
Current Status of *Ancylostoma* Species in Domestic and Wild Animals and Their Zoonotic Implication: Review

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Abstract: Hookworm species are mainly an endo-parasite of cats and dogs and others animals including man. Next to roundworm (*Ascaris suum*) and whipworm (*Trichuris trichuria*) infections, hookworm infections ranked third in terms of disease load in humans. Among hookworms, *Ancylostoma* species are highly prevalent in various species of domestic and wild animals, including humans, and mostly found in Asia and tropical countries. People who live in poor resource countries are more vulnerable than in developed countries. Hookworms in children cause mental impairment that leads to cognitive impairment. Similarly, a disability-adjusted life year (DALY) occurs in hookworms, particularly *Ancylostoma* infects children due to physical impairment. In animals, hookworm may cause diarrhea, stunted growth, and anemia and even lead to death in young animals. Furthermore, *Ancylostoma* causes cutaneous larva migrans, eosinophilic enteritis, and anemia and finally may cause death in humans. As a result of urbanization, climate change, and land degradation, there are various *Ancylostoma* species which are newly emerging in animals. Currently, the *Ancylostoma* is a great concern both in humans and animals, particularly in resource poor countries. The *Ancylostoma* infection may require governmental and public attention. Therefore, a control and prevention strategy strongly requires integration between medical and veterinary communities to improve environmental and personal hygiene.

Keywords: *Ancylostoma* Species, Anemia, Domestic Animals, Hookworm, Wild Animals

1. Introduction

Soil transmitted gastro intestinal helminth infections are common in less developed countries and in the world's poorest populations. Approximately 2 billion of the world's populations suffer from soil-transmitted helminthes infection. 576-740 million people were affected by hookworms worldwide. In Sub-Saharan Africa, Americas, China, and East Asia are the areas where this infection is most prevalent [1]. Hookworms are blood sucking nematodes that live in the digestive tracts of mammals. It has significant importance both in animals and humankind. Initially, the word *Ancylostoma* came from the Greek words ankulos (hooked or crooked) and stoa (mouth), which refer to the worm's identification structures [2]. Hookworms are highly prevalent in humans with mixed infections during the summer-autumn period [3]. Hookworms are one of the blood-sucking

nematode parasites that use a sharp cutting device at the anterior end for attachment to the mucosa and sub-mucosa of the intestine and suck into their buccal chambers a tissue plug [4]. Hookworms are able to initiate and maintain bleeding through capillaries and arterioles rupture due to mechanical damage and chemical activity by hydrolytic enzymes. Hookworms also secrete a range of anticlotting substances to ensure blood flows freely [5].

The adult worms suck impulses up to 120-150 per minute and are known as greedy blood suckers through the help of persistent esophagus movements. A worm can suck 0.2 ml of blood per day [6]. Hence, people are infected by hookworm globally, leading to physical and mental growth retardation and anemia [4, 7]. Disability-adjusted life years (DALY) frequently happen due to physical impairment than death occurs [7].

Ancylostoma species is one of the most important soil transmitted helminth parasites in a variety of animal species,

including man. *Ancylostoma* species are categorized under the family of Ancylostomatidae. Host infection by *Ancylostoma* species could be via fecal-oral route or skin penetration of the third-stage larvae [7]. However, transmammary infection was described in bitches during the pregnancy period and rarely ingestion of paratenic hosts (rodents) which is common in *Ancylostoma caninum* [8, 9].

Anemia, retarded growth, tissue injury, inflammation, and mortality are the main pathological effects of hookworm infections in several wildlife and domestic species [10]. There are some species of *Ancylostoma* species that transmit from animal to human directly or indirectly by means of transmission. The most important species of *Ancylostoma* species which are responsible for human infections are *Ancylostoma caninum*, *Ancylostoma ceylanicum*, and *Ancylostoma braziliense*. Larval migrans in humans were repeatedly reported by *A. caninum* and *A. braziliense* [11].

Currently, some of the *Ancylostoma* eggs and adult parasites of cats and dogs have been detected in the human intestine. The main hookworms in cats and dogs that can affect humans are *A. ceylanicum* and *A. caninum*. The diagnosis of *Ancylostoma* species based on egg morphology was not a convenient and accurate method for differentiation. *Ancylostoma* species identification based on morphological features has some disadvantages in terms of human labour, wasting time and demanding skilled personnel. Due to mixed infection, there is always the risk of being overlooked [12].

