difficult to obtain since retrospective studies cannot accurately provide the information required. The time between infection and occurrence of the first symptoms has been estimated to average between five and fifteen years (31).

**Pathogenesis and clinical features**

The primary location of AE is the liver. Rarely, lesions may also metastasise to the lungs, brain, and other organs (35). In contrast to the CE, AE is characterised by a hepatic lesion consisting of a dispersed, firm, pale tissue, subsegmented by scattered small cysts and vesicles. The lesions may have focal, non-peripheral zones of calcification. In contrast to the infection in rodent hosts, lesions in humans rarely exhibit the formation of protoscoleces and brood capsules within vesicles.

Clinical symptoms are usually non-specific with mild upper quadrant and epigastric pain. Hepatomegaly linked with obstructive jaundice has been reported.

**Diagnosis**

Among the imaging procedures, US and CT are of greatest diagnostic value (2, 35). Irregularly dispersed clusters of calcifications on plain abdominal radiographs may give the initial clues. For mass screening programmes, US is the preferred imaging procedure (10). Magnetic resonance imaging does not visualise microcalcifications but reveals intrahepatic changes or obstruction of the inferior vena cava or the portal venous system. Diagnostic biopsies can be used to investigate speciation using direct immunofluorescence or PCR (15, 46, 69).

Complementary to imaging procedures, immunodiagnosis represents a secondary diagnostic tool which is useful in confirming the nature of the aetiological agent (35, 51). Test operating characteristics enable reliable seroepidemiological studies, and thus detection of asymptomatic pre-clinical cases of AE, in addition to unique cases in which the metacestode lesion dies at an apparently early stage of infection (31, 68). Serological tests are of limited value for the assessment of the efficacy of treatment and chemotherapy (32, 53, 54).

**Treatment, prevention and control**

The treatment of choice is radical surgical resection of the entire parasitic lesion from the liver and other affected organs. Excision of the parasitic lesion follows the principles of radical tumour surgery. Concomitant chemotherapy is recommended in all cases after radical surgery or after non-surgical procedures (90). Long-term chemotherapy is mandatory in inoperable or only partially resectable cases and in all patients after liver transplantation. Presurgical chemotherapy is not indicated in cases of AE (90). Liver transplantation has been proposed for a selected group of patients with extensive lesions restricted to the liver or with secondary liver disease leading to chronic liver failure (90).

The efficacy of treatment programmes by fox baiting with praziquantel is under evaluation as a potential control measure. In highly endemic areas, monthly treatment of cats and dogs with praziquantel may significantly reduce infection risk.

**Diphyllobothriosis**

Within the group of tapeworms belonging to the genus *Diphyllobothrium, D. latum* is the predominant species with regard to numbers of cases: approximately 20 million people are estimated to be infected (23). *Diphyllobothrium latum* has a world-wide distribution with major foci in the freshwater lakes of Europe, in areas of the former Union of Soviet
Socialist Republics, Finland, Scandinavia, the alpine zone, and in Asia and America.

The life-cycle includes copepods as first intermediate hosts and freshwater fish as second intermediate hosts, the latter harbour a number of plerocercoid larvae (66). Following ingestion by definitive hosts, such as humans, the larvae will mature to adult tapeworms that can reach 10 m or more in length and may contain up to 3,000 proglottids. Egg production starts approximately thirty-five days after infection. Intestinal infection with *D. latum* is usually asymptomatic. In some cases, mild gastrointestinal obstruction, rarely diarrhoea and abdominal pain, and occasionally leukocytosis with eosinophilia are present. Anaemia occurs in approximately 2% of the patients, as shown in studies performed in Finland. The cause is related to a high affinity of the tapeworm surface for vitamin B12, which is then absorbed from the host. As infection is acquired by the consumption of raw freshwater fish, preventive measures include appropriate cooking of fish and treatment with praziquantel. In areas with high freshwater fish and carnivore population densities, regular treatment with praziquantel of domestic carnivores, especially those being fed raw fish, can reduce environmental contamination of natural water resources with parasite eggs. This may be particularly useful in relation to freshwater fish aquacultures. Preventing access of wild carnivores to such facilities by appropriate fencing may also provide good results.

