Spirocerca
(helminth: nematode)

Overview

Nematodes are triploblastic pseudocoelomate unsegmented worms that undergo protostomial embryonic cleavage and grow by cuticular moulting (ecdysis). Two groups identified by the presence/absence of sensory phasmids have partly been ratified by molecular studies recognising three subclasses: Enoplia and Dorylaimia (both without phasmids) and Chromadoria (most with phasmids). Many phasmidian parasites of vertebrates are grouped in the chromadorian order Rhabditida; including tylenchinids, rhabditinids and spirurinids. The latter contains the infraorder Spiruromorpha: an enigmatic clade linked by molecular characters, but all having indirect life-cycles involving one or more intermediate hosts, the first invariably being an arthropod. Most possess two trilobed lips (sometimes greatly reduced), a bipartite oesophagus (anterior muscular, posterior glandular) and non-bursate males with coiled tails and two dissimilar spicules. Several superfamilies are recognised: including spiruroids (with prominent lips) containing the spirocercids found in the stomach and aorta of dogs and transmitted by coprophagous beetles in which L3 develop. Small mammals (esp. rodents), birds and reptiles may also act as paratenic hosts for L3. Infections by *Spirocerca lupi* in dogs have been associated with vomiting, anorexia, haemothorax and sudden death.

Classification:

Domain:	Eukaryota (membrane-bound nucleus)
Supergroup:	Amorphea (unikonts with single flagellum, or nonflagellated amoebae)
Kingdom:	Metazoa (multicellular eukaryotes, heterotrophs, notably animals)
Group:	Protostomia (triploblastic, spiral cleavage)
Subgroup:	Ecdysozoa (cuticle moulted = ecdysis)
Phylum:	Nematoda (unsegmented, pseudocoelomate roundworms, tubular digestive tract, dioecious)
Class:	Chromadorea (spiral amphids, three oesophageal glands, usually annulated bodies, free-living and parasitic)
Order:	Rhabditida (Secernentea, Phasmidea) (secretors, with phasmids, bipartite oesophagus, single testis)
Suborder:	Spirurina (mostly parasitic in vertebrate hosts)
Infraorder:	Spiruromorpha (enigmatic clade linked by molecular characters, indirect cycles with IHs)
Superfamily:	Spiruroidea (two trilobed lips, oesophagus never with bulb, coiled tail in males, two unequal spicules)
Family:	Spirocercidae (stout pink-red worm, well-developed buccal capsule, with 6 rudimentary lips)
Genus:	*Spirocerca* (parasitic in oesophagus/aorta of dogs)
Species:	*S. lupi* (causes vomiting and haemothorax in dogs)

Parasite biodiversity and host range: Most Metazoa are multicellular triploblastic animals with differentiated tissues, many being bilaterally symmetrical with a body cavity. Most invertebrate animals are protostomes as their embryonic development involves spiral determinate cleavage. Those that moult their external cuticles during their life-cycles (process known as ecdysis) are grouped together in the unique clade Ecdysozoa, including the nematodes (roundworms), onychophorans (velvet worms), tardigrades (water bears) and arthropods (myriapods, chelicerates, crustaceans and hexapods, all with jointed limbs). Nematodes (roundworms) are unsegmented tubular worms with a fluid-filled body cavity (pseudocoelom) that acts as a hydrostatic skeleton. They have longitudinal muscles and typically exhibit a sideways thrashing motion. They have well developed digestive tracts with various partitions: the foregut comprising the mouth (often with lips and papillae), buccal capsule (sometimes with ridges, rods, plates, spears, stylets or teeth) and oesophagus (glandular, muscular or both); the midgut (nonmuscular absorptive section); and hindgut (rectum) emptying through a subterminal anus (cloaca in males). Most nematodes are dioecious and form separate sexes. Male worms have a single testis (sometimes 2), an elongate vas deferens often equipped with a seminal vesicle and ejaculatory duct (glandular and/or muscular), 1-2 copulatory spicules (sometimes with an accessory gubernaculum), and bursate species with elaborate posterior claspers. Female worms are usually didelphic (some monodelphic or polydelphic) with 2 ovaries, 2 oviducts usually with spermatheca, 2 uteri opening into a common vagina and a vulva often equipped with a muscular ovejector. Female worms are oviparous or viviparous and produce numerous eggs or larvae, respectively. Larval stages undergo several moults (L1-L4) before maturing into adult worms. Some nematodes have direct life-cycles where eggs or larvae infect definitive hosts (per os or per cutaneous), but many have indirect cycles where larvae first develop in invertebrate intermediate hosts before infecting definitive hosts (by ingestion, injection or deposition). Many nematode species are free-living in terrestrial and aquatic habitats, while some species from diverse groups have become plant or animal parasites. Two nematode groups identified by the presence/absence of sensory phasmids have partly been ratified by molecular studies recognising three subclasses: Enoplia and Dorylaimia (both without phasmids) and Chromadoria (most with phasmids). Most Enoplia are free-living marine organisms but some are found in freshwater, and on land as plant parasites. The Dorylaimia comprise numerous freshwater and terrestrial species, including major groups of plant and animal parasites. The Chromadoria is represented by many marine groups as well as a terrestrial group of plant and animal parasites. The taxonomic ranks of many nematode assemblages vary considerably depending

