Uncinaria
(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 spirurinids, tylenchinids and rhabditinids. The latter contains the infraorder Rhabditomorpha which includes strongyloid nematodes characterised by an expansion of the tail of the male known as the copulatory bursa (clasper with one dorsal and two lateral lobes with muscular rays). Many families are recognised: including the ancylostomatids (hookworms) which are characterised by their bent mouths, the anterior ends being bent dorsally. They have a well-developed buccal capsule with cutting plates or teeth, and are voracious blood-feeders in the small intestines of mammals. They have direct life-cycles, involving a geo-helminth phase. Eggs voided with faeces hatch releasing free-living rhabditiform larvae which subsequently develop into infective filariform L3 that are ingested or actively penetrate the skin of their hosts. *Uncinaria* infections are usually acquired by carnivores ingesting L3 or by eating paratenic (transport) hosts (such as rodents) harbouring L3. Percutaneous infections rarely mature, larvae do not undergo pulmonary migration and vertical transmission has not been demonstrated. Infections by *U. stenocephala* may cause low grade hookworm disease (anaemia and diarrhoea) in dogs and cats, and contribute to pedal dermatitis in hypersensitive animals.

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:	Rhabditina (free-living or parasitic in invertebrates/lower vertebrates)
Infraorder:	Rhabditomorpha ('rod-shaped' buccal cavity)
Superfamily:	Strongyloidea (bursate males, prominent buccal capsules, parasites of mammals, birds, reptiles)
Family:	Ancylostomatidae (hookworms, buccal capsule bent dorsally, armed with teeth/cutting plates)
Genus:	*Uncinaria* (parasitic in small intestines in dogs/foxes/cats)
Species:	*U. stenocephala* causes anaemia/diarrhoea in carnivores

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 with 2 ovaries (some monodelphic or polydelphic), 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 His
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.

The superfamily Strongyloidea comprises a range of worms often with prominent buccal capsules and specialised oral structures well-suited to their feeding habits on host tissues and/or fluids. Adults of most species are parasitic in the gastrointestinal tracts of mammals and some birds, while larval stages feed on bacteria in the external environment, although some larvae may infect invertebrates as intermediate or paratenic hosts. The adult worms are sexually dimorphic, the smaller males characterised by an expansion of the tail (bursa) which is used as a copulatory clasping organ. Many classification schemes group these ‘bursate’ nematodes into one or more superfamilies in the order Strongylida (with suborders containing the strongyles, trichostrongyles, hookworms and lungworms), although the families essentially remain the same. Many families are recognised on the basis of parasite morphology, biology, life-cycle, host specificity and tissue tropism; including the following which contain many notorious parasites of vertebrates.

Representative Strongyloidea (cf. Strongylida) [with bursate males]				
Family	**Characters**	**Definitive Hosts**	**Transmission***	**No. genera**
Ancylostomatina (hookworms)				
Ancylostomatidae (hookworms)	large buccal capsule bent dorsally, armed with teeth/cutting plates	primates, carnivores, artiodactyls	transdermal penetration of L3 (sometimes *per os*)	20
Trichostrongylina (trichostrongyles)				
Trichostrongylidae (trichostrongyles)	reduced buccal capsule, ridged synlophe, oesophagus lacking bulb, thin-shelled eggs	artiodactyls, birds	ingestion of L3	50
Molineidae (stomach/intestinal worms)	reduced buccal capsule, cephalic vesicle, female tail with spine or cusps, oviparous/viviparous	mammals, birds, reptiles	ingestion of L3	61
Heligmonellidae (hookworm-like)	body coiled, cephalic vesicle, ridged synlophe, bursa asymmetrical	mammals, birds	transdermal penetration of L3	56
Strongylina (strongyles)				
Strongylidae (strongyles)	large buccal capsule often armed with teeth, leaf crown around mouth	mammals, reptiles, birds	ingestion of L3	32
Chabertiidae (nodule worms)	large buccal capsules, leaf crown of labial collar, L3 sheathed	artiodactyls, primates	ingestion of L3	22
Syngamidae (gapeworm)	cup-shaped buccal capsule, armed with teeth, male attached to female	birds, mammals	ingestion of L3 or invertebrate PH	7
Stephanurinae (kidneyworm)	buccal capsule armed with teeth, leaf crowns and external epaulettes	suids	transdermal penetration or ingestion of L3 or PH	1
Metastrongylina (lungworms)				
Metastrongylidae (lungworms)	small buccal capsule, 2 trilobed lips, bursa with reduced dorsal lobe	suids	ingestion of IH carrying L3	1
Protostrongylidae (lungworms)	small buccal capsule, bursa with large lobes, gubernaculum	artiodactyls	ingestion of IH carrying L3	17
Angiostrongylidae (lungworms)	no or reduced buccal cavity, short club-shaped oesophagus	carnivores, rodents	ingestion of IH or PH carrying L3	28
Dictylocaulidae (lungworms)	small buccal capsule, bursa with large lobes, short stout spicules	ungulates, reptiles	ingestion of L3	5
Filaroididae (lungworms)	small buccal capsule, reduced male bursa, infective L1	carnivores	ingestion of L1	4

