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SCIENCE DIRECT
Veterinary Parasitology 126 (2004) 167–193
veterinary parasitology
www.elsevier.com/locate/vetpar

Review

Waterborne zoonotic helminthiases

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Abstract

This review deals with waterborne zoonotic helminths, many of which are opportunistic parasites spreading directly from animals to man or man to animals through water that is either ingested or that contains forms capable of skin penetration. Disease severity ranges from being rapidly fatal to low-grade chronic infections that may be asymptomatic for many years. The most significant zoonotic waterborne helminthic diseases are either snail-mediated, copepod-mediated or transmitted by faecal-contaminated water. Snail-mediated helminthiases described here are caused by digenetic trematodes that undergo complex life cycles involving various species of aquatic snails. These diseases include schistosomiasis, cercarial dermatitis, fascioliasis and fasciolopsiasis. The primary copepod-mediated helminthiases are sparganosis, gnathostomiasis and dracunculiasis, and the major faecal-contaminated water helminthiases are cysticercosis, hydatid disease and larva migrans. Generally, only parasites whose infective stages can be transmitted directly by water are discussed in this article. Although many do not require a water environment in which to complete their life cycle, their infective stages can certainly be distributed and acquired directly through water. Transmission via the external environment is necessary for many helminth parasites, with water and faecal contamination being important considerations. Human behaviour, particularly poor hygiene, is a major factor in the re-emergence, and spread of parasitic infections. Also important in assessing the risk of infection by water transmission are human habits and population density, the prevalence of infection in them and in alternate animal hosts, methods of treating sewage and

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doi:10.1016/j.vetpar.2004.09.018

drinking water, and climate. Disease prevention methods, including disease surveillance, education and improved drinking water treatment are described.

Keywords: Snails; Copepods; Faecal contamination; Schistosomiasis; Cercarial dermatitis; Swimmer's itch; Fascioliasis; Fasciolopsiasis; Sparganosis; Gnathostomiasis; Dracunculiasis; Cysticercosis; Hydatid disease; Larva migrans

Contents

1. Introduction

Arguably, helminthiases constitute the most common parasitic infections in humans and animals throughout the world. They represent important public health problems with great economic impact in tropical and subtropical countries. Prevalence and intensity of infection and the dynamics of transmission may vary according to the availability of hosts and to local environmental conditions. Many species are zoonotic, highly prevalent and difficult to control. Transmission occurs from man to man, animal to animal or from animal to man. Some are emerging or re-emerging zoonoses in both developing and developed countries. Infection follows parasite contamination of the environment and ingestion with food, soil or water or by skin penetration. In general, water-based helminths leave the host with excreta, then develop further in water or in intermediate hosts living in the water. Therefore, transmission is only possible if the infective stage and suitable hosts are both present in the water. Waterborne zoonotic helminthiases can be grouped into the snail-mediated helminthiasis (schistosomiasis, cercarial dermatitis, fascioliasis and fasciolopsiasis), copepod-mediated helminthiases (gnathostomiasis, sparganosis and dracunculiasis) and faecal water-contaminated helminthiases (cysticercosis, hydatid disease and larva migrans). Rates of transmission and exposure are dependent upon human behaviour, occupation, social practices and cultural beliefs together with poor human hygiene, unsanitary animal husbandry and economic activities. The distribution, prevalence and medical and veterinary importance of a number of zoonotic helminths are reviewed with special emphasis given to those affecting the health of humans and animals in Asia. The transmission dynamics of major waterborne zoonotic helminth diseases are summarized in Fig. 1.

2. Snail-mediated helminthiases

The schistosomes are distributed worldwide and for many decades have been considered the most important group of waterborne helminths affecting the health of humans and animals. *Schistosoma* spp. undergo a complex life cycle involving species of aquatic snails and produce schistosomiasis and cercarial dermatitis. Schistosomiasis is a major occupational risk for agricultural workers in rural areas of the tropics and subtropics and is of considerable socioeconomic and public health importance. Schistosomes are endemic in at least 74 countries of Africa, Asia and Latin America where approximately 200 million people are infected and another 600 million are at risk (Chitsulo et al., 2000). Particularly in Africa, central China and Egypt, the disease poses major health risks. Six species of *Schistosoma* are known to infect humans in different areas of the world: *Schistosoma haematobium*, *Schistosoma mansoni*, *Schistosoma japonicum*, *Schistosoma intercalatum*, *Schistosoma mekongi* and *Schistosoma malayensis* (Agatsuma, 2003; Rollingson and Southgate, 1987). In addition, there are at least 18 species affecting other mammals and birds of which *Schistosoma bovis*, *Schistosoma indicum*, *Schistosoma nasale* and *Schistosoma spindale* are of greatest economic and veterinary importance. As well, the cercariae of many other bovine and avian schistosomes are responsible for cercarial dermatitis affecting humans worldwide.

2.1. Schistosomiasis

In general, the life cycles of all animal and human schistosomes are similar (Rollingson and Southgate, 1987). Eggs are passed in urine or faeces, and contaminate the environment.