on which classification system has been followed. Molecular phylogenetic studies, however, have supported the separate classification of most groups, particularly at the level of superfamily. Collectively, species from at least 16 superfamilies are considered to pose serious threats to human and animal health as infectious diseases.

CLASSIFICATION* OF SUPERFAMILIES OF PARASITIC NEMATODES
Class: Enoplea (Aphasmidea, Adenophorea) (gland-bearers, cylindrical oesophagus, no phasmids, setae, two testes)
Subclass: Dorylaimia (five or more oesophageal glands, buccal stylet (odontostyle), free-living or parasitic)[clade I(2)]
Order: Trichinellida (Trichocephalida, Trichurida) (single spicule, stichosome oesophagus, L1 with buccal stylet)
Superfamily: Trichinelloidea (oesophagus with short anterior muscular and long posterior glandular portions)
Class: Chromadorea (spiral amphids, 3 oesophageal glands, usually annulated bodies, free-living and parasitic)
Order: Rhabditida (Secernentea, Phasmidea) (secretors, phasmids present, amphids anterior, bulbous oesophagus)
Suborder: Rhabditina (free-living or parasitic in invertebrates/lower vertebrates)[clade V(9)]
Infraorder: Rhabditomorpha (‘rod-shaped’ buccal cavity)
Superfamily: Rhabditoidea (open tube stoma, excretory system with lateral canals)
Superfamily: Strongyloidea (bursate males, prominent buccal capsules, parasites of mammals, birds, reptiles)
Suborder: Spirurina (animal parasites, many use invertebrate intermediate hosts (IH))[clade III(8)]
Incertae sedis Superfamily: Dracunculoidea (elongate parasites of vertebrate tissues, freshwater crustacean IH)
Infraorder: Ascaridomorpha (large roundworms, three large lips, numerous caudal papillae)
Superfamily: Ascaridoidea (ascarids, eggs thick-shelled, larvae may undertake hepato-pulmonary migration)
Superfamily: Heterakoidea (preanal sucker anterior to cloaca in males, direct cycle, infection by egg ingestion)
Infraorder: Gnathostomatomorpha (‘jaw-mouthed’ due to unique bulbous armed heads)
Superfamily: Gnathostomatoidea (first IH copepod, often use paratenic hosts)
Infraorder: Oxyuridomorpha (pinworms, pointed tails, oesophagus with terminal bulb, males with single spicule)
Superfamily: Oxyuroidea (common in mammals, birds, reptiles, amphibians)
Infraorder: Spiruromorpha (enigmatic clade linked by molecular characters, indirect cycles with IHs)
Superfamily: Acuarioidea (small parasites mostly of birds, with cephalic cordons, ptilina or serrated shields)
Superfamily: Camallanoidea (conspicuous phasmids, L1 with dorsal tooth, ovoviviparous, L1-L3 in copepod)
Superfamily: Filarioidea (tissue-dwelling filarial parasites, lack lips, infect tissues/vessels, arthropod IH)
Superfamily: Habronematoidea (unique head structures with small pseudolabia and median lips)
Superfamily: Physalopteroidea (stomach worms in mammals, insect IH)
Superfamily: Spiruroidea (pseudolabia, bipartite oesophagus, infect birds (crop/gizzard), arthropod IHs
Superfamily: Thelazioidea (eye-worms of birds and mammals, transmitted by insects)
Suborder: Tylenchina (fungal, plant and animal parasites)[clade IV(10,11,12)]
Infraorder: Panagrolaimomorpha (free-living or parasitic (insects, reptiles, amphibians, mammals))
Superfamily: Strongyloidoidea (dauer stages, lip region without processes, striated cuticle)

