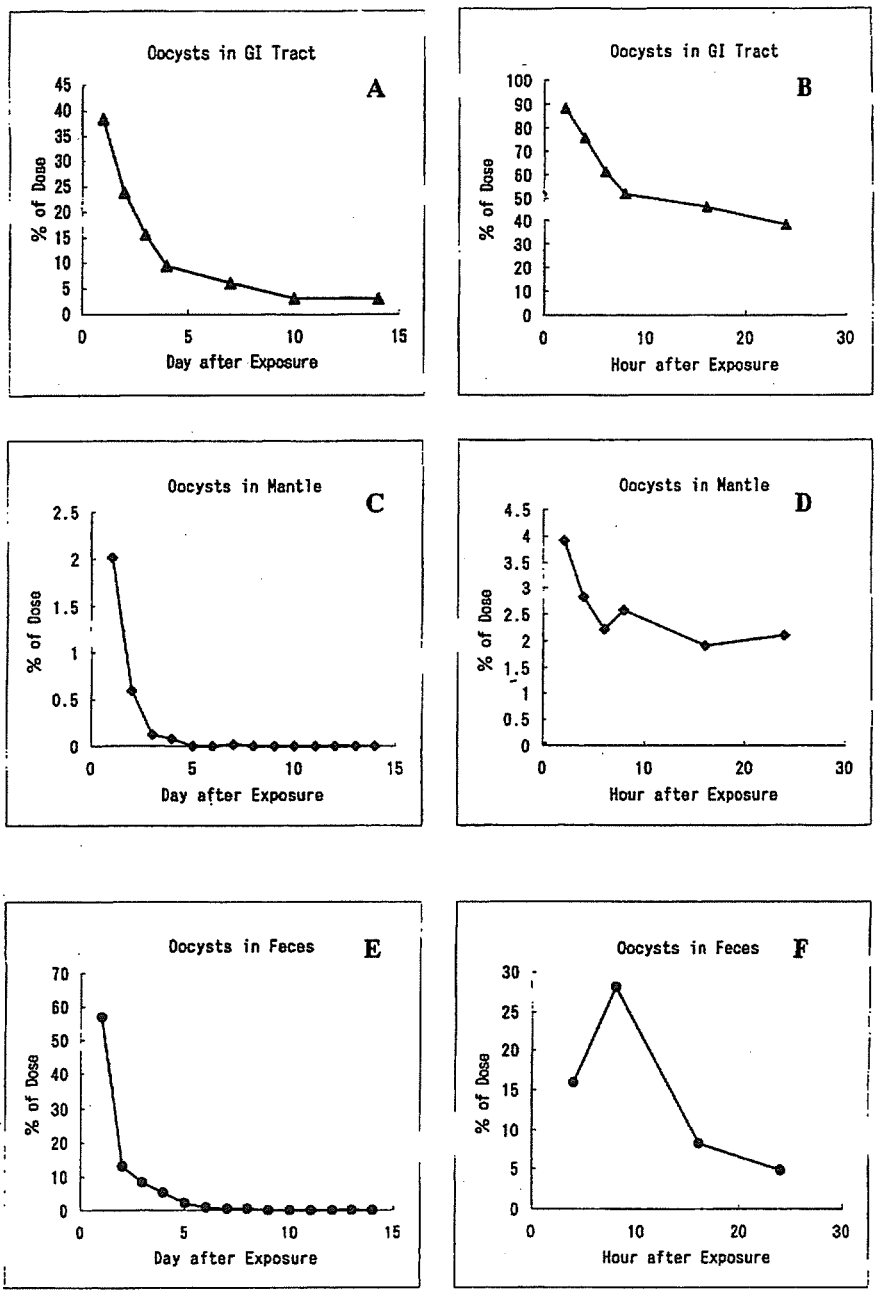

Figure 1. The relative amounts of oocysts detected in the clams and feces after a single exposure of *Cryptosporidium parvum* oocysts to *Corbicula japonica* at 6.67×10^4 /clam.