*IH = intermediate host, PH = paratenic (transport) host, L1 = first-stage larva, L3 = third-stage larva

Hookworms are characterised by their dorsally bent heads with prominent buccal capsules containing paired ventral lancets as well as teeth, cutting plates or lateral jaw-like structures. They are parasitic in the small intestines of mammals and reptiles and infections are acquired by the ingestion or skin penetration of infective L3 followed by tracheal migration. Two families are recognised: Ancylostomatidae (dorsally deviated head, buccal capsule usually armed with teeth or cutting plates, 20 genera in intestines of mammals); and Diaphanocephalidae (anteriorly directed head, buccal capsule forming 2 lateral jaw-like structures, 2 genera in intestines of reptiles). The family Ancylostomatidae contains 2 subfamilies: Ancylostomatinae (buccal capsule subglobular, with dorsal gutter, bursa with short dorsal ray, gubernaculum present, posterior vulva, female tail with terminal spine, most in carnivores); and Bunostominae (buccal capsule subglobular, with tooth-like dorsal cone, bursa with long dorsal ray, gubernaculum absent, anterior vulva, female tail without terminal spine, most in herbivores). Ancylostomatid genera of particular medical and/or veterinary significance are tabulated below.

Genus	**No. spp.**	**Definitive Hosts**	**Location**	**Adult worms**	**Worm eggs**	**Transmission**
Ancylostominae						
Uncinaria	22	carnivores	small intestines	3-15 mm long, well-developed buccal capsule with pair of ventral cutting plates, no pulmonary migration	65-98 x 35-58 µm, ovoid, thin-shelled	oral (direct or via PH), rarely transdermal
Ancylostoma	32	carnivores, primates	small intestines	5-25 mm long, bent heads, buccal capsule with ventral lancets and fused teeth, larval pulmonary migration, hypobiosis	55-95 x 32-58 µm, ellipsoidal, thin-shelled	oral, transdermal, transplacental, transmammary
Globocephalus	18	artiodactyls, rodents, primates	caecum, small intestines	3-9 mm long, large buccal capsule without cutting plates or teeth, larval pulmonary migration	60-75 x 35-41 µm, ovoid, thin-shelled	oral, transdermal
Bunostominae						
Bunostomum	9	artiodactyls, proboscidea	small intestines	10-30 mm long, buccal capsule with ventral cutting plate and 1-2 pairs subventral teeth, larval pulmonary migration, hypobiosis	79-117 x 40-70 µm, ovoid, thin-shelled	oral, transdermal, transplacental, transmammary
Gaigeria	1	artiodactyls	small intestines	10-45 mm long, buccal capsule with pair ventral cutting plates, elongate lancets and teeth, larval pulmonary migration	108-115 x58-61 µm, ellipsoidal, thin-shelled	transdermal
Necator	7	primates, artiodactyls	small intestines	7-11 mm long, buccal capsule with cutting plates, larval pulmonary migration	55-77 x 35-42 µm, ovoid, thin-shelled	oral, transdermal