*Contemporary genotypic classification schemes recognize strong monophyletic clades at the level of superfamily and infraorder, while previous phenotypic classification schemes had ranked many as separate orders.

Molecular phylogenetic studies have grouped a variety of superfamilies into the infraorder Spiruromorpha whose members are parasites of vertebrates with indirect life-cycles involving larval development within invertebrate intermediate hosts. Most members were previously classified within the order Spirurida: either within the suborder Camallanina (worms with conspicuous phasmids, uninucleate oesophageal glands, larvae without cephalic hooks, usually with copepodid intermediate hosts); or the suborder Spirurina (worms with inconspicuous phasmids, multinucleate oesophageal glands, larvae with cephalic hooks or spines, usually with non-copepodid intermediate hosts). Ten spirurinid superfamilies are recognised: Gnathostomatoidea and Physalopteroidea (buccal cavity weakly cuticularized, 2 large lateral pseudolabia); Habronematoidea and Acuarioidea (buccal cavity well cuticularized, 2 large lateral pseudolabia); Filarioidea, Rictularioidea, Aproctoidea and Diplotriaenoidea (buccal cavity well cuticularized, without pseudolabia); Thelazioidea (long cylindrical buccal cavity well cuticularized, body without caudal alae); and Spiruroidea (short buccal cavity well cuticularized, body with caudal alae).

The superfamily Spiruroidea comprises worms with simple non-ornamented heads infecting the stomach (sometimes oesophagus) of mammals and birds and using arthropods as intermediate hosts for the development of distinctive larvae with conspicuous buccal capsules with a left cephalic hook and a rasp of tiny spines. Four families are recognised: Gongylonematidae (body covered with large verruciform thickenings, pseudolabia absent, oral opening octagonal with median lobes, parasites of birds and mammals); Spiruridae (body without verruciform thickenings, reduced pseudolabia, oral opening elongated with lateral elevations, buccal cavity without teeth, parasites of mammals, rarely birds); Spirocercidae (body without verruciform thickenings, reduced pseudolabia, oral opening hexagonal, buccal cavity with teeth, parasites of mammals, rarely birds); and Hartertiidae (body without verruciform thickenings, large pseudolabia subdivided into lobes, parasites of birds). The family Spirocercidae contains 3 subfamilies: Spirocercinae (lips poorly developed, not prominently raised above oral opening, pharynx without rugose or annular thickenings, parasites of mammals and birds); Ascaropsinae (lips poorly developed, not prominently raised above oral opening, pharynx with rugose or annular thickenings, parasites of mammals); and Mastophorinae (lips highly-developed forming 6

denticulate labial lobes over oral opening, parasites of rodents). The subfamily Spirocercinae contains 8 genera (*Cyathospirura, Cylicospirura* (syn. *Petrowospirura*), *Didelphonema, Mazzia, Paraspiralatus, Spiralatus*, *Spirocerca* and *Vigisospirura*) which are differentiated primarily on the basis of differences in adult morphology (cephalic, cuticular and genital structures), larval morphology (anatomy and ornamentation), host occurrence/specificity, geographic distribution and transmission patterns (predation, parateny). Genera of veterinary and medical significance are tabulated below:

Genus	No. spp.	Definitive Hosts	Location	Adult worms	Eggs	Transmission
Family: Spirocercidae (stout pink-red worm, well-developed buccal capsule, with 6 rudimentary lips)						
Subfamily: Spirocercinae (weakly-developed lips)						
Spirocerca	5	carnivores	stomach, aorta	3-8 cm long, body pink-red, buccal capsule with thick wall, 2 prominent trilobed lips, bipartite oesophagus	22-38 x 8-15 µm, elongate, thick-shelled	indirect (L3 in insect IH) [sometimes rodent, bird, reptile PH]
Cylicospirura (red worm)	10	mammals	stomach	20-30 mm long, buccal capsule with 6 longitudinal ribs ending in bifid knobs, 6 teeth, bipartite oesophagus	30-40 x 15-25 µm, elongate, thick-shelled	indirect (L3 in insect IH)
Cyathospirura (red worm)	5	mammals	stomach	6-12 mm long, buccal capsule with 6 longitudinal ribs ending in single knob, 8 teeth, bipartite oesophagus	29-38 x 13-22 µm, ovoid, thick-shelled	indirect (L3 in insect IH)
Subfamily: Ascaropsinae (buccal cavity with rugose or annular thickenings)						
Ascarops (thick stomach worm)	10	artiodactyls, rodents	stomach	10-25 mm long, oblique annuli in buccal capsule, 2 prominent trilobed lips, bipartite oesophagus	34-51 x 20-26 µm, oval, thick-shelled	indirect (L3 in insect IH) [sometimes amphibian or avian PH]
Physocephalus (thick stomach worm)	10	artiodactyls, rodents	stomach	6-22 mm long, transverse annuli in buccal capsule, 2 prominent trilobed lips, bipartite oesophagus	31-39 x 15-17 µm, ellipsoidal, thick-shelled	indirect (L3 in insect IH) [sometimes amphibian or avian PH]
Family: Gongylonematidae (anterior cuticle covered with large bosses or irregular scutes arranged in rows)						
Gongylonema	46	mammals, birds	oesophagus, stomach	2-15 cm long, numerous anterior bosses, 2 prominent trilobed lips, bipartite oesophagus	40-70 x 22-35 µm, ovoid, thick-shelled	indirect (L3 in insect IH)

The genus *Spirocerca* contains several species of oesophageal worms with well-developed buccal capsules without median lobes or teeth but with 2 prominent trilobed lips. They are parasitic in carnivores (particularly canids) and have indirect heteroxenous life-cycles involving larval stages in intermediate hosts (mainly dung beetles) as well as in paratenic (transport) hosts (reptiles, amphibians, birds and small mammals). Infections have been found throughout the world, particularly in warmer regions where conditions are more suitable for their insect intermediate hosts.

***Spirocerca* species**	**Hosts**	**Location [Clinical signs]**	**Intermediate hosts [plus Paratenic hosts]**	**Distribution**
S. arctica	Carnivora: canid (dog, wolf, Arctic fox), mustelid (wolverine)			Northern Hemisphere
S. lupi (syn. *S. sanguinolenta*)	Carnivora: canid (dog, wolf, maned wolf, red fox, gray fox, Iberian fox, culpeo fox, coyote, golden jackal, black-headed jackal), felid (cat, jungle cat,	oesophagus, stomach, aorta [vomiting, weight loss, haemothorax]	Coleoptera: scarabaeid (dung beetle, *Akis goryi, Canthon depressipennis, pilarius, Catharsius pithecius, Chironitis hungaricus, Copris hispana, lunaris, Euoniticellus pallipes, Geotrupes blackburnii, douei, Gymnopleurus aciculatus, koenigi, mopsus, sinnatus, sturmi, Hister lularius, maindronii, Hybosorus lutarius, orientalis, Oniticellus pallens, pallipes, Onitis*	worldwide, esp. tropics