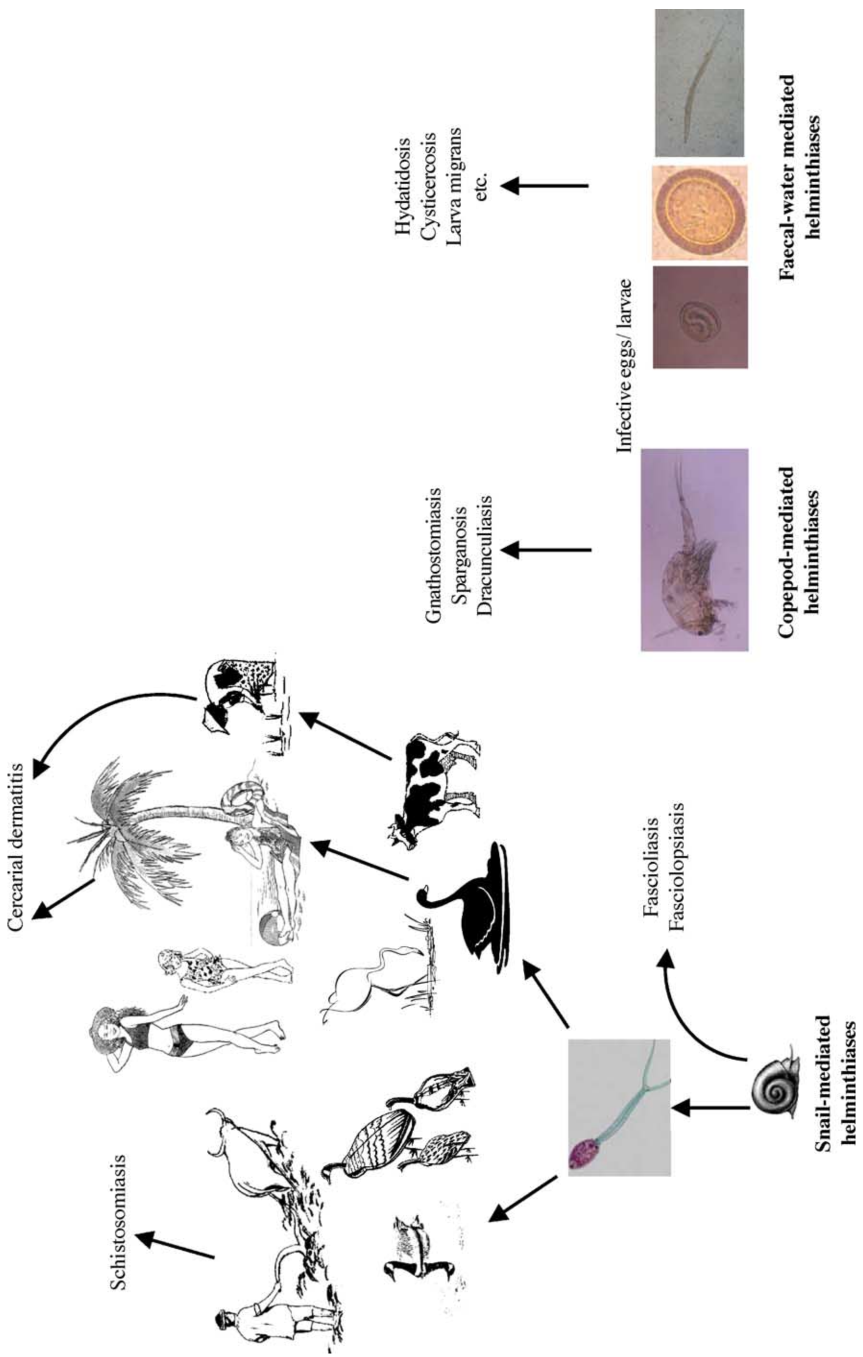

Fig. 1. Transmission of waterborne zoonotic helminthiases.

On reaching water, the miracidia hatch from the eggs, find and penetrate a suitable snail intermediate host, and develop through two generations of sporocysts before producing large numbers of fork-tailed cercariae. These infective cercariae penetrate the skin of a definitive host, shed their tails, become schistosomulae and migrate through the tissues to the liver. Here, male and female flukes copulate and then migrate into venous blood vessels of either the large intestine or the bladder where eggs are laid. Schistosomiasis can result in chronic liver, spleen, intestinal, nasal and bladder damage.

2.1.1. Human schistosomiasis

Oriental schistosomiasis or schistosomiasis japonica was first described in Japan over 150 years ago (Tanaka and Tsuji, 1997) where it was recognized as the cause of hepatosplenomegaly of humans. Infections are also known to occur in domestic cats. Variations in *S. japonicum* seen across its distribution in Asian countries has led to the opinion that the *S. japonicum* complex actually comprises three different species, namely *S. japonicum*, *S. mekongi* and *S. malayensis*. These are differentiated on the basis of geographical distribution, life cycle, species of snail used as intermediate host, morphology and enzyme variation. The best known among these species is the classical *S. japonicum*, which occurs in Japan, China, the Philippines and parts of Indonesia. It is zoonotic, occurring in many mammalian species (Rollingson and Southgate, 1987). In Japan, efforts begun in 1966 to eradicate *S. japonicum* were successful, but it remains endemic in China and in the Philippines. In China, several million people suffer from schistosomiasis japonica and the disease has a large impact on rural economics and human health. In the Dongting lake region of South China and other high-risk areas, the prevalence and intensity of *S. japonicum* in humans are mainly dependent upon water contact activities as well as the geographical site, range and intensity of infected snails. The most important snail intermediate host is *Oncomelania hupensis hupensis*. People between 18 and 49 years old become infected mainly as a result of domestic and occupational duties. Women are exposed while bathing or washing clothes and men become infected when fishing, bathing, and men under 20 years of age are at greatest risk (Jiang et al., 1997).

Serious schistosomiasis is characterized by hepatomegaly and cerebral involvement (Hayashi et al., 1984a, 1984b). A survey of school children during 1975–1981 revealed high rates of infection (28.6–47.4%) that were positively associated with the abundance of the snail, *O. hupensis quadrasi* in endemic areas. In Indonesia, the parasite has been studied since 1971 and two isolated areas in central Surawesi (the Lindu and Napu valleys) report high rates of infection with schistosomiasis japonica. Rates of infection among children and the snail *O. hupensis lindoensis* ranged from 13 to 72% and 2.4 to 17%, respectively. Interestingly, *S. japonicum* was also found to occur in 13 species of reservoir hosts including water buffalo, wild pigs, deer, horses, dogs, cats and rodents (Sudomo, 1984). Since 1975, programs in the endemic areas of Indonesia aimed at improving sanitation and reducing snail habitat have decreased infection rates among rats and snails.

Schistosomiasis, caused by a *S. japonicum*-like parasite, has been known for over 10 years in parts of Southeast Asia before the responsible agent was confirmed as a new species, *S. mekongi* (Voge et al., 1978). The parasite and disease are restricted to a small area of the Mekong River Basin (MRB) in Lao PDR and Cambodia. Schistosomiasis mekongi is an important public health problem and clinical manifestations are not necessarily associated with higher intensity infections. The main clinical sign, hepatosplenomegaly, is similar to that seen in *S. japonicum* infections. Other signs in infected school children include bloody and mucoid stools, portal hypertension, ascites, stunting, delayed puberty and oesophageal bleeding usually leading to death (Stich et al., 1999). So far, only pigs and dogs have been found to harbor *S. mekongi* infections. The infection rate in pigs and dogs was 12.2 and 3.6%, respectively (Matsumoto et al., 2002; Strandgaard et al., 2001). In contrast to *S. japonicum*, transmission of schistosomiasis mekongi requires the aquatic snail *Neotricula aperta* for development (Attwood et al., 1997). This snail survives only on the rocky banks of the MRB and the peak period of cercarial emergence is during the day. Disease with high morbidity and mortality has so far been reported only in southern Laos and northern Cambodia. Here, important risk factors include daytime activities such as fishing, laundering, bathing, swimming and other endeavors involving water contact along the rocky banks of the Mekong River.

Although known to be present for decades, the large impact of schistosomiasis on the health of the local people in Cambodia was only recognized in 1993. In endemic areas, the overall prevalence in fisherman of all ages was between 10.7 and 11.2%. The youngest age group (1–4 year-old) exhibited the highest rates of infection (Schneider, 1976). The disease is a serious health problem in parts of the country as well as in Cambodian refugees at holding centers in Thailand (Keittivuti et al., 1982). Within the endemic area, people at greatest risk live in villages on the left bank of the Mekong River where the prevalence reaches as high as 70% in school-age children. It has been estimated that 11,000 of the 60,000 people were infected and the number of new cases increases each year. Presently, 80,000 people in Cambodia are estimated to be at risk of infection (Urbani et al., 2002). In Laos, schistosomiasis was first reported in 1960 but the disease has been less evident than in Cambodia. Transmission occurs on Khong Island where the overall prevalence in people 4–29 years old ranged from 11.9 to 14.4%. Presently, an estimated 60,000 people are at risk of infection with *S. mekongi* in Laos (Urbani et al., 2002).

S. malayensis is an insignificant Asian schistosomes of humans. Although very closely related to classical *S. japonicum* and *S. mekongi*, *S. malayensis* differs in DNA sequences, geographical distribution and the species of snail required for development (Blair et al., 1997; Upatham et al., 1985). *Robertsiella kaporensis* acts as the intermediate host and infection is found only among the native people of West Peninsular Malaysia (Sagin et al., 2001; Upatham et al., 1985).

Schistosomiasis mansoni, or intestinal schistosomiasis, is caused by *S. mansoni*, the most important blood fluke in Africa, South America, Middle East and parts of Saudi Arabia. Humans as well as other mammals are the natural hosts for this parasite. All primates, particularly the baboon *Papio hamadryas*, plays a significant role as a reservoir host of *S. mansoni* infection in Kenya, Africa. The potential snail intermediate hosts are *Biomphalaria* spp. The disease is similar in other aspects to that caused by *S. japonicum*. The adult parasites produce lesions mainly in the lower colon. Eggs may cause liver cirrhosis, splenomegaly and ascites. Fatigue, abdominal pain and bloody and mucoid stools frequently occur in heavy infections.