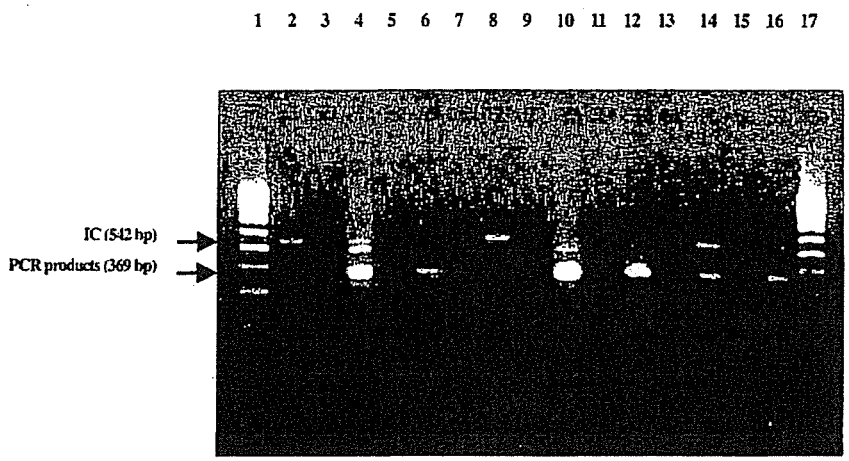

Figure 2. Ethidium bromide-stained 3.0% gel showing the amplification products using trap-C2 primers from clam fecal and GI tract samples.
Lane 1; molecular marker, **lane 2**; negative control, **lane 4**; fecal sample on 1 day after dose, **lane 6**; fecal sample on 6 days after dose, **lane 8**; fecal sample on 14 days after dose, **lane 10**; GI tract sample on 1 day after dose, **lane 12**; GI tract sample on 7 days after dose, **lane 14**; GI tract sample 14 days after dose, **lane 16**; positive control, **lane 17**; molecular marker

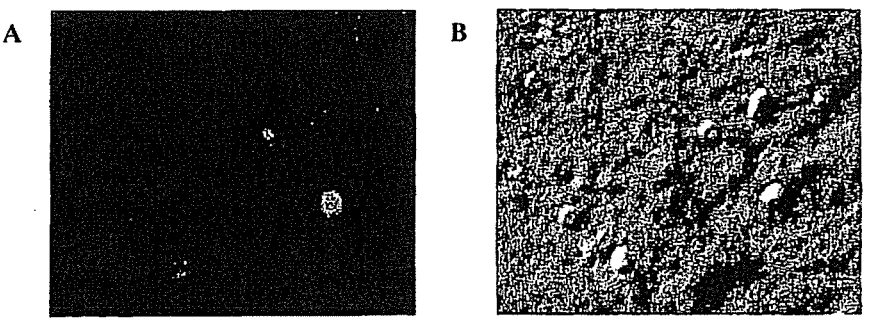

Figure 3. Photographs of developmental stage of *Cryptosporidium parvum* in HCT-8 cells 2 days after inoculation.
A: Fluorescence photograph of a field of foci after 2 days of inoculation.
B: Normarski interference-contrast photomicrograph of the field in panel **A**.

were detected, while, the DNA of *C. parvum* was detected by PCR (Fig. 2). The density of oocysts determined in the clam GI tract and mantle samples was highest 2 hrs after exposure (Fig. 1-B, and -D), almost no oocysts were detected in the gills (<0.01% of dose) during the whole of the experimental period. The oocyst decrease in the GI tract during the first 24 hrs showed two phases, with the decrease in the first 6 hrs steeper than later. One day (24 hrs) after the dose, the level of oocysts in the GI tract decreased further in two

phases, and the decrease in the first 3 day phase was more rapid than later. The slope of the curve in the second later phase was quite flat and appeared to reach a plateau level 10 days after exposure. Overall, the decrease in oocysts in the GI tract appeared to correspond to the fecal excretion in both magnitude and pattern of reduction. For the GI tract, the oocyst residue levels 7 and 14 days after exposure were 6.1 and 3.1% of the dose, and the DNA of *C. parvum* was identified by PCR (Fig. 2). The mantle showed very low oocysts residue levels, and the microscopic examination of the samples 4 days after exposure found no oocysts.

With respect to the infectious activity of *C. parvum* oocysts in the fecal samples, it was shown that the rate of excystation under the experimental condition here was about 70%, and that sporozoits were detected in HCT-8 cells 2 days after inoculation, proving that there are infectious oocysts in the clam feces (Fig. 3).

According to these results, it was presumed that a part of oocysts (about 3%) might nonspecifically adsorb to the GI tract. The present study also showed that the total amount of excreted and clam-retained oocysts was totally about 92%, which was about 8% less than the initial introduced oocyst dose. This may partly be accounted for by the absorption of oocysts by aquarium equipment. Thus far it was reported that *C. parvum* oocysts maintained infectivity for up to 1 year in seawater at 6–8°C, and oocysts captured by mussels, seawater shellfish, retained the infectivity for about 14 days in the clam body (Tamburrini and Pozio 1999), however, the infectivity of oocysts in the feces of shellfish was not yet clarified. As judged by a balance study and infection test to the cultured cells (HCT-8), most of the *C. parvum* oocysts appeared not to be readily digested by clams, and seemed to be excreted in feces with almost intact infectivity. These results suggest that estuarine shellfish may be useful to recover *C. parvum* oocysts from water samples by fecal sedimentation.
The present study indicated that *C. japonica* may serve as an effective scavenger of *C. parvum* oocysts, and that this brackish water clam could be employed as a biological indicator of contamination in river water by *C. parvum* oocysts. The optimum qualitative detection of *C. parvum* oocysts in *C. japonica* was demonstrated in the present study by screening feces and/or GI tract samples of clams with fluorescence-dye treatment. This could lead to improvements in the accuracy of detection of *C. parvum* oocysts especially in turbid water samples, where it is difficult to establish the presence of oocysts by routine filtration methods, because of the various other suspended substances.