	African wild cat, South African wild cat, bobcat, tiger, ocelot, Iberian lynx), ailurid (red panda), viverrid (common genet), mustelid (beech marten, European pine marten, stoat, least weasel, ferret)		*bonasus, dama, gazella, mopsus, philemon, Onthophagus amyntas, deflexicollis, quadridentatus, Orthophagus hecate, pennsylvanicus, sylvanicus, Phanaeus vindex, Scarabaeus sacer, variolosus*), carabid (ground beetle, *Scarites indus*), tenebrionid (darkling beetle, *Pisterotarsa gigantea*); Blattodea: blattid (cockroach, *Periplaneta americana*); Odonata: aeshnid (dragonfly, *Anax parthenope*) [plus PH: Rodentia: murid (mouse, brown rat), caviid (guinea pig), glirid (forest dormouse); Lagomorpha: leporid (rabbit); Eulipotyphla: erinaceid (North African hedgehog, European hedgehog, Amur hedgehog, southern white-breasted hedgehog, northern white-breasted hedgehog), soricid (common shrew, Asian gray shrew, Asian house shrew, Eurasian pygmy shrew, bicoloured shrew), talpid (Caucasian mole, Roman mole); Carnivora: mustelid (steppe polecat), felid (cat); Chiroptera: vespertilionid (serotine bat, greater mouse-eared bat, common noctule, Kuhl's pipistrelle), rhinolophid (greater horseshoe bat, Mehely's horseshoe bat; Artiodactyla: bovid (buffalo, goat); Perissodactyla: equid (donkey); Primates: cercopithecid (rhesus macaque), hominid (human); Sauria: agamid (oriental garden lizard, Caucasian agama), lacertid (rapid racerunner, sand lizard), gekkonid (house gecko), anguid (European glass lizard), varanid (desert monitor); Serpentes: colubrid (large whip snake, spotted desert racer, grass snake, diadem snake), boid (dwarf sand boa), elapid (central Asian cobra), lamprophiid (arrow snake), viperid (blunt-nosed viper); Anura: bufonid (Asian common toad, European green toad), ranid (marsh frog); Anseriformes: anatid (duck); Accipitriformes: accipitrid (Eurasian sparrowhawk, common buzzard); Bucerotiformes: upupid (Eurasian hoopoe); Coraciiformes: coraciid (European roller); Falconiformes: falconid (Eurasian hobby); Galliformes: phasianid (chicken, double-spurred spurfowl); Passeriformes: corvid (carrion crow, alpine chough), laniid (brown shrike), meropid (European bee-eater), motacillid (white wagtail), muscicapid (northern wheatear), turdid (red-throated thrush, mistle thrush); Strigiformes: strigid (little owl, tawny owl), tytonid (barn owl)]	
S. melesi	Carnivora: mustelid (European badger)			Europe
S. vigisiana	Carnivora: canid (wolf, red fox, corsac fox), felid (Pallas's cat)			Eurasia
S. vulpis	Carnivora: canid (red fox)	stomach		Europe

Parasite morphology: *Spirocerca* spp. form 3 morphologically different stages during their developmental cycles: namely, eggs; larvae (4 consecutive stages encoded L1-L4); and adult worms. The thin-walled eggs are small (measuring 22-38 x 8-15 μm), oval-elliptical in shape (but with parallel sides) and embryonated when laid. L1 are short cylindrical stages measuring 110-124 μm, with 2 anterior cuticular rods converging at the tip, and tapering trifid tails (middle point longest). L2 are transient developmental stages which moult to form infective L3 ranging in length from 0.8-2.3 mm with heads containing 2 pointed flaps (also present on *Physocephalus* and *Ascarops*), thick-walled buccal cavities, and short tails with up to 5 spinous processes. Adults are stout pink-red worms with cylindrical coiled bodies measuring 30-80 mm long. The rounded head has 2 pointed flaps (dorsal and ventral) and a hexagonal mouth opening. The buccal capsule is well-developed and thick-walled, without median lobes or teeth but with 6 poorly-developed rudimentary lips (or 2 trilobed lips) not prominently raised above oral opening. The pharynx is short and lacks rugose or annular thickenings (present in the genera *Physocephalus* and *Ascarops* in the subfamily Ascaropsinae). Adult worms are sexually dimorphic, with females being larger than males (50-80 cf. 30-55 mm long). Mature females are didelphic with 2 ovaries and large uteri connected to a common anterior vulva. Mature males have spirally coiled tails with caudal alae, pre- and post-cloacal papillae, a rudimentary gubernaculum, and 2 elongate unequal spicules (left spicule 2.4 -2.8 mm long, right spicule 0.5-0.8 mm long).