Schistosomiasis haematobium or urinary schistosomiasis is a disease of humans caused by *S. haematobium* mainly found in Africa, the Middle East, Saudi Arabia, Iran, Madagascar and Mauritius. Though humans are a main host of this parasite, several mammals, i.e. primates, pigs, sheep and rodents can also be naturally infected. Several snail species in the genus *Bulinus* act as intermediate hosts. Adult parasites are in small veins around the bladder and ureter and high numbers of eggs are deposited in the bladder wall leading to chronic disease. The disease is characterized by haematuria, dysuria, hydronephrosis (van der Werf et al., 2003), calcification of the bladder wall and ureter (Ghandour, 1991), which lead to cancer, an important complication of the infection. Mortality is due mainly to kidney failure and bladder cancer. In Saudi Arabia, the prevalence of infection ranged from 0.16 to 55.7% depending on locality; calcification of the bladder and ureter was observed in 50% of infected persons under the age of 50 years (Wallace, 1979). Suitable species of snail intermediate hosts and the disease occur mainly in the western regions where three important flood-prone river systems of the country are located (Ghandour, 1991). In endemic regions of Saudi Arabia, the prevalence of schistosomiasis haematobium is much lower than that of schistosomiasis mansoni.

S. intercalatum is of minor importance to human health in Central Africa. It has a patchy distribution within the tropical rain forest regions of 10 countries and causes an intestinal schistosomiasis (WHO, 1993). The adult worm is similar morphologically to that of *S. haematobium*, but differs with respect to the location of the adult parasite (rectum), isoenzymes, egg morphology and intermediate host specificity. Infections are often asymptomatic, but bloody faeces and diarrhoea are occasionally seen. Primates, sheep, goats and rats are important reservoir hosts.

2.1.2. Animal schistosomiasis

Animal schistosomes are widely distributed, but those of veterinary importance are restricted to tropical and subtropical areas and are found primarily in ruminants. Generally, their pathogenicity is low, but only occasionally do they affect health by reducing body weight or causing the death of the host. In Africa and Asia, it is estimated that as many as 165 million cattle are infected while another 530 million live in other endemic areas (De Bont and Vercruysse, 1997). Because most cases are asymptomatic, rates of infection are probably underestimated. Of about 10 species known to infect ruminants, the most important in bovids are *Schistosoma mattheei* and *S. bovis* in Africa and *S. spindale* and *S. nasale* in Asia. Except for *S. nasale*, all species reach maturity in the mesenteric veins where they cause intestinal schistosomiasis. In endemic areas, bovine schistosomes and cercarial dermatitis are highly focal because of the aggregated distribution of snail intermediate hosts and the fairly restricted movement of livestock.

S. mattheei is of veterinary importance and commonly found in the mesenteric veins of cattle, sheep and goats of southern Africa. There is evidence for its occurrence in man as well (Pitchford and Visser, 1975). A wide variety of wild mammals including waterbuck, wildebeest, antelope and buffalo are also infected. In domestic cattle, prevalence can be as high as 90% in endemic areas. *S. mattheei* appears to have a narrow intermediate host specificity in snails, with natural infections being found in members of the *Bulinus africanus* complex. It is possible that other species of schistosomes including *S. bovis* are involved in schistosomiasis of ruminants in the same areas.

The adult stage of *S. bovis* is parasitic primarily in the mesenteric veins of ruminants. Although *S. bovis* has been recognized as a serious veterinary problem in some areas of the world, it is not zoonotic. It is widespread in Africa, the Mediterranean and Middle East. In Tanzania, the prevalence of *S. bovis* infection from abattoir surveys is 30.8% in cattle and 3.8% in goats (Kassuku et al., 1986). Various species of *Bulinus* snails are suitable intermediate hosts. Natural infections also occur in horses, donkeys, sheep, goats, camels, dromedaries, pigs, antelope and rodents. Disease caused by *S. bovis* is characterized by diarrhoea, weight loss or poor weight gain, anaemia, eosinophilia and death.

S. spindale occurs in the portals and mesenteric veins of the small and large intestines of ruminants including swamp buffaloes, cattle, sheep and goats. It is widely distributed in India, Sri Lanka, Indonesia, Malaysia, Thailand and Viet Nam where it is considered a major cause of schistosome dermatitis in man. This is a particular problem where infected buffaloes and the intermediate snail host, *Indoplanorbis exustus*, co-occur in rice paddy fields. This mollusc species is commonly referred to as ''the itchy snail'' in Southeast Asia, especially in Thailand and Malaysia (Harinasuta et al., 1965). Under natural conditions, buffaloes and cattle are the main host of *S. spindale* while rodents (*Bandicota* spp. and *Rattus* spp.) are also infected (Inder Singh et al., 1997). Probably, *S. spindale* adapted to infecting hairy hosts present in shallow, muddy waters. Cercarial production in snail is high (greater than 7000 per day) (Haas et al., 1990) and the cercariae are able to infect many species of mammalian hosts, resulting in high prevalence of schistosomiasis in animals and cercarial dermatitis in man.

In Thailand, *S. spindale* occurs year-round in buffalo and beef and dairy cattle. Prevalence ranges from 0 to 80% depending on locality and availability of the snail *I. exustus* (Pholpark et al., 1989). Grazing bovids are infected either through skin penetration or contaminated drinking water. Occasionally high mortality occurs in heavily infected calves under 1 year old. Severely infected animals show signs of emaciation, anaemia, bloody diarrhoea, and oedema and they occasionally die; mild infections are often sub-clinical. In Sri Lanka, the overall prevalence of *S. spindale* in cattle during 1988–1989 was 31.2% as determined by the recovery of adult flukes from the mesenteric veins at slaughter. Animals younger than 2 years were less frequently infected (21.3%) than those older than 5 years (47.9%). Histological study revealed moderate hepatic lesions with periportal cell infiltration and periportal epithelioid cell granulomas within perilobular zones. Submucosal and mucosal granulomas accompanied by cellular changes were present in the small and large intestine (Fransen et al., 1990).

S. nasale causes nasal schistosomiasis, or snoring disease in cattle, sheep and goats, but is asymptomatic in buffalo and native cattle. Adult worms reside in veins of the nasal mucosa and eggs are shed in the nasal discharge. The disease is widespread in the Indian subcontinent and adjacent areas of Burma, Sri Lanka and Bangladesh. It is more common in buffalo than in cattle. The intermediate host is *I. exustus*; *S. nasale* and *S. spindale* use the same snail host. The prevalence of *S. nasale* in cattle at slaughterhouses in Sri Lanka was 12.6% (De Bont et al., 1989). Eggs deposited in the nasal mucosa elicit an inflammatory reaction of infiltrating cells and extensive fibrous tissue proliferation leading to large cauliflower-like growths that obstruct the nasal cavity. Granuloma formation due to the presence of eggs is commonly seen in the respiratory mucosa. The severity of lesions increases with age (De Bont et al., 1989).

