Muellerius
(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 lungworms with small buccal capsules and reduced male bursae. Adult worms are found mostly in the lungs of their hosts, although some inhabit the pulmonary artery, meninges or connective tissues. Five main groups occur: dictyocaulids in ruminants and horses; metastrongyles in pigs; protostrongyles in ruminants; angiostrongyles in carnivores and rodents; and filaroids in dogs. Protostrongyles have indirect life-cycles involving the development of L3 in invertebrate intermediate hosts. Adult *Muellerius* in the lungs release L1 which are swallowed and passed in faeces. L1 then penetrate the foot of a snail or slug and develop to L3. When eaten by ruminants, larvae penetrate to the mesenteric lymph nodes and moult to L4 which then migrate via the lymphatic-vascular systems to form adults in the lungs. Infections by *Muellerius* cause mild respiratory signs in sheep and goats worldwide.

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:	Protostrongylidae (infection of ruminants by ingestion of earthworm/molluscan IH carrying L3)
Genus:	*Muellerius* (parasitic in lungs of sheep/goats)
Species:	*M. capillaris* species causes mild respiratory signs in sheep and goats

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 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.

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**
Metastrongylina (lungworms)				
Protostrongylidae (lungworms)	small buccal capsule, bursa with large lobes, gubernaculum	artiodactyls	ingestion of IH carrying L3	17
Metastrongylidae (lungworms)	small buccal capsule, 2 trilobed lips, bursa with reduced dorsal lobe	Suids	ingestion of IH carrying L3	1
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
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
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

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

Lungworms are characterised mostly by their unique location within the respiratory systems of their mammalian hosts, although some species also infect cardiovascular, nervous or intermuscular connective tissues. Adult worms have a small buccal capsule, often reduced to an annulus, and sometimes possessing lips. Male worms have a caudal bursa that is variable in structure (often with reduced lobes and/or rays), spicules and a gubernaculum and telamon that are often not highly developed. Female worms have a median or posterior vulva, sometimes with a sphincter, and they are oviparous (releasing eggs) or ovoviviparous (releasing larvae). Many species have direct cycles involving the ingestion of infective larvae, while others have indirect cycles involving the ingestion of larvae in invertebrate intermediate hosts, and sometimes paratenic hosts. Eight metastrongyline families are recognised: Metastrongylidae (mouth with 2 large lateral trilobed lips, bursa with large lateral lobes and reduced dorsal lobe, oviparous, indirect cycle, earthworms used as intermediate hosts, 1 genus in lungs of suids); Angiostrongylidae (mouth with or without lips, bursa well-developed, oviparous, ovoviviparous, indirect cycle, gastropods used as intermediate hosts, 28 genera in respiratory and vascular systems of marsupials, rodents, insectivores, lemurs, mustelids, viverrids, felids and canids); Dictyocaulidae (mouth small, bursa with large lateral lobes and large dorsal lobe (divided to base), ovoviviparous, direct cycle, 2 genera in airways of ruminants and horses); Filaroididae (mouth small, bursa absent or reduced (rays reduced to papillae), ovoviviparous, direct cycle, 4 genera in respiratory system of canids, mustelids, pinnipeds, primates, and marsupials); Protostrongylidae (mouth small, bursa with large lateral lobes and prominent dorsal lobe, highly developed gubernaculum and telamon, oviparous, indirect cycle, molluscs used as intermediate hosts, 17 genera in lungs of ruminants, felids, canids, leporids, and skeletal muscles and central nervous system of cervids); Pseudaliidae (mouth small, bursa reduced (rays fused but not reduced to papillae), ovoviviparous, direct cycle, 7 genera in respiratory, auditory, circulatory systems of delphinids, phocoenids, monodontids and mongoose); Skrjabingylidae (mouth small, bursa modified to form lateral fleshy lobes, ovoviviparous, direct cycle, 1 genus in nasal cavities of mustelids); and Crenosomatidae (mouth small, bursa with large lateral lobes and large dorsal lobe (not divided to base), ovoviviparous, direct cycle, 5 genera in respiratory system of canids, felids, pinnipeds, soricids and marsupials). Several protostrongylid genera of significance to livestock production are compared below:

