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Review Article

A Comprehensive Review on Major Zoonotic Parasites From Dogs and Cats

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Abstract
Zoonotic diseases are significant causes of morbidity and mortality in humans and animals, including birds. These diseases are transmitted through several routes and are reported in developing and developed nations of the world. The dogs and cats also act as the reservoirs of a large number of parasitic zoonoses, including toxoplasmosis, giardiasis, leishmaniasis, toxocariasis, and cryptosporidiosis. The roles of pet animals (cats and dogs) in transmitting human infections have been recognized worldwide. Since most of these parasites have an oral-fecal transmission cycle, the transmission of these zoonotic agents could occur through indirect contact with animal feces, contaminated water, and food, or direct contact with infected animals. In addition, the soil is an important route for the transmission of human pathogens. In socioeconomically disadvantaged communities, the poor levels of hygiene and overcrowding, together with a lack of veterinary attention and zoonotic awareness, exacerbate the risks of disease transmission. Traditional husbandry and inadequate management practices, the mixing of wild animals with farm animals, and unrestricted movement and living pastoralists with their animals can all contribute to the development of zoonotic diseases. Therefore, veterinarians are thought to be on the 'front line' of the prevention of pet animal-associated zoonotic parasitic infections.
Keywords: Parasite, Pet animal, Public health, Transmission, Zoonotic infections

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Introduction

Zoonoses are defined as those diseases and infections that are naturally transmitted between humans and vertebrate animals (1,2). Presently, there are over 300 zoonotic diseases of diverse etiologies that occur in both sexes, all age groups, and in all seasons (2). Dogs and cats act as the reservoirs of a wide range of parasitic zoonoses such as toxocariasis, giardiasis, toxoplasmosis, cryptosporidiosis, leishmaniasis, echinococcosis, and dirofilariasis (2-6).

In dogs and cats, intestinal helminths are one of the most prevalent pathogens (7). Among intestinal helminths, *Toxocara* and hookworm species of dogs and cats are most important to public health (2,8). Dog feces harboring infective parasitic forms (larvae, eggs, cysts of helminths, and oocysts of protozoan) are potential sources of environmental contamination, representing a high risk of infection for people; therefore, they have been recognized as a significant public health problem worldwide, especially in developing countries and communities that are disadvantaged socioeconomically (9).

Dogs and cats tend to excrete helminth eggs or larvae with their feces into the environment that are transmittable to the human population (10). Considering that most of these parasites have an oral-fecal transmission cycle, the transmission of these zoonotic agents may occur through indirect contact with animal feces, contaminated water, and food, or direct contact with sick animals (11). Contrary to rural areas, the potential function of companion animals as disease reservoirs has been recognized as a serious public health issue in urban areas. The subject has received attention, priority, and coverage in the medical literature on urban communities primarily because of the availability of resources (12). The uncontrolled populations of dogs and cats live close to their owners in rural areas, and humans often have a close relationship with them. The poor levels of hygiene and overcrowding, along with a lack of veterinary attention and zoonotic awareness, can exacerbate the risks of disease transmission (13). Moreover, close contact between humans, dogs, and cats is part of natural living conditions, particularly where livestock raising is of economic importance (9).

Dogs and cats are often considered to be faithful companions and intimate friends of humans. This human-animal link has the potential to give significant benefits to human emotional development, socialization, and physiological well-being (14). With the increasing number of companion animals, there is more contact between domestic animals and people, exposing humans

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to zoonotic agents (15). In the absence of proper care, the link between humans, animal populations, and the surrounding environment can lead to a serious risk to public health with huge economic consequences. Therefore, this paper aims to review the major zoonotic parasites of pet animals.

Cestodes

Echinococcus granulosus

The burden of cystic echinococcosis (CE) caused *by E. granulosus*, both in terms of monetary burden and/or disability-adjusted life years (DALYs), has been estimated in many countries worldwide (16). Globally, it exceeds 1 million DALYs and 1 billion dollars per year (17). In many areas, the local burden of CE is significant; Echinococcosis may be one of the most common causes of disease burden in some rural nomadic pastoralist populations such as those in western China (18).