A study on the recovery of *C. parvum* oocysts in Asian freshwater shellfish, *Corbicula fluminea* (*C. fluminea*) has been reported, however, no precise balance study of oocysts was carried out (Graczyk *et al.* 1998). The present study may be the first balance study report of *C. parvum* oocysts in bivalves. With respect to clam tissue residue of *C. parvum* oocysts, the present study showed much lower residual magnitudes in the GI tract and gills through the experimental period than in the previous reports on *C. fluminea* (Graczyk *et al.* 1998). Further, from the balance study, the *C. parvum* oocysts seemed to be harder to digest in *C. japonica* than in *C. fluminea* (Graczyk *et al.* 1998). A mortality of 10% in the above-mentioned study with *C. fluminea* seems too high. Under inadequate circumstances, shellfishes are liable to assume a fasting state and mortality would increase significantly, hence the high clam mortality (about 10%) may be presumed to be caused by inappropriate

conditions, and the differences in the retention and digestion of *C. parvum* oocysts in *C. japonica* and *C. fluminea* may be due to both biological metabolic species differences in metabolism and also in the aquarium conditions, involving the water-filtration system for removal of waste, which would affect the recovery of oocysts by its adsorptive function on glass fibers (Kawasaki 1998).

Several reports on the harboring of *C. parvum* oocysts in seawater clams, such as oysters, mussels, and cockles, were recently presented (Fayer *et al.* 1998; Gomez-Bautista *et al.* 2000), and it was shown that some tissue would be of retaining some oocysts. However, no quantitative time-course balance study has been carried out so far. Successive administration of *C. parvum* oocysts to shellfish would be required to clarify and assess water contamination by *C. parvum* oocysts as a bioindicator, as water pollution with *C. parvum* oocysts is not usually a short term phenomenon, but tends to last more than a few days. In addition, other experimental conditions, such as temperature, salt concentration of the water, and size of clams *etc*, that may have an effect on clam metabolism, should be taken into account. Further, other benthic organisms, e.g. *Corbiculidae* and *Unionidae* clams *etc* should be investigated as bioindicators. At present, we are investigating these subjects with *C. japonica* and other benthic freshwater organisms.
Corbicula clams are consumed after heat treatment, at least in Japan, so it may be assumed that there is practically no epidemiological danger of these shellfish to act as a reservoir of *C. parvum* and some helminths. However, some waterfowl, e.g. bay ducks and sea ducks *etc*, have been reported to feed on these shellfishes (Nakamura and Nakamura 1995; Robbins *et al.* 1983), and these wild animals may act as carriers of *C. parvum.* In the same manner, *C. japonica* may play an epidemiologically important role as a reservoir of *C. parvum* in the natural food chain in some cases.

Acknowledgments. We thank the staffs of the laboratory of protozoa of NIID for the technical support and assistance. We are deeply indebted to Prof. T. D. Christensen for the English version.

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Waterborne Zoonoses

Identification, Causes, and Control

Edited by
J.A. Cotruvo, A. Dufour, G. Rees, J. Bartram,
R. Carr, D.O. Cliver, G.F. Craun, R. Fayer and
V.P.J. Gannon

World Health Organization

18

Major helminth zoonoses in water

T. Endo and Y. Morishima

18.1 INTRODUCTION

WHO (1996) reported that, worldwide, *Ascaris lumbricoides*, *Trichuris trichiura*, and hookworms (*Ancylostoma duodenale* and *Necator americanus*) infect 1.4, 1.0, and 1.3 billion people each year, respectively. It is unlikely that increasing urbanization in developing countries will result in a decreasing trend. Unlike the case with other infectious diseases, it is important to realize that the majority of individuals infected with parasites are healthy and will remain so. Thus, there is a great difference between infection and disease. This is simply because, with very few exceptions, helminth parasites do not replicate in the definitive human host. Thus, the public health community tends to recognize helminth infections as common but not a problem requiring high-priority attention. Nevertheless, although the mortality rate from intestinal helminths is thought to be low, the number of deaths is fairly high because of the high

 Waterborne Zoonoses: Identification, Causes and Control. Edited by J.A. Cotruvo, A. Dufour, G. Rees, J. Bartram, R. Carr, D.O. Cliver, G.F. Craun, R. Fayer, and V.P.J. Gannon. Published by IWA Publishing, London, UK. ISBN: 1 84339 058 2.

prevalence of infection in developing countries. About 60 000 deaths per annum occur for *A. lumbricoides* infection as a consequence of intestinal obstruction in young children. Similar figures have also been reported for both *T. trichiura* and hookworm infections due to massive dysentery syndrome and severe iron deficiency anaemia, respectively (WHO 1996).