Genus	No. spp.	Definitive Hosts	Location	Adult worms	Worm larvae
Protostrongylidae					
Muellerius (lungworm)	4	artiodactyls	respiratory tract	10-30 mm long, small buccal capsule, indirect cycle, eggs laid in lungs, swallowed, voided, L3 develop in snail IH	230-340 µm, dorsal spine, tail kink
Protostrongylus (lungworm)	27	artiodactyls, lagomorphs	respiratory tract	13-80 mm long, small buccal capsule, 6 lip-like elevations, indirect cycle, eggs laid in lungs swallowed, voided, L3 develop in snail IH	250-400 µm, fine striations
Parelaphostrongylus (meningeal worm, brain worm)	3	artiodactyls	brain, lung	17-90 mm long, small buccal capsule, indirect cycle, eggs laid in meninges travel via blood to lungs, swallowed, L1 voided, L3 develop in snail IH	300-380 µm, dorsal spine
Elaphostrongylus (brain worm)	3	artiodactyls	muscles, brain, lung	26-70 mm long, small buccal capsule, indirect cycle, eggs laid in tissues travel to lungs via blood, swallowed, L1 voided, L3 develop in snail IH	288-490 µm, dorsal spine

The family Protostrongylidae contains 17 genera: *Cystocaulus, Dukerostrongylus, Elaphostrongylus* (syn. *Protostrongyloides*)*, Imparispiculus, Mariostrongylus, Muellerius, Neostrongylus, Orthostrongylus, Paraelaphostrongylus* (syn. *Odocoileostrongylus, Neurofilaria*)*, Pneumocaulus, Pneumostrongylus, Protostrongylus* (syn. *Gelanocaulus, Synthetocaulus*)*, Pulmostrongylus, Skrjabinocaulus, Spiculocaulus, Umingmakstrongylus,* and *Varestrongylus.* Early works placed some of these genera into separate subfamilies (Elaphostrongylinae, Muelleriinae, Neostrongylinae, Protostrongylinae, Skrjabincaulinae, and Varestrongylinae) but recent molecular studies failed to support them, indicating that several may be monophyletic. Clearly, further work needs to be conducted to differentiate protostrongylid species, genera and subfamilies. The genus *Muellerius* contains lungworms whose males have a reduced bursa with short ventral and lateral rays but a highly-developed dorsal ray (often trifid), telamon with basal and transverse plates, gubernaculum with 2 plates, split spicules, and L1 with a dorsal spine on the tail. Four species have been described around the world in the airways of sheep, mouflon, goats and chamois. The species *M. capillaris* is widespread in ruminants and is transmitted by infective larvae developing in gastropod intermediate hosts (snails and slugs).

***Muellerius* species**	**Definitive hosts**	**Location [Clinical signs]**	**Intermediate hosts**	**Distribution**
M. capillaris (syn. *Synthetocaulus*) (nodular lungworm, hair lungworm)	Artiodactyla: bovid (sheep, argali, mouflon, Cyprus mouflon, chamois, Tatra chamois, goat, wild goat, alpine ibex, Nubian ibex, Iberian ibex), cervid (roe deer, red deer, chital deer, moose)	lung [sporadic coughing]	Gastropoda: agriolimacid (*Agriolimax agrestis, reticulatus, Deroceras reticulatum*), ariophantid (*Macrochlamys*), arionid (*Arion subfuscus, hortensis, circumscriptus, empericorum* (= *ater*)), camaenid (*Fructicola hispida*), clausilid (*Bulgarica fritilaria*), enid (*Chondrula microtraga*, *Zebrina detrita*), geomitrid (*Candidula interecta*, *Cernuella arigonis*, *cespitum*, *virgata*, *Cochlicella barbara*, *Ponentina*, *Trochoidea seetzenii*), helicid (*Arianta arbustorum*, *Cepaea hortensis, nemoralis*, *vindobonensis*, *Helix aspersa*, *pomatia*, *Theba pisana*), hygromiid (*Euomphalia brigantina*, *Helicella bierzona*, *corderoi*, *itala*, *jamuzensis*, *madritensis*, *obvia*, *ordunensis*, *valdeona*, *zaratei*, *Monacha cartusiana*, *umbrosa, Perforatella incarnata*), limacid (*Limax cinereus* (= *maximus*), *flavus*), lymnaeid (*Lymnaea trunculata*), planorbid (*Planorbis*), polygyrid (*Polygyra*), succineid (*Succinea putris, pfeifferi*), trissexodontid (*Oestophora barbula*), urocyclid (*Atoxon pallens*)	worldwide