Nematodes

**Trichinellosis**

**Distribution and public health impact**

Trichinellosis is a cosmopolitan helminth zoonosis, which can occur where humans eat raw or improperly cooked meat or meat products from infected pigs, wild boars, horses, walruses, dogs and many other domestic or wild mammals. *Trichinella* spp. have been reported from approximately 150 mammalian species (7) and even from birds and marsupials in the case of *T. pseudospiralis*. Recently, *Trichinella* spp. have been reported in crocodiles in Zimbabwe (C.M.O. Kapel, personal communication). Although sylvatic trichinellosis is still endemic in western Europe, pigs raised on industrial farms are no longer at risk. Porcine and human trichinellosis still occurs in a few regions in Spain and southern Finland, where traditional pig rearing practices still prevail (61). Most cases of human trichinellosis (more than 2,600 since 1975) in the European Union (EU) have been caused by the consumption of horse meat originating from eastern Europe or North America. Furthermore, between 1975 and 1998, an estimated 1,200 human infections with trichinellosis in the EU were due to the consumption of wild boar meat. In eastern Europe, precise figures are not available, but it is generally accepted that in recent years an increase of animal and human trichinellosis has occurred due to political changes and the resulting socio-economic problems.

In the USA, *Trichinella* infections gradually declined during the 1990s, but have not yet completely disappeared. In Latin America, several countries have a relatively high prevalence of trichinellosis. In Chile, *T. spiralis* larvae were found in 2% of the autopsies carried out during 1992. In Asia and Africa, few data are available on the prevalence of trichinellosis. Trichinellosis in pigs and humans seems to be widespread in regions of the People's Republic of China, Laos, Thailand and Vietnam, whereas in sub-Saharan Africa, less than 100 human cases have been reported. The cases in Africa were due to *T. nelsoni*, which has a low infectivity for humans and domestic pigs. Little is known about the public health importance of *T. pseudospiralis*. After the description of the first human case in 1993, a few outbreaks due to *T. pseudospiralis* were reported, in which serious clinical symptoms and even mortality were observed.

**Parasite biology, life-cycle and epidemiology**

*Trichinella* is a unique nematode having both the adult and larval stages present within the same host. The larvae are encapsulated in muscles, except for *T. pseudospiralis*, where the capsule around the larvae is absent. The latter parasite also has a wider host range and infects both mammals and birds. Humans and animals become infected with *Trichinella* spp. through the ingestion of meat containing viable larvae. Carnivores with cannibalistic or scavenger habits are the most important reservoir hosts of *Trichinella* spp. However, herbivores such as horses, cattle, sheep and reindeer can also become infected. The large number of outbreaks of human trichinellosis due to infected horse meat shows that infection of horses with *Trichinella* is no longer exceptional (22).

Five species are currently recognised within the genus *Trichinella* and three phenotypes (T5, T6 and T8) have an uncertain taxonomic status (62). Some authorities consider that T5, which has been named *T. murrelli*, should be classified as a separate species (65). The phenotype T8 is closely related to *T. britovi* and T6 is more closely related to *T. nativa* (62).

The epidemiology of trichinellosis in Europe has been studied in detail by Pozio and colleagues (61, 63). Three species with different epidemiological features are present, namely: *T. spiralis*, *T. britovi* and *T. nativa*. The transmission of these species occurs only through a sylvatic cycle for *T. britovi* and *T. nativa*, whereas *T. spiralis* is transmitted, according to the region, either through a sylvatic cycle alone, or through both sylvatic and domestic cycles. The domestic cycle of *T. spiralis*, with domestic pigs and synanthropic rats as the most important sources of infection, still exists in eastern Europe and in a few regions of western/northern Europe (for example Extremadura, Spain and southern Finland), where pig rearing is still very traditional (i.e. small farms, poor hygiene, contact with rats, etc.). In these regions, the prevalence of trichinellosis in wild boars is often higher than elsewhere. This is probably due to uncontrolled garbage dumps including remnants of infected pig and wild game carcasses. The sylvatic cycle of *T. britovi* and *T. nativa* is maintained by
wild carnivores, mainly foxes, living in natural ecosystems; rodents do not play a significant role in transmission of the disease. The prevalence of trichinellosis in foxes has been shown to increase with increasing altitude. This is thought to be due to the presence of an ecologically less disturbed ecosystem in mountain areas and to a more pronounced cannibalistic behaviour of foxes in these regions. Trichinella britovi and T. nativa can pass from sylvatic (fox) to domestic (pig) cycles, although they may not be maintained in the latter cycle (63).