There are myriads of emerging pathogens, including helminth parasites, some of which are transmitted by a variety of water sources. For a majority of helminths, only one host is required for a parasite to complete its life cycle. Some species of helminths are highly host-specific. Others are less discriminating and may have several satisfactory hosts, including humans. In many examples, humans are only incidental hosts, with domestic and wild animals serving as reservoirs of the parasites. Multiple host susceptibility to a parasite introduces the concept of zoonosis involving humans, another vertebrate, often arthropods or molluscs, the parasites, and the environment — all forming an ecological whole. Nature consists of an interaction of such living things, which are continuously or sometimes intermittently modified by alterations of the environment.

18.2 LIFE CYCLES

The life cycles of helminth parasites can be divided into two basic types: the direct cycle with only the definitive host, and 2) the indirect cycle with a definitive host and one or more intermediate hosts. Parasites with a direct life cycle usually have a free-living phase during which they develop to the infective stage. Those with an indirect life cycle have a free-living stage between some of the hosts.

The digenetic trematodes have an indirect life cycle exclusively involving molluscs as the first intermediate host; they usually require a second intermediate host that harbours the infective metacercariac stage, with the exception of several species in the genus *Schistosoma*, blood flukes. In nearly all instances, cestodes have an indirect life cycle, with a definitive host and one or two intermediate hosts in the life cycle. Nematodes have either a direct or an indirect life cycle; larvae pass through a series of four moults to become adults.

18.3 ROUTE OF TRANSMISSION

Although, in the case of intestinal parasites, the most common portal of invasion is through the mouth, exposure can occur from one or more of the following sources:

(1) contaminated soil;
(2) contaminated water;
(3) food containing the immature infective stage of the parasite;
(4) blood-sucking insects;
(5) contact with animals, including humans, harbouring the parasite; and
(6) self-contamination.

Soil polluted with human and animal excreta is commonly responsible for exposure in which a few important nematodes actively enter the body through the skin. Water may contain viable embryonated ova of nematodes and cyclophyllidian cestodes and the infective cercarial stage of *Schistosoma* species, as well as (oo)cysts of many parasitic protozoa. Freshwater fishes, crabs, and crayfishes are well documented sources of trematodes and cestodes. Blood-sucking insects that breed in the immediate environment of water resources, irrigation ditches, and other water bodies can transmit a large number of parasites that require development in insect hosts.

Contamination of a water system with sufficient quantities of embryonated ova or infective larvae could potentially result in outbreaks. However, this scenario would be difficult in community water sources, since the ova and larvae are relatively large and would be readily removed by standard processes for drinking-water treatment, including flocculation, sedimentation, and filtration, used by municipal water systems in many countries. However, post-treatment contamination or breakthrough of helminths in water systems with poor or less stringent treatment is highly possible.

18.4 NEMATODES

Many species of nematodes are free-living forms, found everywhere in fresh or salt water, in mud, or in soil. Others are plant nematodes. Myriads of species of nematodes are parasites of invertebrate and vertebrate animals. These parasitic nematodes have both a direct and an indirect life cycle. Several nematode species, such as hookworms, *Ascaris lumbricoides*, *Trichinella spiralis*, and filarial worms, are important human pathogens. Some of them are primarily or absolutely human parasites; others (*T. spiralis*) have a variety of mammalian hosts; and still others (*Strongyloides stercoralis*) have, at least temporarily, exclusively a parasitic phase in humans or exclusively a free-living phase. Filarial species require an arthropod as the intermediate host. In addition, there are many species of nematodes that are commonly parasitic in animals other than humans and incidentally parasitize humans, at times with disastrous consequences.

18.4.1 *Ascaris lumbricoides* and *A. suum*

The roundworm *Ascaris lumbricoides* is found worldwide. The largest nematode parasitizing the human intestine, an adult female may reach over 30 cm. It has a direct life cycle. Ova are found in insufficiently treated sewage fertilizer and in soils, where they embryonate upon exposure to air or oxygen in order to become infective. Under ideal conditions, this usually requires about 3 weeks. The ova may contaminate crops grown in soil or fertilized with sewage that has received non-lethal treatment. People acquire the infection through consuming such raw produce or contaminated drinking-water.

After being swallowed, the infective larvae escape from the ova, penetrate the wall of the intestine, reach the mesenteric lymphatics, and are carried through the right heart to the lungs before they develop into adult worms. The migration of the larvae through the lungs causes the blood vessels of the lungs to haemorrhage, and there is an inflammatory response accompanied by oedema. The resulting accumulation of fluids in the lungs results in "ascaris pneumonia," and this can be fatal in a heavy infection.

While humans are normally infected from another human source, infection with pig *Ascaris suum* does occur. Sanitary disposal of both human and animal excreta is the main method of preventing transmission. All faeces, when used as agricultural fertilizer, should be composted with vegetable refuse, since a temperature of 50 °C will kill the ova.

18.4.2 *Toxocara canis* and *T. cati*

Toxocara canis is a parasite of dogs that is found worldwide, while *T. cati* has been found in domestic and wild cats. The incidence is known to be high in dogs and cats, especially in young animals.