Site of infection: Adult worms infect the walls of the oesophagus (usually the terminal portion) as well as the stomach (gastric cardial region) and the aorta (dorsal thoracic portion). Earlier developing larval stages undertake extensive migrations in the walls of blood vessels (particularly abdominal arteries), although some may undergo aberrant migration into a wide range of organs. Infective L3 develop in the haemocoel and tissues of invertebrate intermediate hosts (coprophagous beetles), but may also be carried in the tissues of various vertebrate paratenic hosts (mammals, birds, reptiles, amphibians).

Pathogenesis: Many infections remain subclinical as only a few parasites are involved, although canids seem to tolerate heavier infections and may not develop clinical signs even when extensive lesions are present. The migratory behaviour of larvae in the walls of blood vessels followed by nodular formation by adult worms in the upper digestive tract can cause a variety of clinical signs depending on the organs involved, the susceptibility of the hosts, the numbers of parasites, and the stage of infection (prepatent or patent). Ectopic lesions may also arise due to aberrant migration of the parasites, and chronic infections by *S. lupi* may result in tumour-like lesions (neoplasia). Infective larvae penetrate the stomach wall and begin migration in the walls of coronary, gastric, gastroepiploic and celiac arteries to the upper abdominal and lower thoracic aorta. En route, they may cause small haemorrhages, inflammation (mediastinitis, endocarditis, pleuritis, peripheral lymphadenopathy, interstitial nephritis) and necrosis (including salivary gland necrosis and sialosis). Hosts may experience discomfort leading to dysphagia, vomiting and inappetence. Once within the walls of the aorta, migrating larvae may cause progressive lesions involving eosinophilic infiltrates, intimal roughening, elastic degeneration, thrombosis, muscle fibrosis, mineralization or metaplastic ossification, all contributing to permanent scarring and aneurysms (the rupture of which may result in haemothorax and sudden death). Larvae then migrate from the aortic wall to the oesophagus via the mediastinum, sometimes causing pleuritis and pyothorax presenting with dyspnoea, coughing and retching. In the oesophagus, larvae develop into adult worms in granulomatous nodules containing pleomorphic fibroblasts and several worms entwined together and feeding on host blood. Most nodules develop a fistula (opening) to the lumen for the passage of eggs but some nodules do not. Nodules may also develop in the stomach and aorta, and occasionally in other locations (mediastinum, intestines, rectum, lumbar fascia, diaphragm, trachea, lung, thymus, heart, kidney, urinary bladder, subcutis and interdigital tissue). The nodules range in size from 5-40 mm in diameter and act as space-occupying inflammatory lesions compressing local tissues and associated nerves, blood vessels and lymphatics, thus causing a wide range of clinical signs, including difficulty in swallowing, odynophagia (repeated attempts to swallow), hypersalivation with drooling (due to vagal interference), regurgitation, vomiting, and sometimes gastro-oesophageal intussusception, oesophageal obstruction or perforation, ulceration, chronic haemorrhagic anaemia, melena, haematemesis, pale mucous membranes, submandibular swelling, coughing, dyspnoea, lethargy, depression, decreased appetite or anorexia leading to weight loss and chronic wasting. Ectopic infections have also been associated with a range of secondary lesions (pyothorax, haemothorax, haemopericardium, secondary megaoesophagus, pleural effusion, lung lobe atelectasis, pyaemic nephritis), congestive heart failure (due to aorticopulmonary shunting, anterior vena cava syndrome), neurological signs (paresis, paraplegia, hyporeflexia), hypertrophic pulmonary osteoarthropathy of long bones, and hypertrophic osteopathy with spondylitis or spondylosis of thoracic vertebrae causing bone deformations leading to gait abnormalities and lameness. Chronic infections by *S. lupi* have also been associated with tumour formation (cauliflower-like oesophageal sarcoma, osteosarcoma, fibrosarcoma) in a small proportion of infected dogs. The tumours are often highly invasive and may produce metastases in the lungs and other tissues. They are thought to arise by malignant transformation of granulomas due to a combination of host, parasite and environmental factors.