A previous study reported that orally administration of a combination of pyrantel, febantel, and praziquantel was found to be helpful in dogs with chronic illness [13]. It is frequently ineffective at eliminating adult worms from the host intestine [14]. Oral administration of Ivermectin is an effective drug with a single oral dose of 12 mg for humans during cutaneous larval migrans that cures 100% [15]. Albendazole and Mebendazole are effective for clearing adult parasites from human intestines for consecutive 1-3 days with an iron supplement [16].

Currently, prevention and control of zoonotic hookworms are becoming serious challenges for various reasons, like, lack of restricted movement of canine and feline animals to social recreational places, walking barefoot, over intimacy with pet animals, and lack of community awareness. In this regard, there is a scarcity of compiled information of *Ancylostoma* species infections in domestic and wild animals as well as in humans. Therefore, this review highlighted and summarized the prevalence and zoonotic importance of *Ancylostoma* species in domestic and wild animals currently circulating in resource-poor and deprived countries.

2. Morphology and Taxonomic Classification

The eggs of hookworm are thin and single membrane which can be broken down throughout the passage of the human stomach. Almost all hookworm eggs, including *A. caninum*, seem to have an oval shape and are about 50 µm in

diameter. The egg seems like a morula containing a group of cells with an elliptical shape and smooth shell. The finding demonstrated that the eggs of *A. caninum* and *A. tubaeforme* were larger than those of *A. braziliense* [17]. The adult parasite of *A. caninum* is different from other species by three pairs of prominent teeth on the ventral side (figure 1).

The presence of three teeth on either side of the ventral midline distinguishes the adults of *A. tubaeforme* from those of *A. braziliense* and *A. ceylanicum*. *A. braziliense* and *A. ceylanicum* have two teeth [11, 18]. At the anterior end of the buccal cavity of *A. ceylanicum*, a pair of large teeth on top and a pair of smaller teeth below are proportionally found. The oral hole is larger and round-shaped as compared to *A. braziliense*. The ventral, dorsal, and lateral rays of *A. ceylanicum* are found in the copulatory bursa [19]. The presence of three pairs of teeth in the buccal cavity was used to identify *A. caninum* morphologically [20].

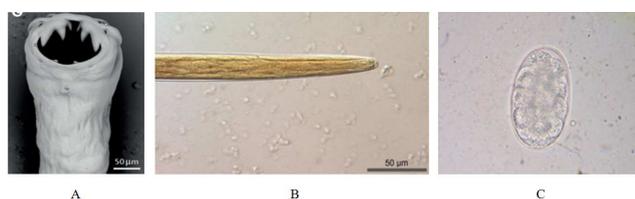


Figure 1. A) Morphology of *A. caninum*, with its 'teeth' clearly visible [1, 2]. B) Filariform esophagus on the anterior of an infective third-stage larva. C) *Ancylostoma caninum* egg found in the fecal sample of a dog, microscope at 1000X.

Taxonomy of *Ancylostoma* species are classified under class of nematode which is important to indicate the genetically relationship of the different species, systems of taxonomy has been developed (Figure 2).

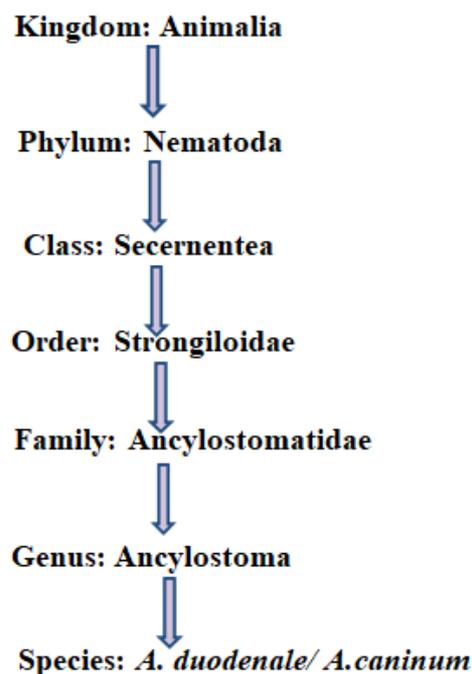


Figure 2. Taxonomic classification of Ancylostomatidae. (<http://www.ncbi.nlm.nih.gov/genome/?Term=N+americanus>).