Larval toxocariasis in human hosts, caused by the second-stage larvae of *T. canis*, had been recognized in the 1950s in children (Wilder 1950; Beaver *et al.* 1952; Nichols 1956). Human toxocariasis results from the presence of larvae in the tissues after ingestion of embryonated ova through swallowing earth containing infective ova or consuming contaminated water. The most outstanding features of the disease in humans are eosinophilia, lasting several months, with a rise from a pre-exposure level of 3–6% to over 50%; and enlargement of the liver associated with hypergammaglobulinaemia, lasting a few months or weeks.

Larvae have been found in the central nervous system. Generalized convulsions have been reported in children with signs but without proof of invasion of the central nervous system. Fatal cases are rare but reported. The migration of the larvae leads to haemorrhage, and the resultant granulomatous

lesions can be widely scattered throughout the central nervous system. The parasite may transport viruses and other microorganisms, especially the virus of poliomyelitis, by destroying the blood–brain barrier in its migration (Woodruff 1968). Eye involvement in *Toxocara* infection is a common presentation in children 4–6 years of age, although a few incidents of eye infection have also been found in much older children and adolescents.

18.4.3 *Baylisascaris procyonis* and other non-human ascarids

Baylisascaris procyonis, known to be the racoon roundworm, is recognized as a cause of fatal or severe neurological disease. This ascarid nematode is an important zoonosis, producing damaging visceral, ocular, and neural larva migrans in humans, too. A small percentage of larvae enter the brain, where they produce marked traumatic damage and inflammation that often result in clinical central nervous system disease. *Baylisascaris procyonis* is receiving increased attention in North America, Europe, and Japan. Racoons are native to North and Central America but have been introduced elsewhere, taking *B. procyonis* with them. Racoons have established in major areas of Europe and Asia, following their escape or release decades ago. For example, it is estimated that more than 100 000 wild racoons occur in Germany, with a prevalence of *B. procyonis* infection of 71% (Gey 1998). The increase in racoons in Europe has been accompanied by *B. procyonis*-induced larva migrans in various species, including humans (Koch and Rapp 1981; Küchle *et al.* 1993). Over 20 000 racoons have been imported into Japan as pets since 1977; some of these may have escaped and/or been released and now inhabit wild areas. Infection of *B. procyonis* has already been confirmed in racoons in Japan (Miyashita 1993). Racoons can be well adapted to coexistence with human beings in both urban and rural areas. This eventually brings extensive opportunities for contact and infection of human beings with *B. procyonis*. Infectivity and pathogenicity of other members of *Baylisascaris* remain to be elucidated. Other non-human ascarid nematodes (*Lagochilascaris*, *Hexametra*, *Porrocaecum*, etc.) might also cause larva migrans (Goddart *et al.* 1985; Rosemberg *et al.* 1986).

18.4.4 *Trichuris trichiura*

Trichuris trichiura is one of the most common human nematodes, and apparently the same species lives in monkeys. Similar species may be found in many other animals, including pigs (*T. suis*). The ova pass from the body to the soil with faeces and within a few weeks develop into larvae that can remain viable for many months under moist conditions (reviewed by Bundy and Cooper 1989).

18.4.5 *Ancylostoma duodenale* and *Necator americanus*

Ancylostoma duodenale and *Necator americanus* are the most important hookworms of humans. Ova of *A. duodenale* embryonate in moist warm soil, and larvae hatch within 24–48 h. In about a week, they become filariform larvae that crawl to a high point of dirt, vegetation, or other moist substrate, ready to enter the host directly through the skin or through ingestion. Excess water at this stage of the life cycle is injurious to the worms. The filariform larvae burrow into the skin, enter a blood or lymph vessel, are carried to the lungs, pass upward to the mouth, and are swallowed, arriving in the small intestine, where they mature to adults.

Symptoms of infection start with ground itch, which occurs during the penetration of the skin by the filariform larvae. Creeping eruption may occur if human skin is penetrated by larvae of other species from animals, such as *A. braziliense* and others, which follow the same general life cycles in their own definitive hosts.

18.4.6 *Strongyloides stercoralis*

Strongyloides stercoralis is unique among helminths in having both free-living and parasitic generations. In the parasitic generation, parthenogenic females live in the mucosa of the small bowel, where they shed ova that hatch *in situ* into larvae. When liberated in the faeces, they develop into either infective filariform larvae or free-living males and females. The infective filariform larvae are ready to penetrate the body of the host. This can occur inside the intestine (internal autoinfection) or outside the body. The free-living generation larvae, on the other hand, reach maturity and complete their free-living life cycle repeatedly under favourable environmental conditions in essentially the same manner as that of any non-parasitic soil nematode. When environmental conditions become unfavourable, however, the rhabditiform larvae develop into the filariform larvae and become infective to humans.