Large wild canids are susceptible to *E. granulosus* and can significantly contribute to disease epidemiology and zoonotic transmission. Human CE belongs to one of the five most frequently diagnosed zoonoses in the Mediterranean and is re-emerging in the endemic areas of south-eastern Europe (19).

Echinococcus multilocularis

Humans and dogs are accidental hosts (20). Alveolar echinococcosis is one of the most severe (lethal) parasitic zoonoses in Europe and worldwide in the northern hemisphere, with highly serious clinical implications and a high burden of disease (21). Clinical manifestations in humans include enlarging alveolar or liver cysts or brain often fatal (5).

The contribution of cats to the transmission of *E. multilocularis* may not be as significant as once believed, they are extremely less susceptible to infection with the parasite than canids (22). Unlike cats, domestic and raccoon dogs excrete comparable large numbers of *E. multilocularis* eggs (23). The prevalence of *E. multilocularis* infection is usually lower in dogs, they can substantially contribute to environmental contamination by parasite eggs, given their high population density, particularly in urbanized areas (24).

Opisthorchiidae

Opisthorchiidae is a group of fish-borne zoonotic trematodes that includes the liver flukes *Opisthorchis felineus, Opisthorchis viverrini,* and *Clonorchis sinensis.* The life cycle of the liver flukes is complex and indirect; immediately following the excretion of embryonated eggs with the feces of the definitive host in a freshwater environment, they infect and hatch within Bithynia snails, the first intermediate host. Free-living cercariae are released into the environment after a time of asexual reproduction in the snail and consumed by a fish of the family *Cyprinidae* (the second intermediate host), where they mature into metacercariae (25). Humans are used as the definitive hosts, and cats and dogs are employed as reservoir hosts. Humans are infected by the consumption of undercooked fish containing viable metacercariae, and the infection induces hepatobiliary pathology that eventually leads to bile duct cancer, cholangiocarcinoma (CCA), the leading cause of death in Asia. *O. viverrini* and *C. sinensis* are known as type 1 carcinogenic agent because of their strong association with CCA (26).

Up to 700 million (10% of the global population) are at risk of infection with *O. felineus* (27). It provides to the global disease burden in terms of DALYs and reflects a substantial impact on the health and well-being of the infected victims in developing countries (28). Infection by the liver fluke causes various non-specific gastrointestinal (GIT) symptoms in some infected individuals, which are related to the intensity of the infection. In *C. sinensis* alone, an estimated 2.5 million people may have some form of illness (29).

CCA has a high case fatality rate, and the district-based prevalence of CCA in opisthorchiasis endemic areas, including northeast Thailand, ranged from 90 to 300 per 100 000. Regardless of surgical treatment, most CCA cases have a poor prognosis, and the survival rate also varies with the stage of cancer and the healthcare system. The greatest CCA patients survive for less than 5 years (30).

Nematodes

Hookworms

Ancylostoma caninum and *Uncinaria stenocephala* are the cosmopolitan hookworms of the intestine of dogs and other canids. Female hookworms excrete morphologically similar thin-shelled eggs, which are passed in the feces of the host, completing the parasitic nematode's life cycle. Under suitable environmental conditions (23-33°C), the 'rhabditiform' L1s hatch from the eggs. The L1s feed on bacteria and molt to L2s in 2 days, then to L3s in 4-5 days. This latter stage retains the cuticle of the L2 (sheath) and is referred as to a 'filariform' larva. Although the larvae of *U. stenocephala* mature into adult males and females in the small intestine of vertebrate hosts, those of *A. caninum* enter subcutaneous tissues and migrate via the circulatory system to the heart and lungs, where they molt to fourth-stage larvae (31-33). The larvae move from the lungs to the small intestine (through the trachea and pharynx), where they grow into adult males and females in 2-7 weeks, depending on the species (Figure 1).

The pathogenesis of hookworm disease is mainly a consequence of blood loss, which is caused by tissue damage and direct ingestion of red cells by the adult worm (34). Occasionally, the migration of *A. caninum* larvae through human skin may cause cutaneous larva migrans, also known as "creeping eruptions" (35).