2.1.3. Cercarial dermatitis (swimmer's itch)

The cercariae of many animal schistosomes are zoonotic, causing dermatitis in humans throughout the world. Schistosome dermatitis, also called cercarial dermatitis or swimmer's itch, is a disease caused mainly by cercariae that normally infect birds and mammals other than humans. Unable to differentiate human skin from that of their normal host, these cercariae penetrate surfaces but do not survive, and dead or dying schistosomulae elicit an intense inflammatory reaction or dermatitis. Cercarial dermatitis is usually accompanied by intense itching and a rash. The severity of the reaction varies with the species of schistosome, intensity of infection and degree of previous exposure. The skin reaction following repeated exposure to animal schistosomes is more severe than that following re-exposure to human schistosomes. Causative agents are mainly members of the family Schistosomatidae including *Schistosoma* spp. of mammals and *Gigantobilharzia*, *Trichobilharzia* and *Austrobilharzia* of avian hosts. Cases of cercarial dermatitis can occur in both fresh and brackish water environments. Skin not covered by close-fitting garments is most likely to be affected. The skin reaction begins shortly after leaving the water and lasts for a few hours to a few days. Petechial haemorrhages and papules may occur at the site of skin penetration. Histologically, penetration sites show marked round cell infiltration of the dermis and epidermis.

It has been long known that cercariae of *S. spindale* are a common cause of dermatitis in Asia, especially in India, Malaysia and Thailand and the snail *I. exustus*, is a major source of infection (Harinasuta et al., 1965). In 1988, an outbreak of cercarial dermatitis caused by *S. spindale* cercariae occurred in a province of southern Thailand. Diagnosis in rice-field workers was based on a history of exposure to water that may have been contaminated with cercariae. The first exposure involved 41 individuals and re-exposure was experienced by 17 persons. The course of the disease ranged from 2 days to 1 month. Infected *I. exustus* snails were abundant in the area (Kullavanijaya and Wongwaisayawan, 1993). In Peninsular Malaysia, *S. spindale* cercarial dermatitis affected farmers in paddy cultivated areas (Inder Singh et al., 1997) and the condition is very common in Assam, India where *I. exustus* was also the source of cercariae (Narain et al., 1998). Cercarial dermatitis from *S. spindale* is mainly associated with rural occupations and activities. Although not life-threatening, it is an annoying disease.

Austrobilharzia spp. is an avian schistosome causing marine cercarial dermatitis in Australia, Europe, North America and Hawaii. The cercariae invade the skin of people who swim in shallow water along the seashore. The adult blood flukes, *Austrobilharzia terrigalensis*, *Austrobilharzia variglandis*, as well as other species, live in the mesenteric veins of several species of waterfowl. Snails belonging to different families act as intermediate hosts. This lack of host specificity is thought to be related to the habits of waterfowl that migrate between the Northern and Southern hemispheres. In Australia, children 5–14 years old are most frequently affected. Cases of dermatitis occur primarily during the day when emergence of cercariae from snails is most common. Exposures times vary considerably, but generally requiring between 30 and 90 min with dermatitis appearing 12–24 h later. The lesions, which sometimes occur over the body with severe itch, persist for 1–2 weeks or longer, with the presence of secondary infection (Appleton and Lethbridge, 1979).

Gigantobilharzia inhabits the mesenteric veins of gulls and passerine in South Africa and Asia (Appleton and Randall, 1986; Matsumura et al., 1984; Miyazaki, 1991). In Japan, cercariae of *Gigantobilharzia sturniae* are shed by the freshwater snail *Polypylis hemisphaerula* in paddy fields (Matsumura et al., 1984). *Gigantobilharzia* spp. has been recorded from a South African coastal bird, *Larus dominicanus* (Appleton and Randall, 1986).

Trichobilharzia spp., the most common of avian blood flukes, parasitize ducks of Europe, Asia and North America. Adults worms occur in veins of the hosts' intestinal walls. Various freshwater lymnaeid snails including *Lymnaea rubiginosa*, *Lymnaea stagnalis*, *Austropeplea ollula* and *Radix japonicus* are the main intermediate hosts. The prevalence and intensity of infected lymnaeids increase according to snail size; larger snails produce more cercariae than smaller ones. In Europe, at least seven species of *Trichobilharzia* have been recorded, but *Trichobilharzia ocellata* is considered the most important (Kock, 2001). During recent years, swimmer's dermatitis has increased across the Northern hemisphere, and in many recreational lakes, the risk factors have been identified for preventive recommendations (Chamot et al., 1998; Allgower and Effelsberg, 1991). In parts of Asia (i.e. Japan, Malaysia, Thailand), dermatitis is strongly associated with working in rice paddies. In Japan, the snail *R. japonicus* and the schistosomes *T. ocellata* and *Trichobilharzia physallae* are mainly responsible for rice-field dermatitis (Miyazaki, 1991). In Thailand, *L. rubiginosa* serves as the intermediate host of *Trichobilharzia maegraithi* of ducks (Kruatrachue et al., 1968). In our study in Ayuthaya and Angthong Provinces, central Thailand during March–July 2003, we observed fork-tailed cercariae of Schistosomatidae and Sanguinicolidae were being shed by lymnaiid, bithyniid and indoplanorbid snails in rice paddies and fish ponds. These endemic areas had an abundance of aquatic birds, cattle and buffalo year-round. Farmers and fishermen working in these contaminated areas often showed signs of spotted dermatitis, probably due to cercariae of animal schistosomes.

2.2. *Fascioliasis*

Fascioliasis is a disease of herbivorous animals caused by two species of large liver flukes, *Fasciola hepatica* and *Fasciola gigantica*. It occurs worldwide in a large variety of grass-grazing animals including sheep, goats, cattle, buffalo, horses and rabbits. Occasionally, humans are infected accidentally. Adult flukes reside in the large biliary ducts of the definitive host. Eggs discharged into the biliary ducts are excreted with faeces. Following development in water, the miracidium emerges from the egg and invades a suitable snail intermediate host of the genus *Lymnaea*. Development through several stages in the snail culminates with the release of cercariae that encyst as metacercariae on aquatic vegetation or on the water surface. Herbivores and humans are infected by ingesting freshwater plants or water containing metacercariae. During the acute phase caused by the migration of the immature fluke, clinical manifestations include abdominal pain, hepatomegaly, fever, vomiting, diarrhoea, urticaria and eosinophilia. These clinical signs can last for several months. In the chronic phase caused by the adult fluke, signs of disease are more discrete and reflect intermittent biliary obstruction and inflammation. Occasionally, ectopic infection such as in the intestinal wall, lungs, subcutaneous tissue and pharyngeal mucosa, can occur.

Historically, human fascioliasis was very sporadic, but within the last three decades, increasing reports of clinical cases and outbreaks have led WHO to acknowledge its importance (Mas-Coma et al., 1999). The number of reports of human fasciolosis has increased significantly since 1980 and several geographical areas have been identified as endemic for the disease. As many as 2.4 million people in 61 countries are estimated to be infected and an additional 180 million are at risk throughout the world (Haseeb et al., 2002). Estimates of the number of people with fascioliasis include 360,000 in Bolivia, 20,000 in Ecuador, 830,000 in Egypt, 10,000 in the Islamic Republic of Iran, 742,000 in Peru and 37,000 in Yemen. Human infections with *F. hepatica* are found in areas where sheep and cattle are raised and where humans consume raw freshwater plants, including Europe, the Middle East and Asia.