Infection in humans and animals is contracted mainly by soil contact and penetration of the skin by larvae. Infection by the gastrointestinal route may also occur. Dogs and cats can be important reservoirs of human infection, as virulent strains may be introduced. Cross-infectivity between humans and dogs will depend on the infectivity within species and geographic strains of the parasite, which differ in their infectivity for different hosts.

18.4.7 *Angiostrongylus cantonensis* and *A. costaricensis*

Humans become infected with *A. cantonensis* and *A. costaricensis* by ingesting the third-stage larvae, either by consuming the molluscan intermediate hosts or

by consuming paratenic hosts that had fed on such infected molluscs. It is theoretically possible for humans to become infected by ingesting third-stage larvae liberated into water from dead or wounded molluscs, but such a source of infection is difficult to prove. The most common clinical feature of *A. cantonensis* infection in humans is meningitis 1–3 weeks after exposure, characterized by headache, moderate stiffness of the neck or back, paresthesia, little or no fever, and a pleocytosis consisting in large part of eosinophilic leukocytes.

Angiostrongylus costaricensis infection in humans (abdominal angiostrongylosis) is characterized by abdominal pain, mostly in the iliac fossa, prolonged fever, anorexia, and vomiting. Pathogenic lesions are found in the appendix and adjacent intestine and lymph nodes, consisting of granulomatous inflammation with intense eosinophilic infiltration. This nematode often reaches sexual maturation and releases ova into the intestinal tissues. The disease is endemic in Central and South America, but an autochthonous African case has been reported (Baird *et al.* 1987).

18.4.8 *Capillaria hepatica*

Capillaria hepatica (syn. *Calodium hepaticum*) lives in the host's liver, generally surrounded by a connective tissue capsule. Rodents are the primary initial hosts affecting humans, while cats, dogs, and rats are the principal transient hosts releasing ova in human habitats. The only known mode of spread to the definitive host, including humans, is ingesting embryonated ova. The ova must be released from the liver of the initial host through digestion in a transient (intercalary) host. The ova then pass out in the faeces, embryonate, and become infective. Embryonation occurs in about 4 weeks at 30 °C. Few verified cases of human infection with this nematode have been reported.

18.4.9 *Dracunculus medinensis*

Dracunculus medinensis is known as the guinea worm and is referred to as Moses' "fiery serpent" in the Bible. Female adult worms of *D. medinensis* range from 750 to 1200 mm in length and live in the connective tissue of humans and other vertebrates, where they migrate from one site to another. When the female is ready to discharge larvae (embryos), its anterior end emerges from a blister or ulcer, usually on the foot or lower limb, releasing large numbers of rhabditiform larvae when the affected part of the body is immersed in water. Larvae can move about in the water as long as 3 days until they are ingested by crustacean *Cyclops*. They moult twice in the intermediate host and are infective to a new host in about 2 weeks. If infected *Cyclops* (0.5–2.0 mm) are swallowed in

drinking-water, larvae are released, penetrate the intestinal and peritoneal walls, and inhabit the subcutaneous tissues. Infection with guinea worm is geographically limited. An ongoing eradication campaign has reduced the incidence of dracunculiasis, which is now restricted to rural, isolated areas in a narrow belt of African countries. The total number of dracunculiasis cases reported worldwide during 2002 was 54 638, of which about 76% were from Sudan (WHO 2003).

The only route of exposure is consumption of drinking-water containing *Cyclops* spp. carrying infectious larvae. The life cycle of *D. medinensis* can be broken by preventing the consumption of drinking-water that contains *Cyclops* spp., preventing the release of *D. medinensis* larvae (embryos) from female worms in infected patients into water, controlling *Cyclops* in water resources by means of fish, or inactivating *Cyclops* in drinking-water supplies by treatment with chlorine or copper sulfate.

18.5 TREMATODES

In general, trematodes are monoecious and require two intermediate hosts in their life cycle. The infectious stages of the trematodes to humans are metacercariae, which develop in the second intermediate hosts, with some exceptions. Ingesting raw second intermediate hosts, such as crabs (*Paragonimus*), fish (*Clonorchis*, *Opisthorchis*, *Echinostoma*, *Clinostomum*, heterophyid species), or vegetation (*Fasciola*, *Fasciolopsis*), depending on the choice by the larval trematode species, constitutes the source for human infections. Viewed in this light, infection of trematodes through drinking-water is unlikely.

18.5.1 *Schistosoma*

Schistosomiasis is a waterborne infection usually contracted by bathing in water that contains the snail intermediate host. There are a wide variety of snail hosts, each adapted to transmission of local strains of the schistosome species. Some snails are entirely aquatic, whereas others are amphibious. Some are abundant in small bodies of water, such as ponds and irrigation ditches; others are abundant in large lakes and in running streams. The amphibious snails are most abundant in and along banks of irrigation canals and drainage ditches, but can be drowned in flooded areas.

Many of the major economic developments in tropical areas are being frustrated by the increased prevalence of schistosomiasis as a result of water development (Ofoezie and Asaolu 1997; Chitsulo *et al.* 2000; Ross *et al.* 2001).