3. Zoonotic *Ancylostoma* Species of Animals

3.1. *Ancylostoma caninum*

Ancylostoma caninum infection is characterized by eosinophilic enteritis and intestinal hypersensitivity [22]. *Ancylostoma caninum* mainly infects dogs and rarely cats, including humans. Cutaneous larva migrans is common in humans [23] or enteric infections in people with eosinophilic enteritis [22, 24]. Follicular dermatitis is also common in humans [25]. There is a phenomenon called "larval leak" in *A. caninum*, particularly in dogs, in which larvae leak from arrested/hypobiotic stages (tissue) to adult stages in the intestine [26, 27]. In these cases, dogs continue to shed hookworm eggs due to new leak out of larval from inactivated form. Even during treatment with anthelmintic, the egg shedding stops for a few days. When the duration of treatment is completed, the eggs also reappear continuously [28].

Ancylostoma caninum can mature from eggs to adults in the human intestine. However, this may occur in a rare condition. An *A. caninum* infection in humans has been documented in Australia [22]. Adult *A. caninum* was detected in a man of 60 years old upon health examination in South Korea [20]. Hookworm eggs were found in human feces in recent research in South Africa [29] and India [30].

3.2. *Ancylostoma ceylanicum*

One of the zoonotic hookworms which may develop into adult stage in human intestine. *Ancylostoma ceylanicum* is one of commonly known hookworm of domestic dogs and cats all over Asian countries [3-5]. *Ancylostoma ceylanicum* was reported from India for the first time [6]. *Ancylostoma ceylanicum* has been found in domestic dogs in Western Australia, Victoria, Queensland, and the Northern Territory [7]. A new case of *A. ceylanicum* was reported in France from traveller who returned from tropical countries [8]. Human infection of *A. ceylanicum* was also reported from Vietnam by molecular identifications [9].

In humans, this parasite was reported from Western Australia [10]. *Ancylostoma ceylanicum* was even reported in humans and dogs in Laos and Thailand. Study conducted in Philippines (Palapag and Laoang) indicated that humans were positive of *A. ceylanicum* [11]. The symptoms manifested in humans are long-lasting abdominal disorder [3, 4]. The following clinical signs are suggestive of being infected by *A. ceylanicum* such as, eosinophilia, transient ground itch, weakness, weight loss, fever, diarrhoea, melena, nausea, and vomiting and difficulty in breathing. Blood loss and iron-deficiency anemia is aggravated in children and pregnant women. In dogs, heavy infections lead to blood loss which revealed by microcytic hypochromic iron-deficiency anemia [12].

3.3. *Ancylostoma tubaeforme*

Ancylostoma tubaeforme are found most commonly in canids, felids, and humans and have significant zoonotic importance. It is highly prevalent in warmer areas of the world [40]. According to previous reports, cats were highly infected by *A. tubaeforme* and dermatitis is the symptoms of *Ancylostoma tubaeforme* infection [41], anemia, pulmonary lesions and weight loss also reported [28].

The larvae of *A. tubaeforme* can infect a host through oral intake or cutaneous penetration. Ingested larvae enter the stomach via the esophagus and, eventually, larvae develop into adults beneath the layer of duodenum and stomach. Those adult hookworms lay eggs in the intestines which they propel to the outside with feces. The infective larvae mature in the environment before infecting a host by skin penetration. After skin penetration, the larvae migrate to the lungs and then move up to the trachea, and down to the esophagus, ultimately reaching the stomach [28]. The total pre-patent period of this hookworm is about 22-25 days [41].

3.4. *Ancylostoma braziliense*

Ancylostoma braziliense is also hookworm of the cats and dogs and lives in intestines. Anemia may occur due to consistent sucking of blood from cats and dogs intestines by adult hookworm [13]. This species is indigenous to the Southern United States, but it can also be found in subtropical locations around the world, such as Central and South America and Southern Asia. Distribution of *Ancylostoma* in Southern Asia is limited to Indonesia, Borneo, and Malaysia [4]. Humans are infected by *A. braziliense* parasites but not true definitive hosts. The immature larvae only migrate to beneath the epidermis, producing lesions. Those immature larvae ultimately die, could not travel to circulatory system or reaching adult stages in the intestine [14, 15].