M. indicus	Sauria: agamid (Oriental garden lizard)			Asia
M. minutissimus	Artiodactyla: bovid (sheep, goat)			
M. tenuispiculatus	Artiodactyla: bovid (chamois, Tatra chamois)		Gastropoda: helicid (*Cepaea vindobonensis*), succineid (*Succinea putris*)	Europe

Parasite morphology: *Muellerius* spp. form 3 different types of morphological stages during their development: namely, eggs, larvae (4 successive stages encoded L1-L4), and adult worms. The eggs are thin-shelled ovoid stages measuring 60-80 x 40-50 μm and they are partially embryonated (containing a multicellular morula) when deposited in host tissues where they hatch. Freed L1 are elongate typically measuring 230-340 μm although some may range up to 400 μm long. They have round heads with well-developed lateral alae, a long flask-shaped oesophagus (extending 33-50% body length), and an S-shaped kinked tail with a small dorsal spine adjacent to the tip (dorsal-spined L1 are characteristic of non-protostrongylines). L2 are similar in morphology but are somewhat larger (500-540 μm) and do not have a conspicuous kinked tail. L3 are even larger (600-630 μm) and have truncated heads, an elongate tubular oesophagus and a tapering tail. L4 are transient parasitic stages that have begun to show adult characteristics, particularly in head structures and developing genitalia (male bursa and female vulva). Adults appear as red-grey slender hair-like worms 10-30 mm long with ridged cuticles (synlophe present), simple mouths, small buccal capsules, stout oesophagi and intestines terminating in a subterminal anus/cloaca. Mature worms are sexually dimorphic, with males being smaller than females (10-23 cf. 18-30 mm). Males have a spirally coiled tail with a small reduced copulatory bursa folded inwards. The bursa comprises 2 lateral lobes (each with 6 short ventral and lateral rays) and a prominent dorsal lobe (with a highly-developed dorsal ray, often trifid). Males also have a highly developed gubernaculum (with 2 sclerotized rods or plates) and a telamon (with basal and transverse plates) and 2 spicules (120-170 μm long) each split into a proximal alate section with 2 distal serrated arms. Mature female worms are didelphic with 2 ovaries and uteri connecting to a common vulva located posteriorly. Gravid females are oviparous and lay partly embryonated eggs in host tissues.

Site of infection: Adult worms are tightly coiled in the pulmonary parenchyma, alveoli and small air passages (bronchioles, bronchioli) of the lungs of their vertebrate definitive hosts (herbivores), sometimes extending into subpleural tissue. Infective larvae develop in the tissues of their invertebrate intermediate hosts (gastropods).