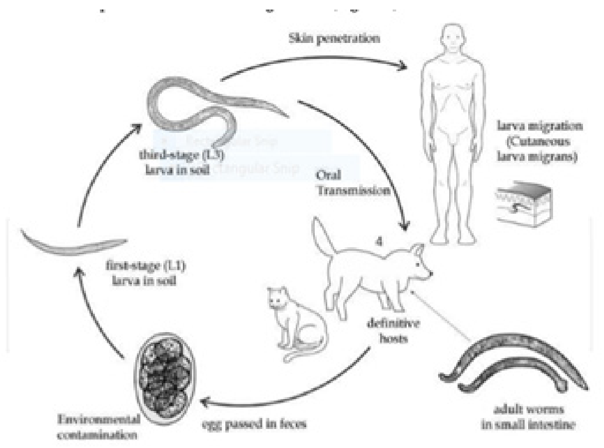

Figure 1. Life Cycle of *Ancylostoma braziliense* and *Ancylostoma caninum*. *Source* (34).

Dirofilariasis

Dirofilariasis caused by *Dirofilaria immitis* and *D. repens* are the most important members, being a common parasite of domestic carnivores, including dogs and cats, but also of other hosts such as wild carnivores and humans (36). Adult *D. immitis* worms are found in the pulmonary arteries and right heart chambers, causing canine and feline heartworm disease, while *D. repens* is found primarily in subcutaneous tissues and causes subcutaneous dirofilariasis (37). Aberrant migrations with ectopic localizations (body cavities, central nervous system, and eye) for both *Dirofilaria* spp. (38).

Dirofilaria immitis has a prepatent time of 120-180 days, while *D. repens* has a prepatent period of 189-259 days. Both species' adult females deposit embryos (microfilariae) into the mammalian host's blood, and these parasites have five larval stages that develop in an intermediate mosquito host (from embryo to infective L3) that also serves as a vector and in a definitive vertebrate host (from L3 to the adult stage). Mosquitoes become infected by feeding on a microfilariaemic host's blood (37). *Aedes vexans*, *Culex pipiens*, and *Aedes albopictus* are implicated as the main natural vectors of these worms (39).

Because of its pathogenicity in companion animals, interest in dirofilariasis was mostly directed at *D. immitis* until a few years ago. However, as the spread of *Dirofilaria* diseases, particularly *D. repens*, has increased in Eastern and Northern European countries, veterinarian awareness and perception have increased as well (40). In addition, both *Dirofilaria* species are zoonotic, and human cases of *D. repens* infection are on the rise in Europe (41).

Protozoan Parasite

Leishmaniases

Leishmaniases are infectious diseases that affect humans, domestic animals, and wild animals all over the world and are caused by *Leishmania* spp. (42). The majority of zoonotic transmission cycles involve reservoir hosts such as rodents, marsupials, edentates, monkeys, domestic dogs, and wild canids. Most *Leishmania* spp. that infect humans are zoonotic, and only a few are strictly anthroponotic (directly transmitted from humans to humans by sandflies). *Leishmania infantum* causes visceral leishmaniasis (VL) transmitted by sandflies from the major reservoir of domestic dogs (43). Canine and human *L. infantum* infections are spread primarily through dogs in an area that stretches from Portugal to China and across South, Central, and parts of North America. In North America, cutaneous leishmaniasis (CL) is endemic within south-central Texas and appears to be spreading northward into the Dallas-Fort Worth metro area, affecting humans, cats, and dogs (44).

The proven modes of non-sandfly transmission include infection through transfused blood products from blood donors which are the carriers of infection, venereal and vertical transmission (45-47). The estimated incidence accounts for 2 million new cases per year, 0.5 million VL, and 1.5 million CL (48). In Europe and Mediterranean countries, about 1,000 people are estimated to be affected by clinical disease annually (49), although asymptomatic or sub-clinical cases are by far more frequent. The prevalence of 2%-40% of the asymptomatic human carriers of *L. infantum* in southern Europe suggests that this parasite is a latent public health threat. Asymptomatic cases are also estimated at a ratio of > 100 asymptomatic clinical cases (50). Mortality rates in human immunodeficiency virus (HIV)-infected patients can reach over 56% (51).