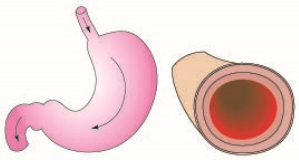
Developmental cycle and mode of transmission: *Spirocerca* spp. have indirect heteroxenous life-cycles involving predator-prey transmission whereby carnivores become infected by ingesting larval stages in invertebrate intermediate hosts or vertebrate paratenic hosts. Female worms in nodules lay embryonated eggs that pass through small fistula to the lumen of the oesophagus where they are excreted with host faeces, sometimes vomitus. Egg production is often intermittent, but profuse (> 1 million eggs per day in heavy infections). The eggs are ingested by coprophagous insects (dung beetles) which act as intermediate hosts supporting further parasite development. Ingested eggs hatch in the beetle gut releasing L1 which penetrate to the haemocoel and undergo 2 moults within 2 months to form infective L3 within delicate capsules. These larvae are quite robust and can be transferred to a wide

range of beetle-eating vertebrates (small mammals, birds, reptiles, amphibians) which act as paratenic (transport) hosts as the L3 do not develop further but encapsulate in various organs and tissues (especially visceral organs, mesenteries, muscles and subcutaneous tissues). L3 may even ascend the food chain being transferred from one paratenic host to another, re-encapsulating each time. Final hosts become infected when they consume infective L3 contained within intermediate or paratenic hosts. The L3 are released in the stomach and invade the mucosa beginning an extensive migration in the walls of blood vessels (predominantly abdominal arteries) to reach the aorta within 3 weeks. They moult to L4 in 4-5 weeks and then migrate directly from the aorta via the mediastinum to the oesophagus in 12-14 weeks. Here they moult to subadults (often referred to as L5) which provoke the development of granulomatous nodules in which they mature to adults by 20 weeks. The prepatent period (time from infection to first excretion of eggs) ranges from 112-170 days, and the patent period (duration of egg excretion) may last up to 2 years.

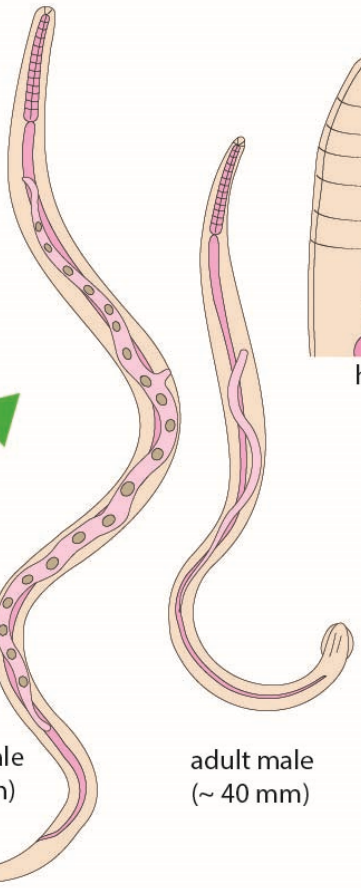
Differential diagnosis: Clinical infections may present with a wide spectrum of signs, none of which are pathognomic. Chronic infections often involve recurrent regurgitation with weight loss and weakness, and haematological examinations often reveal anaemia and leucocytosis. Infections are usually diagnosed by the microscopic detection of worm eggs in faecal samples, mainly following their concentration by sedimentation in water and floatation in saturated sugar or heavy metal salt solutions with high specific gravities. The eggs are relatively characteristic in morphology (small, thin-walled, ellipsoidal with flat sides, and embryonated) but are similar to those of other spirurids. Egg excretion is intermittent so repeat samples may be required to rule out false negatives. The numbers of eggs excreted also does not correlate well with the intensity of infection as some nodules remain blind and do not develop fistula to release eggs. Modern imaging techniques (radiography, computed tomography, ultrasonography) may help reveal nodules or dense masses (tumours) in internal organs (especially terminal oesophagus) as well as irregularities (undulations) of the aortic wall and spondylitis of bones. Endoscopy may also be performed to determine the location and extent of nodules and tumours, and to collect biopsy samples. Infections may be diagnosed at post-mortem by the detection of granulomatous masses containing worms in the oesophagus, stomach, trachea, lungs and mediastinum. Immunofluorescence tests developed to detect specific host antibodies against parasite antigens have recorded good sensitivity and specificity in canids. Modern molecular biological techniques have recently been used to explore parasite DNA variation between species from different hosts from different geographic locations following the polymerase chain reaction (PCR) amplification of nuclear (small subunit (18S) ribosomal RNA, internal transcribed spacer 1) and mitochondrial genes (cytochrome c oxidase subunit 1).