In Asia, *F. gigantica* is the predominant species of bovine large liver fluke. Animals infected with *F. gigantica* have been reported in Asia and Africa resulting in economic loss from both acute and chronic infection (Kithuka et al., 2002; Ogurinade and Ogunrinade, 1980; Srihakim and Pholpark, 1991). In Thailand, the prevalence of *F. gigantica* in cattle and buffalo vary considerably, ranging from 0 to 85% (Srihakim and Pholpark, 1991). The prevalence is highest in areas surrounding dams or large ponds where *L. auricularia rubiginosa* was abundant. Only 12 human cases of fascioliasis gigantica and fascioliasis hepatica have been recognized in the northeastern and northern provinces (Tesana et al., 1989; Wong et al., 1985; Kachintorn et al., 1988; Buranasin and Harinasuta, 1970; Khamboonruang and Sakulwong, 1971; Chitchang et al., 1982; Parichatikanond and Sarasas, 1984). However, it is possible that *F. hepatica* may not occur in Thailand, as the identification in those reports was based entirely on the morphology of worms. Similarly, only five cases of human fascioliasis have been reported in Korea. On the other hand, large numbers of cases of human fascioliasis caused by *F. gigantica* have been reported in Viet Nam (500 since 1978, mostly from the central provinces) (Tran et al., 2001) and in northern Iran where 10,000 cases were diagnosed in 1999 (Rokni et al., 2002).

2.3. Fasciolopsiasis

Fasciolopsiasis is a snail-mediated zoonotic helminthiasis caused by *Fasciolopsis buski*, the largest intestinal fluke of humans and pigs. It occurs in Asia and the Indian subcontinent, particularly in areas where pigs are raised in open spaces and have access to freshwater vegetation. Most infections are light and asymptomatic. But in cases of heavy infection, clinical signs including diarrhoea, abdominal pain, fever, ascites, anasarca and intestinal obstruction may be seen. The life cycle of this fluke is similar to that of *Fasciola* spp. Definitive hosts are infected after ingesting metacercariae on aquatic plants or on the water surface. In China, 3.6% of metacercariae were frequently found on the water surface in endemic areas and it has been estimated that 10.3–12.8% of infected humans and 35.1–40% of infected pigs may have contracted the parasite through contaminated drinking water (Weng et al., 1989). To date, fasciolopsiasis remains an important public health problem in rural and suburban areas of many Asian countries where the prevalence of infection in pigs can be as high as 40% in endemic foci. The infection is highly endemic in China, Taiwan, India, Bangladesh, Laos, Viet Nam and Thailand. (Graczyk et al., 2001; Bhatti et al., 2000; Weng et al., 1989; Ditrich et al., 1992; Waikagul, 1991). Disease in humans usually occurs focally and is most prevalent in school-age children. Rates of infection in children in mainland China, Taiwan, Bangladesh, India and Thailand ranged from 10 to 57% (Graczyk et al., 2001) and were also high in 2–10-year-olds in Dacca District of Bangladesh (Gilman et al., 1982). *F. buski* develops in two species of planorbid snails (*Segmentina* (*Trochorbis*) *trochoideus* and *Hippeutis* (*Helicorbis*) *umbilicalis*) and reported rates of natural infection in snails range from 0.5 to 2% (Gilman et al., 1982). Fasciolopsiasis in most countries is now controlled by chemotherapy, modern pig farming practices and education, and is unlikely to be of widespread public health importance.

3. Copepod-mediated helminthiases

Some important zoonotic helminths (nematodes and cestodes) use copepods as intermediate hosts. Ingestion of infected copepods can establish infections in humans who drink unfiltered water in some parts of the world. Included in this group of animal parasites are members of the genera *Gnathostoma* and *Spirometra* whose immature stages cause visceral and cutaneous larva migrans or creeping eruption in humans. Also included is *Dracunculus* of humans and wild animals, a disease agent responsible for severe pain and disability.

3.1. Gnathostomiasis

Gnathostomiasis is a zoonotic disease of canids and felids caused by a water-based spirurid, *Gnathostoma spinigerum*. The parasite and disease occurs worldwide but is most commonly found in Southeast Asia, particularly Thailand and Japan, and parts of South America, including Mexico and Ecuador (Diaz Camacho et al., 2002; Nawa, 1991; Daengsavang, 1980). People are accidentally infected with third-stage larvae by ingesting *Cyclops* spp. The disease is characterized by the ensuing cutaneous or visceral migration of larvae. Records at the Faculty of Tropical Medicine, Mahidol University, Thailand indicate that 47% of suspected cases (400–500 patients annually since 1995) test seropositive for *Gnathostoma* infection. Generally, humans become infected when they ingest raw or undercooked freshwater fish, eels, chicken, frogs or other mammals that serve as second intermediate or paratenic hosts. Rarely, humans may be infected by drinking water contaminated with infected *Cyclops*, or by skin penetration of the larvae from *G. spinigerum*-infected meat (Daengsvang, 1976). However, infection rate in *Cyclops* is very low; examination of approximately 2000 *Cyclops* collected from an area where 80–100% of freshwater fishes were infected with the infective larvae of *G. spinigerum* (Setasuban et al., 1991) were negative for this parasite (unpublished data). The infection rate in dogs and cats, the natural definitive hosts, was relatively low. Faecal examinations of 1000 stray dogs for *G. spinigerum* eggs revealed an infection rate of only 1.2% (Rojekittikhun et al., 2000). Postmortem examinations of 2940 dogs in northeastern Thailand found 4.1% to have adult *G. spinigerum* (Maleewong et al., 1992). Following infection of humans, infective larvae begin a continuous migration through subcutaneous tissues or the viscera. The most common clinical manifestation is intermittent swelling of the skin and subcutaneous tissues. Occasionally, larvae migrate to the central nervous system and the eyes causing brain and intra-ocular damage leading to irreversible blindness (Punyagupta et al., 1990; Vejjajiva, 1978). Eosinophilia, in association with cutaneous swelling, is the most common indicator of *Gnathostoma* infection.

3.2. Sparganosis

Sparganosis is a rare zoonotic disease of humans in Asia and South America, resulting from infection of a metacestode of the genus *Spirometra*. The adult tapeworm occurs in the small intestine of dogs and cats. The parasite is common worldwide, including Thailand. The life cycle requires two intermediate hosts, a copepod and any one of a variety of vertebrates including, amphibians, reptiles, fish, birds, rodents, insectivores, swine, non-human primates and humans. To date, only 36 human cases have been recorded and these have all been from the central, northeastern and northern parts of Thailand (Settakorn et al., 2002; Phunmanee et al., 2001; Tesjaroen, 1991; Kittiponghansa et al., 1988). The most common sites of infection were beneath the skin of the abdomen (60%) and in the eyes (24%). Brain and lungs were rarely infected (Tesjaroen, 1991; Phunmanee et al., 2001). One Thai patient had eight spargana causing a detectable mass and swelling of the eyelid (Tansurat, 1966). Seventeen spargana were recovered from another Taiwanese male (Wang and Cross, 1974). Sparganosis can be acquired by ingesting raw or undercooked birds, chickens, rodents, wild pigs and other wild mammals or by drinking water containing infected copepods. As well, the practice of old-fashion medicine and using infected flesh of the second intermediate host as a poultice to promote wound healing, can also lead to infection (Markell et al., 1992). Following infection, spargana readily migrate to various parts of the body, increasing in size and possibly undergoing multiplication. Most spargana eventually localize in soft subcutaneous tissues, often forming nodules over superficial muscles of the limbs, chest or abdominal wall. The pathology associated with sparganosis depends on the number and size of spargana, and on the particular organs affected. Inflammation at the site of infection may cause pain and itchiness. Pathological findings include necrotic foci and migratory tracts. Infection of the eye may lead to serious injury and blindness, and involvement of the brain and spinal cord may be fatal.