Toxoplasmosis

Toxoplasmosis is an important protozoon zoonosis of global public health importance and is caused by *Toxoplasma gondii* which has a complex life cycle (52). The development of *T. gondii* occurs asexually in various tissues of herbivorous or omnivorous intermediate hosts and is related to a sexual phase of development in the gut of felids, the final hosts. Tachyzoites, bradyzoites contained in tissue cysts, and sporozoites contained in sporulated oocysts are the three infectious stages of the parasite's life cycle. The parasite can invade the gut, become systemic, and localize in vital organs such as muscles and nervous system tissues. In most cases, infection is asymptomatic, but the devastating disease can occur (53).

Felids are definitive hosts for *T. gondii*, but all warm-blooded vertebrates (including humans) may behave as intermediate hosts and potentially be infected by bradyzoites in meat, sporulated oocysts, or tachyzoites intrauterine (4). The parasite *T. gondii* has become adapted to exploit multiple routes of transmission through a sexual cycle in the definitive hosts (felids) and asexually, through carnivorous behavior, and transmitted vertically by tachyzoites passed to the fetus via the placenta (54).

Congenital toxoplasmosis causes around 2300

DALYs per year in the Netherlands (55). Furthermore, toxoplasmosis is a well-known consequence of HIV infection, and acquired toxoplasmosis can cause chorioretinitis. It is increasingly being connected to neurological and psychological problems such as epilepsy, migraine, and schizophrenia (56). Ocular toxoplasmosis is a progressive and recurring necrotizing retinitis, with vision-threatening complications such as retinal detachment, choroidal neovascularization, and glaucoma (57).

Although seroprevalences are decreasing in many regions of the world, there is currently little that can be performed to control or eliminate this disease (58), possibly linked to increased living standards. In addition, with the increased intensification of the pork industry, there is a lower prevalence of pork, with a lower risk of transmission to humans (59). At least, in theory, transmission could be ameliorated by testing meat for toxoplasmosis, and ensuring infected meat is frozen to destroy the bradyzoites before consumption (60).

Giardiasis

Giardiasis is an emerging protozoon disease that is common in warm climates (61). The host range of *Giardia* species varies significantly, with *Giardia duodenalis* having the largest host range and the greatest public health importance (62). Historically, allozyme analysis divided all human isolates into two genetic categories (assemblages A and B). Multigenic sequence analyses confirmed this assemblage separation and identified additional lineages of *G. duodenalis* from animal assemblages C and D from dogs, assemblage E from artiodactyls, assemblage F from cats, assemblage G from rodents, and assemblage H from marine vertebrates (63).

Giardia has a direct life cycle, and the parasite's infective stage, the cyst, becomes encysted and infectious as soon as it is released into the feces. Cysts can live for months in cool and damp environments and remain infectious. Cysts excyst in the duodenum after being consumed by the host releasing the trophozoites. The latter undergoes several mitotic divisions and forms cysts that are resistant to the environment. Cysts pass through the intestine in feces and are spread by contaminated water, food, and fomites and by direct physical contact (2,62).

Giardia infection in animals is often asymptomatic but has been associated with the occurrence of diarrhea and ill-thrift in puppies and kittens (64). It is commonly believed that infection with *Giardia* is related to economic losses through the occurrence of diarrhea, poor growth, and death (65).

Cryptosporidium

Cryptosporidium parvum of bovine, but not human, the origin can infect dogs (66), a human and his dog were found to have different genotypes in Japan. In Osaka respectively, all genetic isolates from dog feces were of *Cryptosporidium canis*, which is thought to be non-pathogenic in humans (67).

However, the dog strain has been recovered from 1 out of 1680 patients with cryptosporidiosis in England (68), and an HIV-infected human in America (69). Infection in immunocompetent people is regarded as moderate and self-limiting, which sharply contrasts with the prolonged severe diarrhea in immunocompromised patients (70). *Cryptosporidium* occurred in the dog in Colorado (3.8%) (71).