Treatment and control: A wide range of drugs have been used in attempts to treat clinical infections in canids, but parasites are generally detected late in the course of infection when they are encapsulated in granulomatous nodules, and sometimes when tumour formation has already commenced. Variable success has been reported using several anthelmintics, including benzimidazole-methylcarbamates (albendazole), imidazothiazoles (levamisole), diethylenediamines (diethylcarbamazine), macrocyclic lactones (ivermectin, doramectin, milbemycin, moxidectin) and even disphenol sodium (now discontinued in many countries). Supportive therapy is often provided for several weeks in the form of anti-inflammatories, phenobarbital for excessive salivation, and feeding animals whilst upright to prevent regurgitation due to megaoesophagus. If neoplasia is suspected, anti-cancer drugs and/or surgical interventions should be considered. Treatment with doxorubicin and/or carboplatin has improved survival in dogs, especially those with osteosarcomas rather than fibrosarcomas. A range of preventive strategies may be implemented in peri-domestic situations where interventions can be used to reduce environmental contamination by worm eggs and to limit their transmission to intermediate, paratenic and definitive hosts. Animal holding facilities should be regularly cleaned and disinfected, and sanitary processes used to dispose of faeces and vomitus. Insecticides may be used to reduce beetle populations, rodent control measures should be implemented, and wild animals should be excluded. Animals should be provided with clean food and water and not be fed uncooked viscera from potential paratenic hosts (e.g. chickens or wild birds). They should be prevented from scavenging, hunting and roaming outdoors. Regrettably, most of these strategies are not feasible in situations involving free-ranging animals or wildlife, and the indiscriminate use of insecticides against coprophagous beetles should be discouraged in natural ecosystems.

Spirocerca

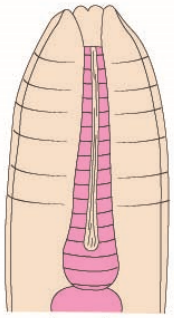


oesophagus, stomach, aorta
(nodules, inflammation,
vomiting, haemothroax)

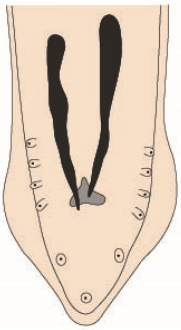


adult female
(~ 70 mm)

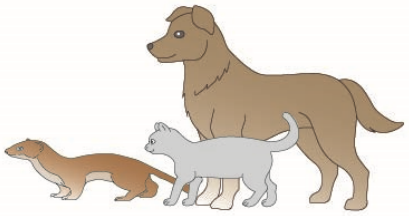
adult male
(~ 40 mm)



head



male
tail



Definitive Hosts
(carnivores)

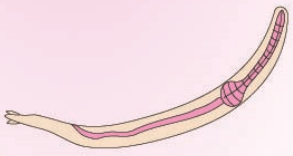
larval migration,
esp. in walls of
blood vessels

eggs
excreted
in
faeces

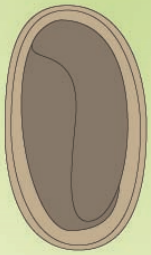
PH/IH/L3
ingested

L3 encapsulate in PH

third-stage larvae
(L3) (~ 1.5 mm)



first-stage larvae
(L1) (~ 120 µm)



eggs
(~ 30 µm)

Paratenic Hosts (IH)
(rodents, birds, reptiles)
(viscera, muscles)

eggs ingested
by IH

Intermediate Hosts (IH)
(dung beetles, cockroaches)
(haemocoel, tissues)

Spirocerca adult worm

Spirocerca worm egg

Spirocerca adult worm, head