Pathogenesis and clinical features

Trichinellosis in pigs is generally asymptomatic, except in heavily infected animals, where loss of appetite, malaise, diarrhoea, hind limb paralysis and incontinence have been observed. In horses experimentally infected with larvae of T. spiralis, a transient muscle disorder has been reported.

Clinical symptoms caused by Trichinella spp. in humans depend on the number of infective larvae ingested, the immune status of the host (first infection or reinfection) and the species of Trichinella. Clinical signs comprise a transient intestinal stage followed by a longer lasting extra-intestinal stage (8). High eosinophilia in combination with fever, muscle pain and orbital oedema are suggestive for trichinellosis, especially if the history shows that the patient has eaten raw or improperly cooked meat from potentially infected animals.

Diagnosis

Using random amplified polymorphic DNA-polymerase chain reaction (RAPD-PCR), identification of the five species and three taxa (T5, T6 and T8) of Trichinella is now possible. The sensitivity of this technique is 100% for a single larva if the DNA is not damaged. The specificity increases from 88% to 100% if up to five larvae are examined (64).

In animals, trichinoscopy, artificial digestion of one gram samples and ELISA using excretory-secretory (ES) antigens were shown to have a sensitivity of 3 larvae per gram of tissue (LPG), 1 LPG and 0.01 LPG, respectively. Recent investigations have demonstrated that the pooled sample of 1 g of muscle which is artificially digested detects only between 3 LPG and 5 LPG (28). In order to detect an infection level of 1 LPG of T. spiralis, which is generally considered a potentially dangerous public health threat, examination of 5 g samples of tongue or diaphragm has been recommended (28). In horses, 1 g samples were demonstrated to be unreliable in detecting infection levels of < 3 LPG (29). After the multifocal outbreak of human trichinellosis in 1993 in France, due to the consumption of horse meat which had been declared free of Trichinella using the former technique in North America, the EU decided to increase the sample size from 1 g to 5 g. In horses, larvae accumulate preferentially in the tongue, followed by the masseter, neck, supraspinatus, trapezius and diaphragm muscles.

The ELISA, using ES antigens (ES-ELISA), is a highly sensitive technique which is very useful for epidemiological surveillance of porcine trichinellosis, although false negatives may occur in infected pigs prior to seroconversion (28). The ES-ELISA may also fail to detect infected horses, especially those with older infections, because the antibodies disappear much more rapidly than in pigs (78).

In humans, muscle biopsy and consecutive artificial digestion of the sample is the method of choice for the parasitological confirmation of trichinellosis (32). The species of Trichinella involved can be identified using RAPD-PCR as mentioned earlier (64). Although some progress has been made in the field of antigen detection, antibody detection tests (especially the IgG-ELISA) are generally more useful, because specific antibodies remain present for a long period after infection (8).

Treatment, prevention and control

Treatment of animal and human trichinellosis is possible using benzimidazole compounds. Mebendazole and albendazole are the anthelmintics of choice (8, 52).

Since trichinellosis is only transmitted through ingestion of infected meat, the following preventive measures should be employed:

- waste food and swill containing meat should be heated (100°C for 30 minutes) before use as pig feed
- architectural barriers should be created to avoid the entrance of rodents and other synanthropic animals to animal premises and food-stores
- animal carcasses should be promptly and properly disposed of (52, 83).

Although these measures are difficult to implement in some regions of the world due to cultural, socio-economic or historical reasons, many large industrialised farms in the EU, the USA and elsewhere have used these measures with success. The risk of contracting trichinellosis from these farms is very low. Nevertheless, the EU laws require that all pigs for export be examined for Trichinella, at a cost of US$3 per pig. Since 190 million pigs are slaughtered per year, it has been calculated that the EU could save US$420 million and simultaneously improve Trichinella control by restricting examination to those pigs originating in small farms or in regions with traditional pig rearing practices (61). Proposals for alternative Trichinella control within the EU are currently being discussed. These suggest that pigs from large commercial farms, which are situated in non-endemic Trichinella areas and which take the necessary measures to avoid infection, should no longer have to undergo Trichinella control at the slaughterhouse (83). In these areas, a representative sample of indicator animals, e.g. foxes, could be examined in order to monitor the evolution of trichinellosis.
In countries where meat inspection for Trichinella is not obligatory (e.g. the USA) or where the detection techniques used in abattoirs are not sufficiently reliable, the most reliable method to avoid trichinellosis infection is to ensure that meat reaches an internal temperature of 60°C for at least a minute during cooking. Freezing at —15°C for twenty days kills Trichinella larvae, except T. nativa. Since this species has been found in domestic pigs, frozen pork can no longer be considered safe for the consumer, or at least pork originating from T. nativa endemic regions. Another method of killing Trichinella larvae is low level gamma irradiation (< 1 kGy). Prevention of trichinellosis might also be achieved by vaccination. Several reports indicate that high protection levels against re-infection can be obtained after experimental immunisation of swine.