The subfamily Ancylostominae contains 8 genera classified in 4 tribes: Ancylostomatinea containing worms with oral openings armed with teeth, and globular buccal capsules not divided into articulating plates (*Ancylostoma* (syn. *Agchylostoma*, *Anchylostomum*, *Ankylostoma*, *Ankylostomum*, *Ceylancylostoma*, *Diploodon, Dochmius*) and *Galoncus*) parasitic in carnivores, primates, edentates, rodents, and suids; Uncinarinea containing worms with oral openings with well-developed cutting plates, and buccal capsule not divided into articulating plates (*Uncinaria* (syn. *Dochmoides*, *Dochmius*, incl. subgenera *Uncinaria*, *Megadeirides*) and *Bioccastrongylus*) parasitic in insectivores, primates, and carnivores; Arthrocephalinea containing worms with buccal capsules divided into articulating plates (*Arthrocephalus*, *Arthrostoma*, and *Placoconus*) parasitic in carnivores; and Globocephalinea containing worms with oral openings lacking teeth and cutting plates (*Globocephalus* (syn. *Characostomum*, *Crassisoma*, *Cystocephalus*, *Raillietostrongylus*)) parasitic in suids, primates, mustelids, rodents, ruminants, and South American marsupials. The genus *Uncinaria* contains over 20 species of hookworms with globular buccal capsules armed with 2 ventrolateral and 2 dorsolateral cutting plates. Most species infect wild animals, although the species *U. stenocephala* is commonly found in companion animals, mainly working dogs. Infections are often found worldwide in regions with cooler climates, including temperate and subarctic zones in the Northern and Southern Hemispheres. Occasionally, humans may become infected transdermally with larval stages causing transient cutaneous larval migrans.

Uncinaria species	Definitive Hosts	Location [Clinical signs]	Distribution
U. bauchoti	Afrosoricida: tenerecid (greater hedgehog tenerec)		Madagascar
U. bidens	Carnivora: procyonid (crab-eating raccoon, coati)		Asia
U. brasilensis	Carnivora: canid (dog)		South America
U. carinii	Carnivora: canid (crab-eating fox)		
U. criniformis	Carnivora: mustelid (European badger, Iberian badger, pine marten, beech marten)		Eurasia
U. felidis	Carnivora: felid (cat, leopard cat)		Asia
U. hamiltoni	Carnivora: otariid (brown fur seal, New Zealand fur seal, South American fur seal, Australian sea lion, South American sea lion)	small intestines [anaemia]	Australia, South America
U. hydromyidis	Rodentia: murid (Australian water rat)		Australia
U. longespiculatum (possibly *Arthrocephalus*)	Carnivora: viverrid (masked palm civet, small Indian civet)		Asia
U. lucasi	Carnivora: otariid (northern fur seal, Steller sea lion), phocid (ringed seal)		North America
U. lyonsi	Carnivora: otariid (California sea lion)		North America
U. maxillaris	Carnivora: procyonid (crab-eating raccoon)		Asia
U. maya	Carnivora: felid (iriomote cat)		Asia
U. muridis sp. inq.	Rodentia: murid (Southern African vlei rat)		Africa
U. olseni	Scandentia: tupaiid (treeshrew)		Asia
U. parvibursata	Carnivora: mustelid (honey badger)		Africa
U. philippinensis (possibly *Arthrocephalus longespiculum*)	Carnivora: viverrid (Asian palm civet)		Philippines
U. rauschi	Carnivora: ursid (black bear, brown bear)		North America
U. sanguinis	Carnivora: otariid (Australian sea lion)	intestines [anaemia]	Australia
U. skrjabini	Carnivora: mustelid (sable)		Eurasia
U. stenocephala (Northern hookworm, European hookworm) (syn. *Dochmius balsami*, *U. polaris*)	Carnivora: canid (dog, dingo, coyote, wolf, maned wolf, red fox, eastern American red fox, arctic fox, Darwin's fox, grey fox, swift fox, corsac fox, Iberian fox, Bengal fox, golden jackal, raccoon dog, culpeo), felid (cat, sand cat, lynx, lion), mustelid (European badger); Artiodactyla: suid (pig); Rodentia: murid (mouse) [plus larval infections in Primates: hominid (human)]	small intestines [anaemia, diarrhoea]	worldwide, esp. temperate zones
U. trigonocephala (syn. *Ankylostoma*)	Carnivora: canid (bat-eared fox, red fox)		Africa
U. yukonensis	Carnivora: ursid (American black bear, brown bear)		North America