4. Life Cycle of *Ancylostoma* Species

Adult male and female hookworms mate in the intestine at the start of their life cycle (figure 3). The adult female then lays an egg, which is passed through the feces and hatches in the environment. The L1 feeds on cells of bacteria and then moults twice to generate non-feeding, eventually develop to L3. Infective L3 molts twice before reaching adult stage in the small intestine, infection may happen by epidermis penetration or ingestion of paratenic hosts such as rats. In *A. caninum*, the larval developmental arrest (hypobiosis) in the host after L3 reached to skeletal or intestinal muscle [16]. Due to increase transforming growth factor, the hypobiotic L3 would be initiated the reactivation and travels to the mammary gland in pregnant females [46]. Newly born pups get infected via colostrum/milk of bitch with infective larvae [9]. In paratenic or transport hosts like rodents and insects muscle, L3 development of hookworm remains in hypobiotic stages. *Ancylostoma caninum* larvae were detected in mice, cats, and monkeys [47].

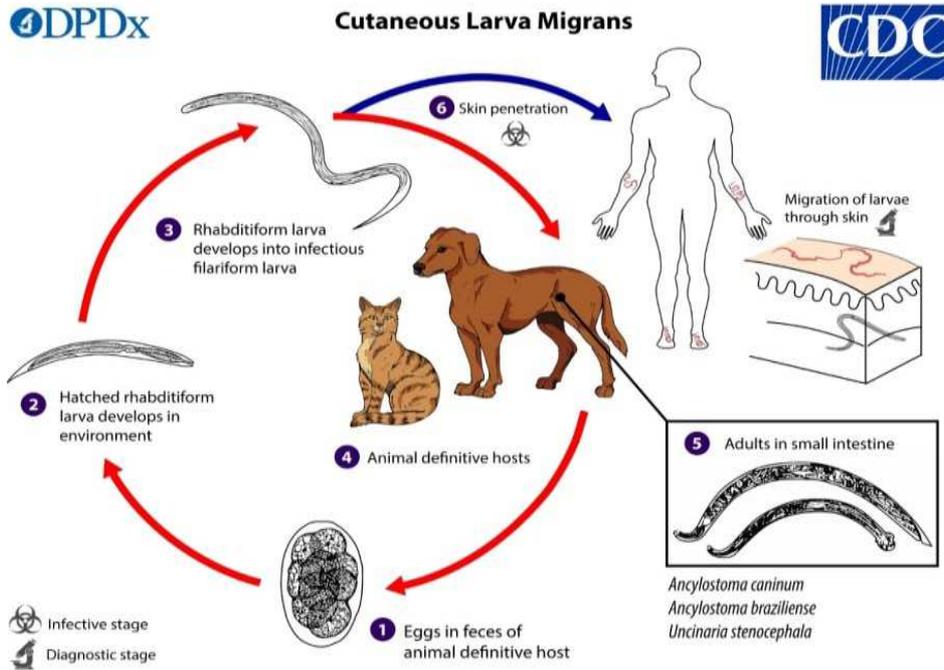


Figure 3. *Ancylostoma* species and canine hookworm life cycle. (<https://www.cdc.gov/dpdx/zoontichookworm/index.html>).

5. Geographical Distribution of *Ancylostoma* Species in Wild Animals

There are newly emerging parasitic nematodes in wild life due to alteration of land scenery, climate change, increased urbanization, and human wildlife interaction. Furthermore, the establishment of zoological gardens for endangered and valued animals has the potential to change natural host-parasite dynamics [48, 49]. As a result, hookworm species such as *A. tubaeforme*, *A. pluridentatum*, *A. braziliense*, and

human hookworms like *N. americanus* have a wide host range of wild animals [10]. *Ancylostoma* species infect wild animals as a result of over flow from domestic animals [50]. The importance of animal-human-wildlife interaction in disease transmission particularly, in spillover and spillback that is important in the maintenance of hookworm in wildlife and domestic animals [10]. The dynamics of nematode infections in wild animals may be influenced by changes in landscapes and climate change [48]. *Ancylostoma* species can be found in wild animals all over the world reported as summarized (Table 1) below.