Pathogenesis: Most infections remain asymptomatic, and clinical respiratory signs (dyspnoea, cough, bronchopneumonia) rarely develop even in heavy infections. However, lungworm infections do damage the lungs and predispose hosts to secondary bacterial infections which may also cause pneumonia. Pathogenicity depends largely on host susceptibility (greater in young animals of permissive species, and moderated by levels of innate resistance and acquired immunity), the intensity of infection (numbers of parasites) and the stage of infection (prepatent or patent periods). Early larval stages migrating through the lungs during prepatency cause transient traumatic damage, while patent infections by adult worms may cause chronic disease with nodule formation. Worms living in the small airspaces (alveoli) and airways (bronchioles) cause local inflammation with epithelial desquamation, leucocyte infiltrations, fibrous reactions and exudates contributing to diffuse congestion with airway occlusion, bronchitis, peribronchitis, atelectasis, emphysema, and nodular pneumonia with small firm spherical gray nodules developing usually on the lung surface. The nodules are necrotic granulomatous masses filled with live and degenerating parasites, leucocytes and pulmonary tissue surrounded by fibrous connective tissue and occasional giant cells. They are usually small (2-4 mm diameter) but some may grow larger (up to 20 mm) and begin to calcify. Although emphysemic nodules may be extensive, pneumonic signs are rarely observed, but may include chronic bronchopneumonia with sporadic coughing, lethargy, and weight loss (similar to dictyocaulosis but not as severe). Infections in sheep are usually benign as the parasites are rapidly killed by host immune responses and encapsulated, but without the acquisition of any strong protective immunity so infections accumulate with the age of the sheep. Heavier infections develop in goats apparently due to their broader foraging behaviours, and the infections are more severe due to their poorer immune responses allowing the parasites to cause greater damage over time.

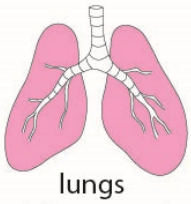
Developmental cycle and mode of transmission: *Muellerius* spp. have indirect heteroxenous life-cycles involving transmission to obligate molluscan intermediate hosts in which infective L3 develop. Gravid female worms lay eggs inside the lung nodules where they complete embryonation and hatch releasing L1. These larvae escape from the nodules and ascend the respiratory tract via the mucociliary escalator to the trachea where they are swallowed and excreted with host faeces. L1 are relatively resistant to desiccation and may survive for months in faecal pellets. They are most active at temperatures ranging from 17-27°C and are not killed by cold conditions, including freezing. L1 are then eaten or penetrate the foot of gastropods (snails and slugs) which act as intermediate hosts supporting the development of infective L3 over 12-21 days. Infective L3 have been found to live as long as their gastropod hosts (several years) and even remain viable for up to 1 week after their death. Herbivorous definitive hosts are infected when they consume infected gastropods on contaminated pastures. Ingested L3 invade the intestinal walls and migrate to the mesenteric lymph nodes where they moult to L4 before moving to the lungs via the lymph and/or blood. The larvae infect

pulmonary tissues and moult to young adults (sometimes referred to as L5) which subsequently mature in developing nodules. The prepatent period (time from infection to first excretion of L1) ranges from 6-10 weeks, and adult worms may persist in nodules for up to 2 years. The larvae of some species have been found in the liver and lungs of foetuses and newborn lambs, suggesting that transplacental transmission has occurred, but infections are rarely found in animals younger than 6 months. Infections are very prevalent in sheep in temperate regions, especially those with winter rainfall or cool mountainous regions supporting dense gastropod populations on pastures.

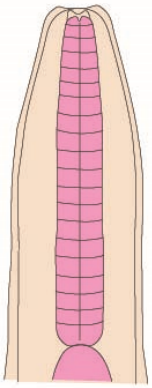
Differential diagnosis: Few infections cause clinical disease, but even then, diagnosis is not easy as symptoms and signs are non-specific and may be caused by other respiratory ailments, including dictyocaulosis, strongyloidosis, pulmonary hydatosis, and viral or bacterial bronchopneumonia. Infections are generally diagnosed by the microscopic detection of L1 in faecal samples, usually following their harvest by Baermann filtration. The L1 can be differentiated from those of *Dictyocaulus* by the absence of an anterior protoplasmic knob, and from some protostrongyles by the presence of a kinked tail and dorsal spine. Infections may be diagnosed at post-mortem by the detection of characteristic grey 'lead-shot' nodules on the lungs, but the recovery of intact worms is difficult as they are tightly coiled within nodules and many nodules may be pustular or calcified. Molecular biological techniques have been used to determine parasite phylogenetic relationships by the polymerase chain reaction (PCR) amplification of nuclear or mitochondrial genes (internal transcribed spacer 2 of ribosomal RNA and cytochrome c oxidase subunit I, respectively).