Parasite morphology: *Uncinaria* spp. form 3 different types of morphological stages in their development: namely, eggs, larvae (4 consecutive stages usually encoded L1-L4), and adult worms. Female worms produce elliptical eggs measuring 65-93 x 35-58 μm that have thin eggshells and contain a central embryonic mass (morula) usually at the 8 cell (blastomere) stage. L1 and L2 are free-living (preparasitic) stages measuring from 300-500 μm in length and they have long narrow buccal capsules, short rhabditiform (double-bulbed) oesophagi and tapering tails. L3 are ensheathed stages (still encased in L2 cuticle) measuring 450-540 μm in length and they have closed mouths, elongate strongyliform oesophagi, and pointed non-notched tails. L4 are transient parasitic stages that have begun to show adult worm characteristics, particularly with regard to mouthparts and developing genitalia. Adult hookworms are small stout white worms ranging in length from 3-15 mm and having heads with a prominent dorsal deviation (hook). They have an enlarged subglobular to funnel-shaped buccal capsule not divided into articulating plates but with a pair of well-developed chitinous cutting plates on the ventral border and a pair of spear-shaped subventral teeth. The buccal capsule has a dorsal gutter on its inner surface containing the duct of the oesophageal gland, and the oesophagus is flask-shaped and elongate occupying the anterior third of the worm. Adult worms are sexually dimorphic, with females being longer and stouter than males (7-15 cf. 3-9 mm long). Mature males have a well-developed copulatory bursa with 2 large separate lateral lobes, each supported by 6 finger-like rays (formed by muscular elements following nerve channels to terminal papillae), and a short dorsal lobe (supported by a short ray bifurcating into 4-6 branches). They also have a gubernaculum around 25 μm long and 2 slender spicules measuring up to 800 μm long. Mature female worms are didelphic, with 2 ovaries and uteri with short wide vaginas and symmetrical longitudinal ovejectors opening into a prominent vulva located posterior to midbody, and they have short tapering tails with terminal spine.

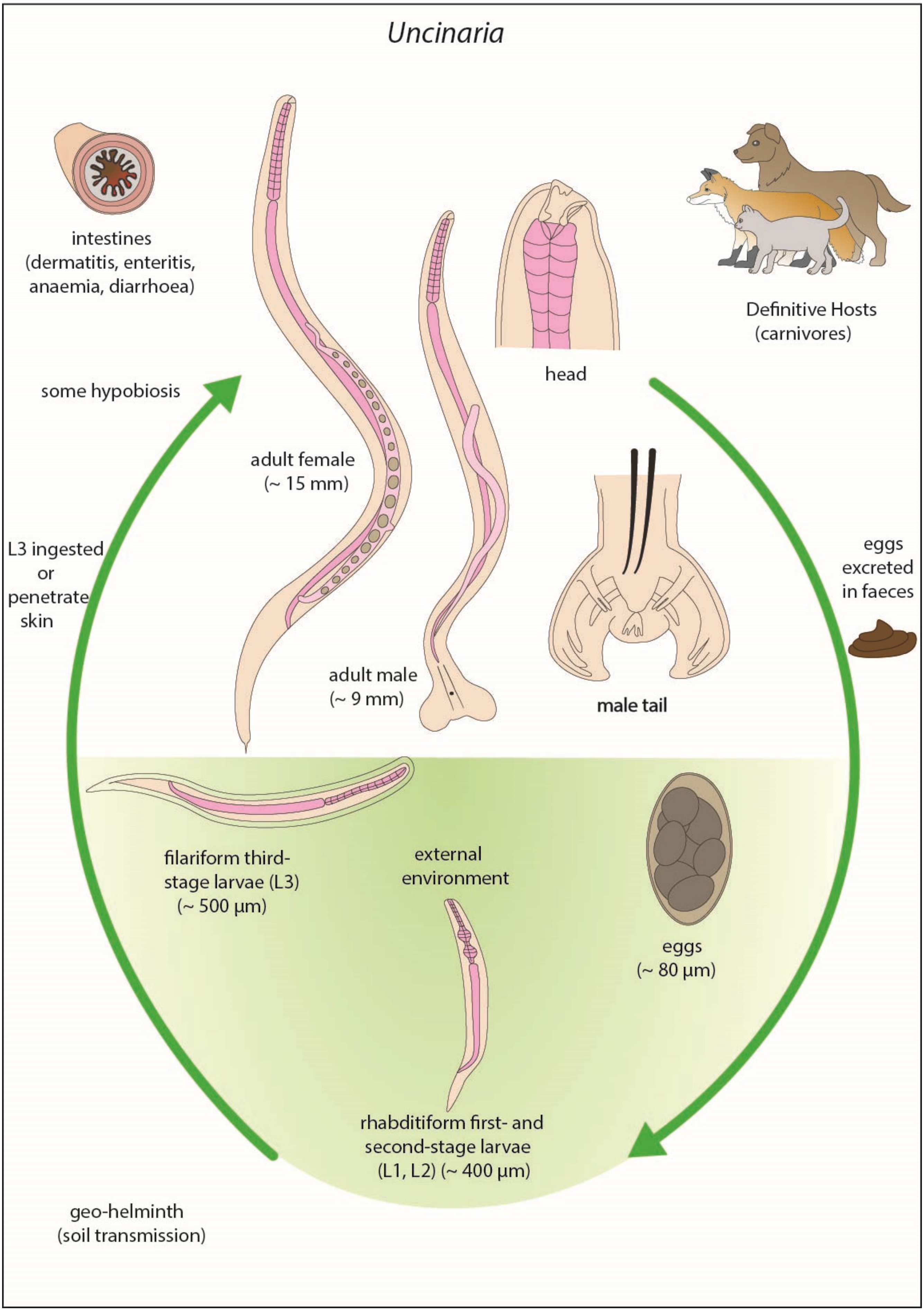
Site of infection: Adult worms infect the small intestines of their definitive hosts (predominantly carnivores), while earlier parasitic larval stages undergo histotrophic development in mucosal tissues (rarely undertaking pulmonary migration). Free-living larval stages develop from excreted eggs and contaminate the external environment.