3.3. Dracunculiasis

The guinea worm, *Dracunculus medinensis* is the causative agent of dracunculiasis and is transmitted to humans who drink water containing infected copepod intermediate hosts (*Cyclops* spp.). This zoonotic parasite also occurs in the dog, horse, cow, wolf, leopard, monkey and baboon. The majority of human infections have been reported in parts of West and East Africa, India and Pakistan (Hopkins et al., 1995; Imtiaz et al., 1990). Following infection, the worms mature slowly in subcutaneous tissue, reaching full development after 1 year. The gravid adult female with extruded uterus, protrudes through the damaged skin and discharges larvae into the water. The most significant pathology results upon the death of the female worm after it has discharged larvae. The disease is rarely fatal, but the socioeconomic impact of such a severe illness and occupational disability often prolonged by secondary infection, is considerable. In 1986, WHO targeted dracunculiasis for global eradication emphasizing health education and the use of cloth water filters and cyclopsicides (Hopkins et al., 1995; Kaul et al., 1992). Eradication programs were first applied successfully in Pakistan and are now being implemented in the remaining endemic countries. Methods pioneered in Pakistan's National Guinea Worm Eradication Program, demonstrated that dracunculiasis can be prevented by boiling drinking water or filtering it through cloth to remove copepods. The program was also based on educating villagers not to contaminate their water sources, providing clean, underground drinking water from borehole wells that cannot be contaminated, and on using a cyclopsicide that is safe for human consumption (Hopkins et al., 1995). Other informative descriptions are well documented and reviewed elsewhere (Cairncross et al., 2002).

4. Faecal water-transmitted helminthiases

Several zoonotic helminths are capable of direct faecal-oral transmission and are important contaminants of water. The resulting diseases include cysticercosis, hydatidosis and larva migrans caused by ascarids, hookworms and threadworm (*Strongyloides*). Parasite transmission occurs directly per os or per cutis. Infective eggs can persist for long periods of time in tropical and subtropical environments.

4.1. Cysticercosis and taeniasis solium

Cysticercosis in man is a dangerous zoonotic disease caused by *Cysticercus cellulosae*, the metacestode (cysticercus) of *Taenia solium*, a tapeworm that lives as an adult in the human small intestine. Cysticercosis and taeniasis solium are mainly distributed in Africa, Central and South America and Asia. Pigs, the natural intermediate host, become infected with metacestodes in the skeletal musculature after ingesting eggs of *T. solium*. Humans acquire the adult tapeworm after eating raw or undercooked pork. However, humans are also suitable hosts for the metacestode. Following ingestion of *T. solium* eggs in contaminated food, soil or water, the metacestode develops in muscles of various parts of the body and occasionally in brain tissues leading to neurocysticercosis. Human cysticercosis can also result from autoinfection when a gravid proglottid moves up into the duodenum or stomach and the eggs hatch. Cysticercus infection is often associated with backyard swine production commonly practised throughout rural Asia.

Thirty-eight percent of people in a pig farming community had intestinal taeniasis and approximately 50% of them experienced seizures related to neurocysticercosis (Prasad et al., 2002). Similar clinical signs with epileptic seizures from neurocysticercosis have been recorded in Nepal, Viet Nam, Indonesia and China (Talukdar et al., 2002; David and Mathai, 2000; Erhart et al., 2002; Margono et al., 2001; Joshi et al., 2001). Throughout China, cases of cysticercosis are numerous and have profound effects on the health of individuals. Occurrence of the disease is correlated with a high prevalence of *T. solium* and cysticercus infection in pork (Zhao et al., 1997). In Thailand, during 1979–1988, 98 cases of neurocysticercosis were recorded at the neurological hospital and 4% of the affected individuals had proglottids in their stools (Jitsukon and Towanabut, 1989). In another report, stool examination of three neurocysticercosis patients revealed *Taenia* eggs in one of their stool sample (Chotmongkol, 1992). Annually, only a small number of cases of human cysticercosis is seen at the Hospital for Tropical Diseases, Mahidol University, Thailand, and this correlates with the sporadic findings of *C. cellulosae* in pigs slaughtered in the rural communities (Vanijanonta, personal communication; Khamboonruang, 1991). In Central and West Africa, clinical cases of neurocysticercosis with epileptic seizures are common (Zoli et al., 2003; Vondou et al., 2002). In Brazil, a high proportion of epileptic patients seropositive for cysticercosis were also positive for taeniid coproantigen (Gomes et al., 2002).

The prevalence of *C. cellulosae* in pigs in Indonesia varied from 0.02 to 2.6% and taeniasis solium in people varied from 10 to 20% (Anonymous, 1988; Kusharyono and Sukartinah, 1991). A special dish prepared using half raw pork and served at traditional ceremonies was the source of infection (Suweta, 1991; Depary and Kosman, 1991). In the Philippines, *C. cellulosae* in swine was relatively common (1.67%) (Arambulo et al., 1976) but fewer than 1% of people had taeniasis solium (Eduardo, 1991). Cysticercus infection in swine and taeniasis solium in humans in China are highly endemic, particularly in rural communities where raw food is a favorite dish and the public health services are poor (Xiaopeng, 1991). The main source of infection is from pork slaughtered locally without veterinary inspection. Pork and pigs exported to Hong Kong are a high-risk source of infection to people (Ko, 1991). Infection is endemic in the mountainous areas of Taiwan where 10–20% of aborigines are infected with *T. solium* (Chen, 1991). In Thailand, epidemiological surveillance of *C. celulosae* in pigs killed at abattoirs has so far been inadequate to accurately determine the prevalence of infection.

In Zambia and Nigeria, a high prevalence of *C. cellulosae* (20%) was found by inspecting pig carcasses at abattoirs (Phiri et al., 2002; Onah and Chiejina, 1995). Most of the infections were generalized with the entire musculature being heavily infested with live cysticerci. The overall prevalence of taeniid ova in 1525 human stool samples was 8.6%; most infected Nigerians were over 30 years old. Throughout South America, cysticercus infection in pigs is diagnosed mostly by inspecting meat for *C. cellulosae*. In Peru, 14–25% of pork is estimated to be infected based on tongue examination (WHO, 1993). This may be an underestimate, however, since infection rates determined by necropsy can be somewhat higher than results from tongue examination (31.2%: 23.4%) (Gonzalez et al., 1990). In Mexico, the prevalence of taeniasis solium was 1.5% while 23% of pigs were positive for cycticerci as determined by tongue examination (Rodriguez-Canul et al., 1999).

4.2. Cysticercosis and taeniasis saginata

Taeniasis saginata is a food-borne zoonosis in man caused by *Cysticercus bovis* and is distributed worldwide. The prevalence of *Taenia saginata* infection is higher than that of *T. solium* infection and is particularly high in rural communities. The eggs of *T. saginata* passed in human excreta are ingested by grazing ruminants with contaminated vegetation or in drinking water. In Iran, the prevalence of *C. bovis* in cattle ranged from 7.7 to 10.7%. The most commonly infected sites were muscles of the shoulder, masseter, tongue and heart, and 34.6% of infected carcasses were condemned (Oryan et al., 1995). In India, only 1.5% of humans have *T. saginata* (Ahmed et al., 1988), while taeniasis saginata was widespread throughout China with prevalence ranging from 2 to 70% (Xiaopeng, 1991). In Indonesia, the prevalence of *C. bovis* varied from 0.3 to 2.4% (Anonymous, 1988), and in endemic foci in the Philippines, 10.3% of people have *T. saginata* (Cabrera, 1973). Infection rate among aborigines in the mountainous areas of Taiwan was 10–20% (Chen, 1991). In Thailand, *C. bovis* in the muscles of cattle and buffalo is rare, and only a few positive cases are found annually. However, in Nigeria, the prevalence of *C. bovis* infection in cattle slaughtered in abattoirs was 26.14% (Okafor, 1988).