Parastrongylosis (angiostrongylosis)

The species Angiostrongylus cantonensis and A. costaricensis have been reclassified in the genus Parastrongylus. The term ‘angiostrongylosis’ should, therefore, now be replaced by ‘parastrongylosis’. Thousands of human infections occur with the larval stage of the rodent nematode Parastrongylus cantonensis. Infection occurs by eating infected mollusces or food contaminated by contact with snails. Infection causes eosinophilic meningitis. This parasite has spread in recent years, with the dissemination of one of the intermediate hosts, the giant African land snail (Achatina fulica), which is a popular food item in some countries. Chemotherapy may include albendazole or ivermectin, but always requires concomitant medication with steroids.

**Conclusion**

Parasitic protozoan water-borne zoonoses, particularly Giardia and Cryptosporidium, which cause diarrhoea in animals and humans, are estimated to infect more than 300 million people annually. The cysts and oocysts of these protozoa are resistant to standard water treatment systems and spectacular epidemics have been reported in developed countries. The inability of non-industrialised countries to keep pace with population growth, migration to urban areas and the demand for clean, safe, drinking water means that water-borne zoonoses will continue to exact an increasing burden of ill health. The same scenario is true for sanitation and, in addition to protozoan zoonoses, numerous helminth infections, including T. solium, T. saginata, and numerous trematode species will continue to proliferate. Close association with cats and dogs facilitates the transmission of T. gondii and Echinococcus spp. Eating habits and access to flora and fauna which contain infective parasitic stages for humans are important in determining human infections, in addition to increasing definitive host populations, which was the case with foxes and E. multilocularis in central Europe. Food-borne zoonoses transmitted through the consumption of raw or undercooked meat include such organisms as Sarcocystis, T. gondii, T. solium, T. saginata, and Trichinella spp. Consumption of raw, improperly cooked or pickled fresh-water fish facilitates transmission of a large number of zoonotic infections, and an estimated 70-100 million people have been infected with parasitic trematodes such as Clonorchis spp., Opisthorchis spp., H. heterophyes, M. yokogawai, E. ilocanum, E. revolutum, E. malayanum, E. echinatum and E. hortense. Fish also serve as intermediate hosts for the cestode D. latum and the nematodes C. philippinensis and G. spinigerum. Anisakiasis infections arise from eating salt-water fish. Eating raw crabs, which are sometimes pickled in wine or brine, may result in Paragonimus spp. Infection and the consumption of mollusces may expose humans to infection with P. cantonensis and P. costaricensis. The proliferation of food items in the average supermarket in the USA (from a selection of about 300 items in the 1950s to over 3,000 today) has resulted from the

**Parastrongylosis**

*Parastrongylosis* occurs over a wide geographical area extending from the Philippines, where infection occurs as small epidemics along rivers, to Egypt where individual cases have been reported. Infection arises from eating raw or undercooked fish which serve as intermediate hosts. The adults live in the upper small intestine where autoinfection is responsible for maintaining infection over many years. A chronic malabsorption syndrome may develop, which has occasionally been reported to be fatal. Monkeys appear to be the usual definitive hosts. Control is performed by treatment with mebendazole and through education. The parasite has been greatly reduced in areas where the practice of consuming undercooked fish has been discontinued.

**Gnathostomosis**

Zoonotic infections occur with several species of the genus *Gnathostoma*. Mammalian carnivores such as cats, dogs, tigers and leopards usually serve as definitive hosts. Copepods serve as initial intermediate hosts. When infected copepods are ingested by fish or frogs, these species serve as secondary intermediate hosts in which infective L3 larvae develop. Infection in definitive hosts occurs by eating raw or undercooked fresh-water fish (*G. spinigerum*). Most reported cases have occurred in Thailand and Japan. A cutaneous or visceral larva migrans condition may arise in humans when infected fish or frogs are eaten. Treatment for superficially occurring larvae may be surgical removal.