Pathogenesis: Most infections remain asymptomatic because few worms are involved, although heavier infections may cause clinical disease, either when larvae migrate through tissues or when adult worms feed on blood in the intestines. The severity of disease depends on the virulence of the parasite species, the intensity and route of infection, and host susceptibility (young and/or malnourished individuals are most at risk). Infective larvae coming into contact with host skin may penetrate dermal tissues and cause trauma and transient inflammation when migrating through tissues, including erythema, dermatitis with papules and severe pruritus (condition commonly known as cutaneous larva migrans or creeping eruption). Lesions are commonly found in areas with high exposure to contaminated soils, and are often found between the toes or on the forearms, and sometimes on the bellies of resting animals. Migrating larvae only move a few millimeters each day, producing characteristic lesions until they leave the tissues or succumb to host immune responses (innate and acquired, including eosinophilia). Dermal lesions are usually transient and self-limiting, although several cases have reportedly lasted for over a year. Lesions in dogs are often worse in individuals sensitized by prior exposure, resulting in erythematous interdigital skin, pedal dermatitis, swollen and painful pads sometimes with hyperkeratosis and fissures in severe chronic cases. Cutaneous infections in humans are superficial and transient as the larvae are unable to penetrate deeper into dermal tissues and soon die. When adult worms develop in the small intestines, they feed on blood and intestinal mucosa using their large mouths and cutting plates to ingest, lacerate and digest plugs of tissue. Although they are reportedly not as voracious as other hookworms, taking 0.3 µl of blood per worm per day (cf. 100 µl for other hookworms), the blood loss is exacerbated when feeding worms detach and move to new feeding sites leaving behind haemorrhagic lesions. The cumulative blood loss can lead to erythropenia and the development of an acute normocytic normochromic anemia progressing to a hypochromic microcytic anaemia due to iron deficiency. Trauma to the small intestinal mucosa may lead to inflammation, villous atrophy and/or fusion, maldigestion, fluid and protein leakage leading to hypoproteinaemia (esp. hypoalbuminaemia), diarrhoea (often bloody with black tarry stools (melena)), dehydration and anorexia, all contributing to failure to thrive, reduced growth, weakness, lethargy, wasting, emaciation and sometimes death.