Schistosomes are unusual trematodes, in that the sexes are separate and there are no second intermediate hosts in their life cycles. There are a number of species of schistosomes that can infect humans, but most human infections are caused by one of the following three species: *Schistosoma mansoni*, *S. haematobium*, and *S. japonicum*. These primary species of human schistosomes have been well documented. The pathological lesions and clinical manifestations due to *S. haematobium* infection are distinct from those produced by the other two species. The adult worms of the former species migrate to the plexus or veins around the bladder, where they deposit their ova. The ova eventually escape into the urine, causing irregular haematuria, or they are engulfed in granulomatous lesions and papillomas. An accumulation of ova in the tissues of the bladder and ureters with the development of fibrosis may result in the formation of carcinoma of the bladder. The adult worms of the latter two species are found in the mesenteric and portal venous systems. The main pathogenic lesions are in the bowel and liver. They produce a focal colitis, which may present as a dysenteric syndrome. The extensive deposition of ova in the liver results in the development of multiple granulomas, periportal fibrosis, and, finally, hepatosplenic disease.

There are several other species in the genus *Schistosoma*, such as *S. intercalatum*, *S. bovis*, *S. mattheei*, and *S. rodhaini*, that can incidentally develop to maturity in humans and produce characteristic ova in the excreta.

18.5.2 Cercarial dermatitis

Avian schistosomes, including *Trichobilharzia ocellata*, developing in freshwater snails are known to be responsible in their cercarial stage for the production of papular eruptions of the skin of persons bathing in infected waters (Horak *et al.* 2002). Similarly, another type of avian schistosome dermatitis develops along saltwater beaches, with marine molluscs serving as the intermediate hosts and saltwater or migratory birds as definitive hosts. They are well documented as cercarial dermatitis or swimmer's itch (Cort 1950; Kirschenbaum 1979).

Other species known to cause cercarial dermatitis (Miyazaki 1991) include *Gigantobilharzia sturniae*, *Trichobilharzia brevis*, *T. physellae*, *Austrobilharzia variglandis*, and *Schistosoma spindale*.

18.5.3 *Fasciola hepatica*

Fasciola hepatica is found in most herbivores and averages 20–30 mm in size. *Fasciola hepatica* gives rise to cercariae during its asexual reproduction in *Lymnaea* snails. Cercariae, when released into the environment, swim to aquatic

vegetation and encyst as metacercariae. The vertebrate host, including humans, acquires infection by ingesting the metacercariae with water plants or drinking-water. Following maturation of the young flukes, the adult worms are found in the liver, gall-bladder, or associated ducts. They can cause severe damage, depending on the number of worms present and organs infected. The ova are passed with the bile into the faeces to continue the cycle.

There are two other related species in the family Fasciolidae: *Fasciola gigantica* and *Fasciolopsis buski*. The adults of the latter species are found not in liver but in the intestine of humans and pigs. Red caltrop (*Trapa natans*; water chestnut) is well known to carry metacercariae in China.

18.5.4 Miscellaneous

Cercarial dermatitis and ocular infection of the cercariae of *Diplostomum spathaceum* and mesocercarial invasion of *Alaria marcianae* have been reported. A fine review is provided by Smyth (1995).

18.6 CESTODES

The adult tapeworms of humans consist of a chain of a few to many ova-producing units (proglottids), which develop from the distal end of a scolex, which anchors the worm to the intestinal wall of its host. Cestodes infecting humans are found in two distinct orders: Cyclophyllidea and Pseudophyllidea. The former requires only one intermediate host, while the latter requires two intermediate hosts (copepods, aquatic vertebrates). In natural situations, the larval cestodes develop in mammals with which the respective final hosts have a predator–prey relationship.

Ova (embryophores) of some tapeworms are protected by thick shells and, in the most environmentally resistant species, are embryonated and infective when passed from the host. The genera *Taenia* and *Echinococcus* are among those most likely to be distributed in environments where they can infect humans and other animals. In areas of the world where the processes are inadequate for parasite destruction, dispersal of these tapeworm ova to the environment could constitute a serious public health hazard. Ova from both genera have been found in sewage.

18.6.1 Cyclophyllid cestodes

The order Cyclophyllidea contains two major genera that occur in humans: *Taenia* and *Echinococcus*. A high degree of host specificity is characteristic of

the adults of these cestodes. The range in intermediate hosts, however, is influenced by both phylogenetic and ecological factors.

18.6.1.1 Taenia solium and Taenia saginata

Taenia solium, the pork tapeworm, infects humans in both its adult and larval stages. Adults inhabit the human small intestine. Patients may be asymptomatic, but gastrointestinal disorders, including diarrhoea, flatulence, tympanites, and abdominal pain, are often reported. Humans become infected by larval *T. solium*, called cysticercosis, by ingesting food or water contaminated with embryonated ova. Massive invasion of skeletal muscles causes myositis, with pain, swelling, and weakness. Severe involvement of the myocardium causes heart failure. Clinical features of cerebral infection can include visual failure, seizures, episodes of abnormal behaviour, transient obstructive hydrocephalus, disturbed equilibrium, and other abnormalities. The degeneration of cysticerci in the brain results in a pronounced tissue reaction. Because of taboos concerning the use of pigs as food, *T. solium* is rarely found in Muslim and Jewish populations.