Treatment and control: Infections in livestock have been successfully treated using a range of anthelmintic drugs, including benzimidazoles (laxabendazole, albendazole, oxfendazole, fenbendazole, flubendazole), imidazothiazoles (levamisole) and macrocyclic lactones (abamectin, moxidectin, eprinomectin, ivermectin). No drench resistance has yet been reported, but some infections required higher doses and/or repeat treatments. Supportive therapy with anti-inflammatories or antibiotics may also be required to lessen complications due to initial adverse inflammatory reactions to dead parasites or secondary bacterial infections in damaged lungs. Various preventive strategies should also be introduced to reduce transmission rates, by improving sanitation (faecal removal, cleaning pens), maintaining hygiene (clean water, food troughs for supplementary feed), restricting gastropod populations (draining wet pastures, applying molluscicides), grazing management (quarantining new livestock, reducing stocking rates, separating cohorts) and pasture management (rotational and/or mixed grazing, cultivating or spelling pastures).

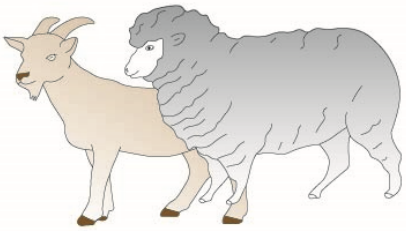
Muellerius



lungs
(nodules, sometimes
bronchopneumonia)

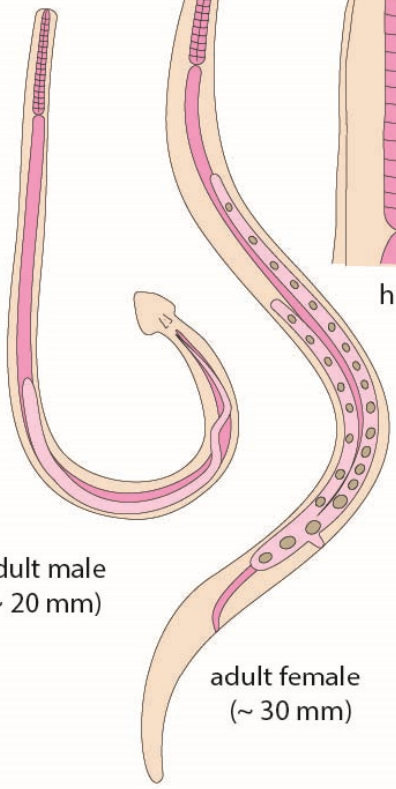


head



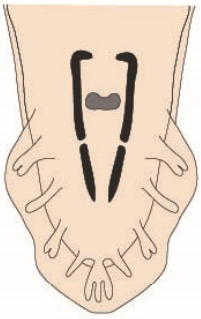
Definitive Hosts
(artiodactyls)

rarely vertical
transmission



adult male
(~ 20 mm)

adult female
(~ 30 mm)



male tail

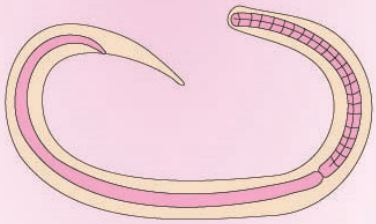
IH/L3
ingested

L1
excreted
in faeces

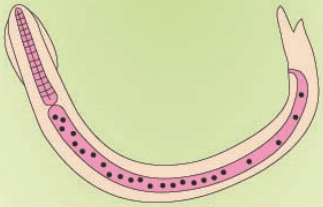
eggs hatch in host

IH

external
environment



third-stage larvae (L3)
(~ 600 µm)



first-stage larvae (L1)
(~ 300 µm)

Intermediate Hosts
(mainly helicid snails)
(internal tissues/sinuses)

L1 ingested
or penetrate
snail

Muellerius lung lesion

Muellerius larva