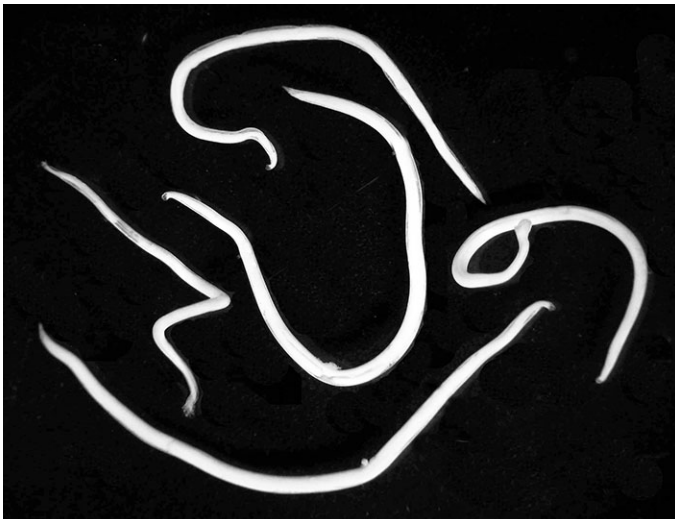
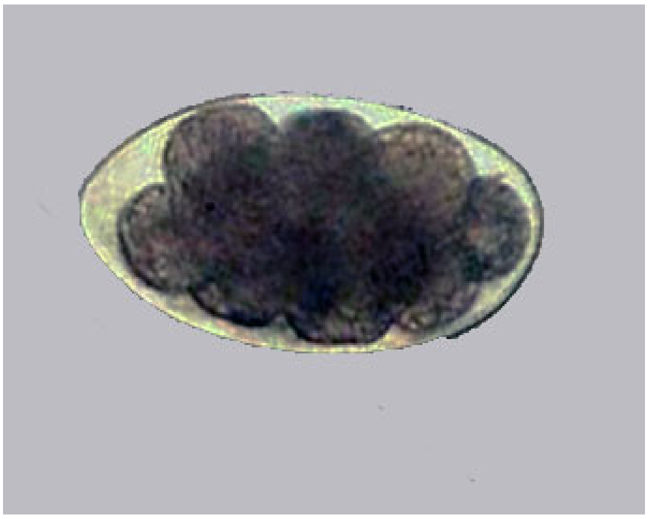
Developmental cycle and mode of transmission: These hookworms have direct monoxenous life-cycles involving the oral ingestion of larval stages from the environment (faecal-oral transmission), or more infrequently and less successfully, by penetration of infective larvae through the skin (percutaneous or transdermal transmission). Gravid females lay eggs (up to 3,000-5,000 per day) which are excreted with host faeces into the external environment. The eggs embryonate and hatch within several days under suitable climatic conditions, optimal in cool moist conditions although they can develop in colder conditions, but do not survive freezing. Hatched eggs release free-living rhabditiform larvae which feed and grow before moulting to L2 which also feed. These larvae then moult forming strongyliform L3 which have retained the L2 cuticle as a protective sheath and are unable to feed. Infective L3 may be formed in as little as 5-10 days and they are able to survive for several weeks in favorable conditions dispersing from faecal material into the surrounding soil and vegetation. In some species in seals, larval development from L1 to L3 has been reported to occur entirely within eggs before they hatch. Definitive hosts become infected mainly by the oral ingestion of infective L3, which exsheath in the gut and enter gastric glands in the pylorus of the stomach and the crypts and glands in the duodenal mucosal where they undergo histotrophic development (these larvae do not undertake pulmonary migration). The larvae usually emerge after several days to moult and mature as adults in the small intestines. The prepatent period (time from infection to first egg excretion) ranges from 13-21 days, and adult worms have been reported to live from 4 months to 2 years. The larvae of some species (including *U. stenocephala*) have also been reported to undergo developmental arrest (hypobiosis) emerging weeks to months later to resume development. The triggers for hypobiosis are not fully understood but have been associated with climatic changes (particularly sudden drops in temperature) and physiological changes in hosts (notably hormonal changes during pregnancy and lactation). However, there is no substantive evidence that transplacental and transmammary transmission occurs for these hookworm species. Infective L3 in the soil may penetrate host skin and they are well-documented as causes of dermatological lesions in a range of hosts. However, these percutaneous infections by *Uncinaria* spp. rarely mature, although a very small number of larvae are thought to complete pulmonary migration through the circulation to the lungs where they enter alveolar air-spaces and ascend the mucociliary escalator to the trachea to be swallowed and enter the gut. There have also been several reports of carnivores becoming infected by ingesting dormant L3 carried in small vertebrate prey animals (notably mice) which act as paratenic (transport) hosts. The majority of infections in dogs, however, have been associated with infective larvae on pastures used for training purposes, with peaks in seasonal abundance coinciding with the first rainfalls in autumn.