Epidemiology of Zoonotic Gastrointestinal Parasites in Pet Animals

Globally, there is significant variation in the prevalence of GIT parasites present in dogs and cats with the percentage ranging between 26% and 96% (12). The high prevalence of GIT helminth in dogs and cats in Brazil ranges between 88% and 90% (15). Likewise, the GIT helminths in rural dogs in Argentina represented prevalence rates ranging from 37.9% to 52.4% (9).

The high prevalence of hookworm infections among dogs and cats in rural communities can play a significant role in the occurrence of zoonotic ancylostomiasis such as creeping eruption and eosinophilic enteritis or less frequent symptoms of localized myositis, erythema multiform, and ophthalmological manifestations in human (35).

The role of dogs and cats in the transmission of *Ascaris lumbricoides* to humans is well recognized. *Ascaris* from positive dogs is 100% homology with *A. lumbricoides* derived from the human fecal sample using molecular-based tools in India. The dog that tested positive for *Ascaris* belonged to a family that included at least one member afflicted with *A. lumbricoides* (72).

Giardia and *Cryptosporidium* are among the potential zoonotic protozoan parasites of dogs and cats that are infective humans. Some Giardia genotypes, particularly assemblage A, can be infective for both human and animal hosts (73). Similarly, the zoonotic potential of *Cryptosporidium* spp. is well known, and domestic animals are an important reservoir of infection for humans (74). Overall, 16 different *Cryptosporidium* spp. and over 40 genotypes with new genotypes have been identified regularly (75).

Transmission of Zoonotic Parasite

Contaminated Food and Water

Toxoplasma gondii is the most important pathogen transmitted by food in the USA and possibly Europe (76). Many human infections are thought to be spread by eating raw or undercooked meat such as pork or lamb. However, the high prevalence of *T. gondii* infection in people who do not eat meat or eat it raw demonstrates that infection through the environment (e.g., oocysts in soil, water, or uncooked vegetables) could also be a factor. Only a small proportion (less than 0.1%) of people acquire infection congenitally (77).

Developments in the molecular and genetic analyses of waterborne protozoan parasites, including the determination of species identity and subtyping species, will help in determining the contributors to environmental contamination. Several genotyping techniques have been developed for *Cryptosporidium, Giardia, Microsporidia* spp., and *Toxoplasma* (61,78). The small size of *Microsporidia* (1-5 mm) makes them difficult to remove using conventional water filtration techniques, and there is concern that they may possess increased resistance to chlorine disinfection similar to *Cryptosporidium*. The spores may be susceptible to disinfection (79).

Soil-transmitted

Toxocara canis is transmitted to humans mainly by the incidental ingestion of embryonated eggs present in the soil or soil-contaminated food (2,3,80). Most eggs (51%-95%) recovered from the soil of temperate countries were fully embryonated and, therefore, infective (81). Although larvae may not develop further, parasites can live for up to seven years following infection (Figure 2). Moreover, direct contact with sick puppies and kittens is not typically thought to be a risk factor for human toxocariasis because the eggs shed by these animals must be embryonated in the soil before becoming infective, and these pets may contain embryonated eggs in their fur (82).

Zoonotic Risk

Pet Ownership

Pet ownership is an important risk factor for the occurrence of toxoplasmosis (4). The low schooling level of owners has been regarded as a risk factor for the occurrence of zoonotic gastrointestinal parasites (*Ancylostoma, Uncinaria, Toxocara* spp, *G. duodenalis*, and *T. gondii*) in dogs and cats (83). Among intestinal protozoa, *Cryptosporidium* spp. is prevalent in people with congenital or acquired immunodeficiency, including patients with acquired immunodeficiency syndrome (61,84).