Table 1. Summary of reported *Ancylostoma* species in wild animal.

<i>Ancylostoma</i> Species	Hosts	Country	References
<i>A. kusimaense</i>	Nyctereutes procyonoides, raccoon dog, red foxes	Asia	[17, 18]
<i>A. Malayanum</i>	Bears	Japan	[19]
<i>A. lotoris</i> ,	Black bears	South eastern United State	[20]
<i>A. lotoris</i>	Skunks	North America	[21]
<i>A. conepti</i>	Skunk, Conepatus chinga	South America	[22]
<i>A. duodenale</i>	Spotted hyenas	Ethiopia	[23]
<i>Ancylostoma</i> sp.	Hyena	Kenya	[24]
<i>A. ceylanicum</i>	Malay civet	Malaysia	[25]
<i>Ancylostoma</i> sp.	Cercopithecids	Cameroon	[26]
<i>A. caninum</i> , <i>A. pluridentatum</i> <i>A. tubaeformae</i> , <i>A. braziliense</i>	Bobcat and Cougars	South eastern United States	[27-29]
<i>A. buckleyi</i>	Crab-eating fox, Pampas fox	State of São Paulo, Brazil	[30, 31]
<i>A. braziliense</i> , <i>A. ceylanicum</i> , <i>A. caninum</i>	Dingo	Cairns, Far North Queensland	[32]
<i>A. caninum</i>	Golden Jackal	Hungary	[33, 34]
<i>A. pluridentatum</i>	Jaguar	Colombia and Panama	[35]
<i>A. tubaeforme</i>	Persian Leopard	Iran	[36]
<i>A. ailuropodae</i>	Wild giant pandas	Southwest China	[37]
<i>A. buckleyi</i>	Pampas foxes	Southern South America	[30, 31]
<i>A. tubaeforme</i>	Feral cats	Southeastern Mexico	[38]
<i>A. caninum</i>	Wolves	Poland	[39]
<i>A. caninum</i>	Red fox and Jackal	Tunisia	[30, 31]
<i>A. kusimaense</i>	Raccoon dogs	Japan	[30, 31]
<i>A. caninum</i>	Red fox	Denmark	[40]
<i>A. caninum</i>	Wild dog	South Africa	[41]

6. Prevalence and Geographical Distribution of *Ancylostoma* Species in Domestic Animals

Nematodes are among the gastrointestinal zoonotic parasites that can be found in dogs and cats [42]. Carnivores

are usually definitive hosts, and they help to spread zoonotic infection by dispersing infective eggs or larvae throughout the environment. In felids and domestic animals, *Ancylostoma* species parasitizes the small intestine. *Ancylostoma* species are prevalent in Sub-Saharan Africa, Americas, China, and East Asia (Table 2).

Table 2. Prevalence of *Ancylostoma* species from domestic animals in different countries of the world.