**Anisakiasis**

This condition arises in humans infected with the larvae of *Pseudoterranova decipiens*, a common nematode parasite of marine mammals, cod and other sea fish, or with larvae of species of *Anisakis*, which infect sea fish such as herring and mackerel. Infection is acquired by consuming uncooked or raw fish filets commonly sold in stores. Clinical manifestations may include tingling throat syndrome or ulceration of the gut (70). Therapy includes surgical removal of larvae. No appropriate chemotherapy has been reported as yet, although ivermectin is assumed to exhibit reasonable efficacy.

**Capillariosis**

*Capillaria philippinensis* occurs over a wide geographical area extending from the Philippines, where infection occurs as small epidemics along rivers, to Egypt where individual cases have been reported. Infection arises from eating raw or undercooked fish which serve as intermediate hosts. The adults live in the upper small intestine where autoinfection is responsible for maintaining infection over many years. A chronic malabsorption syndrome may develop, which has occasionally been reported to be fatal. Monkeys appear to be the usual definitive hosts. Control is performed by treatment with mebendazole and through education. The parasite has been greatly reduced in areas where the practice of consuming undercooked fish has been discontinued.

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importation of foods from many different parts of the world. Tourists travel in ever increasing numbers from industrialised countries to the tropics and the consumption of local foods, presented in a traditional way, contributes to the occurrence of exotic zoonoses in non-endemic countries. Most parasitic zoonoses can be treated but a lasting reduction in infection will require the combination of a number of different approaches to control. Changing human behaviour through education, to encourage the proper cooking of food, which may have cultural and social significance, will remain as challenging as the provision of safe drinking water and sanitation for the control of zoonotic parasitic diseases. Further studies are also required on the veterinary importance of parasitic zoonoses.

Zoonoses parasitaires d’origine alimentaire ou hydrique
C.N.L. Macpherson, B. Gottstein & S. Geerts

Résumé
Selon les dernières estimations, près de la moitié de la population mondiale serait affectée par des infections d’origine alimentaire ou hydrique. Parmi ces infections, les zoonoses parasitaires ont des conséquences graves pour la santé publique et occasionnent des pertes directes et indirectes sévères à l’agriculture. Étant donné que les pays non industrialisés ne parviennent pas à apporter une réponse adaptée à la croissance démographique et à l’exode rural, ni à fournir une eau potable de bonne qualité ou des systèmes d’assainissement efficaces, les zoonoses d’origine hydrique vont sans doute devenir un fardeau de plus en plus lourd pour la santé publique de ces pays. La consommation de viandes, de crustacés, de poissons d’eau douce et de légumes crus ou mal cuits favorise la transmission d’un grand nombre de zoonoses. Le développement de l’industrie du tourisme, l’émigration des populations humaines et l’importation de denrées alimentaires en provenance de régions endémiques se traduisent par un accroissement du nombre de ces infections dans les pays qui en sont indemnes. Les auteurs étudient l’épidémiologie des principales infections parasitaires transmises par les aliments ou par l’eau, ainsi que leur importance pour la santé publique et animale et l’évolution récente en matière de diagnostic, de traitement et de prophylaxie.

Mots-clés

Zoonosis parasitarias transmitidas por vía hídrica o alimentaria
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Resumen
Las estimaciones actuales sugieren que casi la mitad de la población mundial se ve afectada por infecciones que se transmiten a través del agua o los alimentos. Las zoonosis parasitarias contribuyen a esa estadística imponiendo un duro tributo en términos de salud humana y causando, directa o indirectamente, grandes pérdidas en el sector agrícola. La incapacidad de los países no industrializados para responder adecuadamente al crecimiento demográfico, la
migración de zonas rurales a núcleos urbanos y la creciente demanda de agua potable limpia y segura y de infraestructuras de saneamiento apropiadas se traduce por un incremento previsible del impacto de las zoonosis transmitidas por el agua en el estado de salud de aquellos países. La ingestión de carne, crustáceos, pescado de agua dulce o vegetales crudos o insuficientemente cocinados facilita la transmisión de un gran número de infecciones zoonóticas. La floreciente industria del turismo, las migraciones y la importación de alimentos desde regiones endémicas han resultado en un aumento del número de diagnósticos de esas infecciones en países donde no son endémicas. Los autores examinan la epidemiología de las infecciones parasitarias más importantes que se transmiten por vía hídrica o alimentaria, así como sus repercusiones en materia de salud pública y veterinaria y los últimos avances realizados para el diagnóstico, tratamiento y control de esas enfermedades.

Palabras clave

References