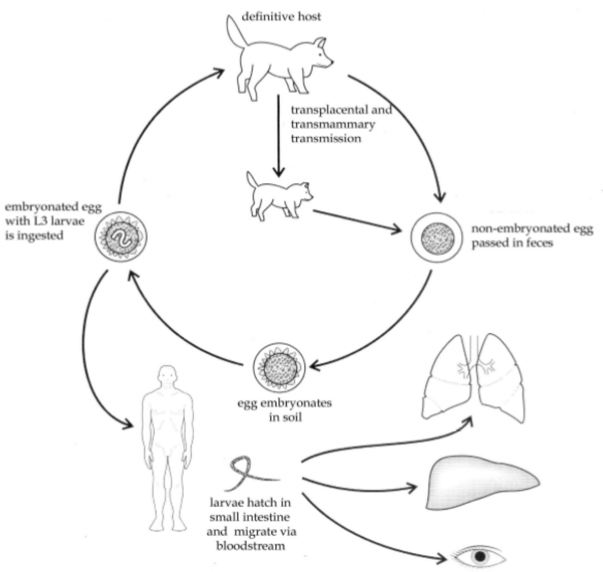

Figure 2. Life Cycle of *Toxocara canis*. Source (61).

Management Practices

The important factor that was found to be associated with helminthosis was dog management concerning the degree of house confinement. Dogs that roam freely had a higher prevalence (92.5%) of helminthosis than dogs confined within the premises of their owners (64.5%). Similarly, a higher prevalence (97.34%) of helminthosis was documented for stray dogs in Hawassa as compared to confined dogs (69.6%) (85).

The majority of animal health professionals are knowledgeable about the source of infection, transmission, treatment, control, and prevention of animal-borne zoonotic diseases. However, due to a lack of joint work and programs with medical professionals, none of them had ever identified the disease in animals or attempted to teach the community. On the other hand, the majority of medical professionals have limited knowledge of zoonoses, and none of them had ever diagnosed zoonotic diseases such as toxoplasmosis, hydatidosis, and the like in humans; the reason for the diagnosis problem was the lack of facility, and no attention was given to the diseases next to a lack of awareness (86).

Prevention and Control of Zoonotic Parasites

Controlling infections by soil-transmitted helminths requires the prophylactic deworming of companion animals regularly, as well as educational programs directed at pet owners. In addition, veterinarians' perception concerning small animal-derived zoonosis should be improved, with an emphasis on their role in disseminating information about these diseases to their clients. In Canada, 80-90% of the protocols recommended for puppies and kittens were inappropriate (87) . Veterinarians are also thought to be on the 'front line' of the prevention of pet-associated zoonotic parasitic infections (3). In southeastern Brazil, a significant decrease was observed in the incidence of a cutaneous larval migrant after the replacement of the soil in sandboxes and the enclosure of playground areas with fences (88,89). Similarly, in Turkey, fenced parks were free of *Toxocara* eggs, while 64.3% of open areas were contaminated with eggs (90-92). Although domestic dogs are more likely to undergo regular deworming treatments, restricting the spread of the virus to wild carnivores populations, feral dog populations play an important role in the contamination of the environment by *Toxocara* eggs, thus effectively acting as a "bridge" between domestic and wild host populations (83,93). Control of stray dogs and dog deworming campaigns are of vital significance for the control of these zoonotic diseases (61,94,95).

Conclusion and Recommendations

The zoonotic parasites of pet animals are the most important diseases, which are distributed throughout the world. In the absence of proper care, the link between humans, animal populations, and the surrounding environment can lead to a serious risk to public health with huge economic consequences. The potential for the zoonotic transmission of intestinal helminths and the human health risks associated with dog and cat ownership is now increasing from time to time, thus there is an urgent need to obtain more recent and up-to-date information on the zoonotic parasites of dogs and cats for better designing appropriate control and prevention strategies. These recommendations are based on the above-mentioned conclusion:

- Companion animals should be dewormed regularly, and pet owners should be educated.
- There is a need to have stray dog control and dog deworming programs throughout the world.
- Veterinarians are also thought to be on the 'front line' of the prevention of pet-associated zoonotic parasitic infections.

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Authors' Contribution

Conceptualization: Mahendra Pal.
Data curation: Dinaol Tolawak.
Investigation: Mahendra Pal.
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Supervision: Mahendra Pal.
Validation: Mahendra Pal.
Visualization: Dinaol Tolawak.
Writing–original draft: Mahendra Pal.
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Competing Interests

There is no conflict of interests.

Ethical Approval

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