Ova of *Taenia saginata*, the beef tapeworm, may be distributed where cattle or sheep graze pastures that have been irrigated with untreated wastewater. Although transmission of *T. saginata* to cattle exposed to sewage wastes has been reported, little information is available relating to the magnitude of the threat to public health in either developing or developed nations. Pawlowski and Schultz (1972) reviewed the disease aspects of infections with tapeworms, including potential transmission of the beef tapeworm through sewage and sludge. However, additional data are urgently needed on the frequency of transmission to humans from utilization of variously treated or untreated sewage and/or sewage sludge. Larval beef tapeworms have not been found in humans.

18.6.1.2 Echinococcosis

Humans become infected by the larvae of four species of *Echinococcus*: *E. granulosus* (cystic hydatid disease), *E. multilocularis* (alveolar hydatid disease), *E. vogeli* (polycystic hydatid disease), and *E. oligarthrus* (polycystic hydatid disease). In the natural hosts, the larvae of the respective species are distinctive morphologically, but not in their basic organization. The range of pathological changes and clinical manifestations that develop in humans is largely attributable to sites of localization.

The characteristic feature of alveolar hydatid disease caused by *E. multilocularis* infection is the proliferation of the larvae in the liver, the primary site of localization in humans and in the natural intermediate hosts, by exogenous budding, invading irregularly and destroying the surrounding hepatic

tissue. The disease is chronic and usually asymptomatic until the lesion becomes large. Metastasis to the lungs and brain in humans may occur and is ultimately fatal.

The intermediate hosts, including humans, become infected through ingestion of ova shed in the faeces of foxes or dogs. The area inhabited by foxes may be grossly contaminated by their faeces. Dogs as synanthropic hosts appear to be a more important source of infection than wild foxes. Water contaminated by *E. multilocularis* is a major concern in Hokkaido, Japan (Yamamoto *et al.* 2001), where drinking-water plants have found their way into remote villages and are operated with scrupulous care.

Since the larval *E. multilocularis* produces large numbers of protoscolices in the natural intermediate hosts, such as voles, massive infections in the final host tend to occur.

Cystic hydatid disease induces a variety of clinical characteristics, attributable to the site of localization of the larvae of *E. granulosus* and complications. A single cyst in the lungs or liver may be asymptomatic unless it has become unusually large or ruptured. Leakage of cyst fluid may cause allergic reaction, including anaphylaxis. Suppuration of ruptured cysts is a frequent complication, especially in the lungs. Rupture of cysts in abdominal organs may lead to secondary dissemination in the peritoneal cavity. Metastatic foci may develop in the lungs or brain when cellular elements of the larvae enter the circulation. Cysts in skeletal locations may cause severe erosion.

Large numbers of cestodes may develop from a single cyst eaten by the final host; 60 000–70 000 adult cestodes have been recorded in individual dogs. Cystic hydatid disease is almost exclusively a consequence of contact with dogs harbouring the adult *Echinococcus*. The raising of livestock in association with dogs results in the establishment of a closed system; under such conditions, humans frequently become infected. Surface water and streams running in or near such fields raising livestock in association with dogs can be easily contaminated by the ova, and water may play an important role in the dissemination of the hydatid diseases, although the actual route of infection is still unclear. Economic losses due to cystic hydatid disease are of great concern throughout much of the world's farming country (Attanasio *et al.* 1985; Battelli 1997).

Echinococcus vogeli and *E. oligarthrus* have been reported to cause human polycystic echinococcosis in Latin America. The clinical presentation of the polycystic echinococcosis is very similar to infection with multiple cysts of *E. granulosus*. The latter is an extremely rare cause of human echinococcosis.

18.6.2 Pseudophyllid cestodes

Cestodes in the order Pseudophyllidea that infect humans include *Diphyllobothrium latum* and related species, such as *D. nihonkaiense* and *Diplogonoporus grandis*. Transmission to humans is by ingestion of hosts that harbour second-stage larvae (spargana), mostly fish.

Human infection with larval stages of *Spirometra erinaceieuropaei* can be acquired by ingestion of copepods in drinking-water. Other modes of transmission have been reported. Symptoms can develop rapidly after infection by cutaneous or mucocutaneous invasion, but may not develop for months or years if infection results from ingestion of larvae. Signs and symptoms depend on the site of migration and localization of the larvae.

There is still confusion concerning the classification of the diphyllobothriid larvae occurring in humans. Larval cestodes are not morphologically distinct, and there is little information regarding adult worms that develop from them.

18.7 REFERENCES

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