Country	Animal spp	Prevalence (%)	Spp. identified	Test method	References
China/ Guangdong	Dog	33.1	<i>A. ceylanicum</i>	PCR	[42]
	Cat	51.1	<i>A. ceylanicum</i>		
	Dog	59.9	<i>A. caninum</i>		
	Cat	48.9	<i>A. tubaeforme</i>		
Mexico	Dog	7	Mixed infections	light microscopy	[43]
	Dog	73.8	<i>A. caninum</i>		
China/ Guangzhou	Cat	95.1	<i>A. caninum</i>	PCR-RFLP	[44]
	Cat	40.2	Mixed <i>A. caninum</i> & <i>A. ceylanicum</i>		
Malaysia	Dog	52	<i>ceylanicum</i>	Formal-ether & PCR	[45]
		48	<i>A. caninum</i>		
		54.3	<i>A. ceylanicum</i>		
Vietnam	Dog	33	<i>A. caninum</i>	PCR-RFLP	[46]
		12.7	Mixed <i>A. caninum</i> & <i>A. ceylanicum</i>		
China/Heilongjiang	Dog	66.3	<i>A. caninum</i>	Morphological keys and descriptions	[47]
		61.4	<i>A. caninum</i>		
Brazil /São Paulo State	Dogs	12.5	<i>A. braziliense</i>	PCR	[48]
		26.1	mixed <i>A. caninum</i> & <i>A. braziliense</i>		
Iraq/ Basra	Dogs	7.5	<i>A. caninum</i>	Centrifugal flotation	[49]
		29.6	<i>A. ceylanicum</i>		
Malaysia /Klang Valley	Cat	6.6	<i>A. caninum</i>	PCR–HRM	[50]
		44.5	<i>A. ceylanicum</i>		
		8.8	<i>A. caninum</i>		
Iran/Mazandaran	Dogs	41.2	<i>A. caninum</i>	Sheather's flotation & PCR	[51]
Sudan /Shendi	Dogs	0.8	<i>A. caninum</i>	flotation & microscope	[52]
Ethiopia	Dogs	14.7	<i>Ancylostoma</i> spp	Formole ether concentration	[53]
Brazil/ Seropédica	Dogs	13.6	<i>A. caninum</i>	Flotation by centrifuge ation-flotation	[54]
Mexico/ Tabasco	Dogs	15.9	<i>A. caninum</i>	Centrifugal flotation	[54]
Italy/ Teramo	Dogs	0.6	<i>Ancylostoma</i> spp	Flotation sodium nitrate solution	[55]
Japan	Dogs	0.2	<i>A. caninum</i>	Formalin-ethyl acetate sedimentation	[56]
Northern Thailand	Dogs	82.1	<i>A. ceylanicum</i>	Sucrose flotation & PCR	[57]
		Cat	95.8		
Uruguay/ Tacuarembó		49.4	<i>A. braziliense</i>	Sedimentation and fixed in 10%formalin.	[58]
		96.3	<i>A. caninum</i>		
		11.7	<i>Ancylostoma</i> sp.		
USA/ Georgia	Cat	11.7	<i>Ancylostoma</i> sp.	Centrifugation sugar flotation	[59]
Northern mississippi	Cat	34	<i>Ancylostoma</i> sp.	Fecal flotation	[60]
Czech Republic /Prague	Dogs	0.4	<i>Ancylostoma</i> sp.	Fecal flotation	[61]
		36	<i>A. caninum</i>		
		24	<i>braziliense</i>		
North eastern India	Dogs	24	<i>braziliense</i>	PCR-RFLP	[62]
		38	Mixed infection <i>A. caninum</i> & <i>A. braziliense</i>		

PCR- polymerase chain reaction; RFLP- Restriction Fragment Length Polymorphism; HRM-High resolution melting analysis

7. Prevention and Control Measures

Creation of awareness about zoonotic *Ancylostoma* species among rural communities and municipal offices is the most important point of prevention and control. Hence, a periodic deworming of pet animals and communities awareness to wear shoes outdoors have a key role in prevention. Regular deworming of pet animals should be strongly mandatory to

reduce the risk of transmission to humans. Prior domestic and international movement of dogs, implementation of laws for restraining stray dogs, routine parasitic examination and treatment need to be strictly executed [63, 64]. A one health approach is the best methods to address long-term control of zoonotic hookworm. Moreover, deworming with Albendazole and Mebendazole in human populations on a regular basis can help to minimize morbidity [39]. In order to control

hookworm infection in the communities, proper hygiene and sanitation could play an essential role [65].

8. Conclusions and Recommendations

Currently, the hookworm is a commonly found in humans and animals, particularly in resource poor countries. *Ancylostoma* species are the most common zoonotic hookworms which transmit from animals to humans. The *Ancylostoma* species has a significant impact on the physical and mental growth of children from resource-deprived countries. Hence, based on above conclusions the following recommendations are forwarded: the integrated approach between human and veterinary worker is necessary to prevent and control *Ancylostoma* species in endemic countries. The following measures need to be implemented, such as awareness creation in communities, restriction of animals (feline and canine) from recreational areas, avoiding walking on bare feet, regular deworming of pets and humans, and maintaining proper personal and environmental hygiene and sanitation and further studies on hookworm vaccine development and molecular epidemiology have significant role in prevention and control.

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