Differential diagnosis: While clinical signs may be highly suggestive of hookworm disease due to migrating larvae (dermatitis) or feeding adults (anaemia, diarrhoea), they are nonspecific and may be attributed to a variety of other conditions or infections. Most infections in dogs also have a history of poor husbandry with dogs housed on dirt runs or grassed areas and not provided with adequate worm control. The differential diagnosis of suspect dermatological cases may be aided by cytological examination of hair plucks and skin scrapings or biopsies, mostly to rule out other aetiological agents (bacteria, fungi, mites) as larvae are rarely found in eruptive tracts and histopathological examination is frequently non-specific (perivascular dermatitis containing eosinophils and neutrophils). Diagnosis is conventionally made by the microscopic detection of worm eggs in faecal samples, usually in concentrates following centrifugal floatation. However, the eggs are not sufficiently characteristic in morphology to discriminate between hookworm genera or from other strongyles, particularly the metastrongyles (lungworms). Recourse is sometimes made to the coproculture of faecal samples to harvest developing larvae, as the L1 of various genera vary in structure (those of *Uncinaria* having long buccal tubes (short in *Strongyloides*) and tapering tails without kinks or spines (kinked in *Filaroides*, kinked and spined in *Aelurostrongylus* and *Angiostrongylus*). Several immunoserological tests have been developed to detect specific host antibodies against hookworm antigens, but many demonstrated considerable cross-reactivity between hookworm genera. Modern molecular biological techniques have been used to characterize hookworm species following the polymerase chain reaction (PCR) amplification and restriction fragment length polymorphism (RFLP) analysis of nuclear genes (ribosomal DNA region spanning the first and second internal transcribed spacers (ITS1 and ITS2) plus the 5.8S gene).

Treatment and control: Infections by adult hookworms have been successfully treated with a range of anthelmintic drugs, including benzimidazoles (fenbendazole, albendazole, mebendazole), tetrahydropyrimidines (pyrantel), isoquinolines (praziquantel), macrocyclic lactones (ivermectin, moxidectin), chloronicotinyles (imidacloprid), substituted isothiocyanates (nitroscanate), diethylenediamines (piperazine), imidazothiazoles (levamisole), and depsipeptides (emodepside) with or without the symmetric triazines (toltrazuril). Cutaneous infections by migrating larvae are usually self-limiting but they have responded well to treatment with albendazole or ivermectin. When treating heavy infections with significant anaemia, supportive therapy may be required in the form of fluid/electrolyte replacement, and dietary supplementation (esp. protein and iron). It is often recommended that puppies and kittens be treated before and after weaning, and that dogs be dewormed on a regular basis as they may be quickly re-infected when returned to contaminated surroundings. A variety of management practices have been used to limit the transmission of infections, primarily through improved sanitation (regular removal of faeces), good hygiene (disinfection of holding pens/cages, provision of clean food, water and bedding), and sensible husbandry (avoid overcrowding, separate cohorts, keep facilities dry, and restrict access to earthen and/or grassy runs). The use of stringent chemicals to disinfect contaminated soils had variable success and no appeal due to concerns over toxic residues and environmental pollution. Preliminary studies on vaccine development have reported restricted adult development and reduced egg counts in dogs given irradiated larvae.



Uncinaria
intestines
(dermatitis, enteritis,
anaemia, diarrhoea)
Definitive Hosts
(carnivores)
head
some hypobiosis
adult female
(~ 15 mm)
L3 ingested
or
penetrate
skin
eggs
excreted
in faeces
adult male
(~ 9 mm)
male tail
filariform third-
stage larvae (L3)
(~ 500 µm)
external
environment
eggs
(~ 80 µm)
rhabditiform first- and
second-stage larvae
(L1, L2) (~ 400 µm)
geo-helminth
(soil transmission)

 *Uncinaria* adult worms	 *Uncinaria* worm egg
 *Uncinaria* adult worm, female tail	 *Uncinaria* adult worm, head