4.3. Hydatidosis

Hydatidosis or echinococcosis is an important emerging zoonosis infecting a large number of animals and humans. It is a serious disease caused by the larval stage of two species of the tapeworms, *Echinococcus granulosus* (cystic hydatidosis) and *Echinococcus multilocularis* (alveolar hydatidosis). The adult *E. granulosus* develops in the small intestine of dogs and other canids, and the cystic forms develop mainly in the liver and lungs of intermediate hosts, mostly sheep and goats but also includes other ruminants, pigs, horses, donkeys and humans. Hydatid cysts isolated from liver and lungs of the sheep show higher infectivity than cysts from liver and lungs of goats, cattle and buffalo. Hydatidosis occurs worldwide and is common in sheep herding areas of developing countries where many inhabitants live under poor sanitary conditions and in close proximity to their domestic animals (Vuitton, 1997). The prevalence of the disease varies greatly. Adult *E. multilocularis* occurs in canids and cats, and alveolar or *multilocularis* cysts are found in livers of microtine rodents and some larger mammals such as humans. *E. multilocularis* occurs primarily in the Northern hemisphere, including North America, Greenland, Scandinavia, Central Europe and Middle East; it is also in India and Japan.

Humans and animals become infected when they accidentally ingest eggs of *Echinococcus* spp. from either contaminated soil or water. The cysts usually develop in the liver, although they may infect other organs including lungs, spleen, kidneys and other internal organs. The cysts can cause life-threatening illness associated with liver failure, pulmonary edema and anaphylactic shock.

Two forms of echinococcosis due to *E. granulosus* and *E. multilocularis*, are present in Turkey. Cystic hydatidosis occurs throughout the country whereas alveolar hydatidosis occurs predominantly only in the eastern Anatolian region of the country. In domestic animals, the prevalence ranged from 11.2 to 50.7% (Altintas, 2003). The greater interest in cystic hydatidosis is due to its high morbidity rates among people in the Mediterranean region; *E. granulosus* is present in nearly all countries of the region while *E. multilocularis* infection is limited to a few of them. The main endemic regions for human alveolar hydatidosis caused by *E. multilocularis* are Central Europe, Russia, Turkey, Japan, China, eastern France and North America. Growth of the parasite is usually intrahepatic. Two cases of intracerebral *E. multilocularis* disease occurred in France (Algros et al., 2003). Occurrence of *E. multilocularis* in the brain is rare but is a very serious disease often leading to death. The incidence of cystic echinococcosis in humans in eastern Libya was estimated to be at least 4.2 cases/100,000, with significantly more female cases than male. The prevalence of echinococcosis was higher in sheep than in other ruminants (Tashani et al., 2002). In Greece, the prevalence of infection in farm animals was very high, approximately 82% in cattle and 80% in sheep (Sotiraki et al., 2003). In Thailand, six human cases of hydatidosis (four pulmonary and two hepatic) have been reported; only two of them were indigenous patients who had never been outside the country (Na Songkhla, 1980; Koanantakool et al., 1992; Limawongpranee, personal communication). Also, hydatid cysts in spleen and liver of cattle and buffalo have been observed (unpublished data) but no reports of infection in canids exist. Though cystic and alveolar hydatidosis are considered a serious public health problem and are of importance to the livestock industry. Public awareness of hydatid disease is low in most of these countries.

5. Water-transmitted larva migrans

Water related larva migrans in humans can occur naturally following infection by two major routes, direct penetration of the skin by infective larvae and by the ingestion of infective eggs or of intermediate hosts containing infective larvae. Examples of the latter that use copepods intermediate hosts (*Gnathostoma* and *Spirometra*) were discussed earlier in this article. Important emerging zoonotic diseases can be transmitted to humans in the absence of an intermediate host when infective forms in soil contaminate drinking water. Major causes of zoonotic larva migrans in humans in this category include ascarids (*Toxocara*, *Baylisascaris*), hookworms (*Ancylostoma*) and threadworms (*Strongyloides*) of canids, felids and raccoons. Infection with ascarids results from ingestion of infective eggs containing L3 in contaminated soil or occasionally in drinking water in endemic areas. Infection with hookworms and threadworms results from skin penetration of infective L3 in damp or muddy soil or in environments contaminated with floodwaters. These zoonotic helminths are especially abundant in animals and soils and, because of longevity and resistance of their infective stages, present high risk to human health. They are widespread in most parts of the world, particularly in developing countries of Asia, Africa and South America.

5.1. Larva migrans of ascarids

Ascarids of major zoonotic importance are the large roundworms inhabiting the small intestine of canids and felids (*Toxocara* spp.), and *Baylisascaris procyonis* of raccoons. Infection in humans, generally, is by accidental ingestion of infective eggs in contaminated soil or water, on hands or on the hair coat of infected animals. Large numbers of ascarid eggs are produced daily in excreta and can contaminate soil and water. The eggs are extremely resistant and remain viable for months to years. Following infection in man, the larvae migrate through various tissues and organs and usually becoming arrested in the liver and lungs causing visceral larval migrans. The seriousness of infection depends on the site of parasite migration. These aberrant larvae occasionally invade the central nervous system and eyes. In the case of ocular larval migrans, vision loss and permanent blindness may result.

Toxocariasis is the clinical disease in man caused by infection with *Toxocara canis* and *Toxocara cati* of dogs and cats, respectively. It is common in both developing and developed countries and leads to larva migrans. Transmission occurs by ingestion of infective eggs in the environment. Children more often show clinical symptoms than adults because of their closer contact with contaminated soil in yards and sandpits, the lack of hygiene, and eating dirt. *Toxocara* larval migration in the body can cause various clinical syndromes such as visceral larva migrans, ocular larva migrans, and covert toxocariasis (Overgaauw, 1997). *T. canis* has been recognized as the causative agent of ocular toxocariasis leading to damaged vision and blindness although the possible role of *T. cati* in this condition is still unclear (Taylor, 2001). The seroprevalence of *Toxocara* infection in children 2–5 years old in Brazil varied from 3 to 86%; but infection was mostly asymptomatic (Alderete et al., 2003). Interestingly, the hair coat of 25% of dogs examined had *T. canis* eggs in higher numbers than were found in soil samples (Wolfe and Wright, 2003). In Japan, 63.3% of sandpits were found contaminated with *Toxocara* eggs and the ratio of *T. canis* to *T. cati* eggs recovered was 2:3. Sixty-eight percent of 144 puppies examined had *T. canis* eggs in their faeces (Shimizu, 1993).

In Italy, the risk of human infection with larvae of *T. canis* was estimated for both urban and rural areas by detecting infections in dogs (Habluetzel et al., 2003). Higher rates of infection were found in rural hunting dogs (64.7%) than in urban companion dogs (22.1%).

Larva migrans caused by the common raccoon ascarid, *B. procyonis*, is a zoonotic disease of increasing importance in both North America and in Japan (Sato et al., 2003; Evans, 2002). It is well recognized as a cause of visceral, ocular, and neural larva migrans in birds and mammals, including man. Following accidental ingestion of infective eggs, the larvae migrate to extraintestinal organs and become encapsulated in various tissues. Larva migrans due to *B. procyonis* is widespread. The highest rates of infection are seen in humans that share environments or habitation with raccoons (Kazacos and Boyce, 1989). When raccoons become peridomestic animals living close to human residences, there is a high risk for human exposure, and infection rates may be greater than currently recognized. Pet owners and public health workers should be made aware of the potential risk of this serious zoonosis, and of the difficulty in cleaning contaminated areas.

5.2. *Larva migrans of hookworms and threadworms*

Cutaneous larva migrans or creeping eruption is caused by skin-penetrating larvae of animal hookworms, most commonly *Ancylostoma caninum* and *Ancylostoma braziliense*. Skin lesions typically manifest as spongiotic dermatitis with spongiotic vesicles containing neutrophils and eosinophils and a mixed-cell dermal infiltrate with numerous eosinophils (Balfour et al., 2002). The larvae penetrate and migrate erratically just beneath the epidermis causing serpentine tracks most frequently seen on the skin of the hands, feet, buttocks and genital areas. The tracks usually progress 1–2 cm per day. The inflammatory response is erythematous with pruritic papules. Untreated, the disease is self-limiting with death of the larvae occurring within 1–2 months. In addition, *A. caninum* can cause eosinophilic enteritis in humans. Infections have been reported in Egypt and Australia (Bahgat et al., 1999; Prociv and Croese, 1990, 1996). In Thailand, the canine hookworm infections are predominantly caused by *A. caninum* in dogs, especially in puppies (Anantaphruti et al., 2000a). The dominant species of hookworm in cats is *Ancylostoma ceylanicum* (Setasuban et al., 1976). In endemic areas, travelers usually become infected when bare areas of skin, such as on the feet or torso, come in contact with contaminated soil or water (Jelinek et al., 1994). In Brazil, an outbreak of cutaneous larva migrans occurred in schoolchildren due to contaminated playgrounds. Typical lesions were located on the hands, feet, buttocks, thighs, vulva and scrotum (Araujo et al., 2000). A high prevalence of *A. braziliense* and *A. caninum* infection was reported in stray dogs in Uruguay in association with human cutaneous larva migrans (Malgor et al., 1996).

Strongyloidiasis caused by threadworm is a widespread, soil-transmitted, intestinal zoonotic helminthiasis commonly found in tropical and subtropical countries. It is found sporadically in the temperate zone, especially in closed communities and among people living under poor social conditions. Most species of threadworms have a predilection for only one host, but their host specificity is not strict. Human strongyloidiasis is caused by *Strongyloides stercoralis* but when animal species of *Strongyloides* infect humans, an intense allergic reaction in the form of cutaneous larva currens and larva migrans or creeping urticarial eruption is seen. Chronic strongyloidiasis acquired in endemic areas may last for decades and give rise to various dermatologic lesions, the most characteristic of which is larva migrans or creeping urticarial eruption. Intense itching, erythematosus papule and petechiae develop at the site of the skin infection. Rapidly progressing urticarial streaks are pathognomic cutaneous manifestations of larva currens. The erythematous, linear stripes are due to migrating larvae in the skin. The most common non-specific symptoms are urticaria, maculopapular exanthema, localized or generalized pruritus and prurigo. Creeping skin eruption is known to follow exposure to canine and feline hookworm larvae encountered in contaminated soil in humid, tropical and subtropical regions. A little known hazard of infection among veterinarians and laboratory workers is exposure to *Strongyloides* larvae. Continued exposure may lead to hypersensitivity and severe hyperimmune reaction. Sometimes, gastrointestinal, pulmonary and cutaneous symptoms may arise during the migration of the larvae. A 20-year-old landscape worker in Texas was evaluated for widespread cutaneous eruption consisting of papules, pustules, and burrows (Jones et al., 1991). Cutaneous scrapings revealed live and dead larvae of a free-living soil nematode, *Pelodera strongyloides*. This is the third instance of human dermatitis due to this organism, and the first reported in an adult host. In Thailand, human strongyloidiasis infections usually co-exist with hookworm infections, but at lower prevalence; infections in schoolchildren in endemic areas ranged from 1.8 to 6.5% (Anantaphruti et al., 2000b). *S. stercoralis* infection in animals occurs worldwide especially in the tropical and subtropical zones. In dogs infected with *S. stercoralis*, prenatal vertical transmission does not occur, but transmammary transmission is possible (Shoop et al., 2002).

6. Control measures

Most waterborne helminthiases occur accidentally by contacting water contaminated with helminth infective stages. Theoretically, transmission can be stopped by completely avoiding natural surface water. However, this is difficult, particularly in areas where no alternate supply of clean water is available and the community must rely entirely on natural water sources. Lack of knowledge and exposure associated with certain occupations ensure a continuing problem with parasite transmission. Especially in remote areas, educational programs and more practical measures should be carried out to prevent or reduce transmission.

6.1. Reduction of parasite contamination

A main source of helminth eggs and larvae is from human and animal waste deposited on the open ground and washed by rain into ponds and lakes where the parasites continue to for further transmission. Solutions include better control of animals and the proper disposal of human excreta by constructing latrines and encouraging their use. In poor areas where private latrine construction is impossible because of cost, facilities in schools and other public institutions should be opened for public use. Also, excreta from farm animals must be properly treated before being released into natural water sources. The methodology required for effective treatment is discussed in another chapter of this issue (Betancourt and Rose, 2004). Excreta from wild birds, ruminants and rodents are also important sources of water contamination, but they are difficult to control.

6.2. Monitoring surveillance

Areas with open water for public use, and a threat of parasite contamination, should have a national or local policy ensuring vigilance through regular monitoring. The public should be informed promptly if there is a possible risk of parasitic infection. For example, Pak Moon Dam, in the northeast of Thailand, is a breeding place for *N. aperta*, the snail intermediate host of *S. mekongi*. Although this is not an endemic area for schistosomiasis, precautionary measures were begun in 1999 by the Disease Control Department. An annual survey includes the collection of stool and serum samples from residents in four settlements surrounding the dam; snails are also sampled. If eggs or antibody are detected, or snails are positive for cercaria, a prevention and control program is ready for immediate implementation. Since the implementation of the program, not a single positive case of human schistosomiasis has been detected in the area.

6.3. Information dissemination

A system for disseminating public health information should be developed so that communities can be informed immediately of any health risks. For example, in areas with an open ponds where cattle, buffalo, ducks or other birds regularly occur, the public must be informed of the possibility of contracting cercarial dermatitis. Posted signs are an effective way of warning local people as well as visitors unfamiliar with the area.

6.4. Preventive education

Health promotion must be taught in schools beginning at the primary levels. Young children should be properly trained to avoid undesirable risk behaviours related to disease transmission. The important messages are simple, such as drink only clean water, wash your hands before and after eating and wear shoes before leaving the buildings. In areas where schistosomiasis is endemic, people should be advised not to contact or enter natural water sources.

Many countries with national policies on helminth control use deworming as a major tool in endemic areas. Recently, school-based approaches to parasite control have been recognized globally as an effective tool in disease prevention measures. Under the Japan Global Parasite Control Initiative, three training centers have been established in the Greater Mekong sub-region of Southeast Asia, and West and southeast regions of Africa. These centers, supported by Japan, inform health officers and teachers about a school-based parasite control program that focuses on children as messengers conveying information about infection prevention measures to the community. Concurrently, WHO, UNESCO, UNICEF and the World Bank have formulated a partnership program called Focusing Resources for Education in School Health (FRESH) to promote effective school health programs.

Helminth control programs in schools should be carried out cooperatively between the Ministries of Health and Education with support from NGOs in areas where it is necessary. Properly trained personnel to deliver control programs are essential. Treatment is also important in decreasing infection rates. WHO has set a target of delivering regular anthelminthic treatment to at least 75% of school-aged children by the year 2010 in countries where schistosomiasis and soil-transmitted helminthiases are endemic (Montresor et al., 2002). However, the most important component of efforts to stop re-infection with waterborne parasites can be achieved by education. The participation of children in the health education process is the most effective way of changing risk behaviour and reducing rates of parasite transmission.

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