

Metastrongylus
(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 spirurids, 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. Metastrongyles have indirect life-cycles involving the development of L3 in invertebrate intermediate hosts. Adult *Metastrongylus* in the lungs lay eggs which are swallowed and passed in faeces. The eggs hatch and emergent L1 are ingested by earthworms where they develop to infective L3. When eaten by pigs, larvae penetrate to mesenteric lymph nodes and moult to L4 which then migrate via the lymphatic-vascular systems to form adults in the lungs. *Metastrongylus* spp. cause respiratory signs in pigs 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, 3 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: Metastrongylidae (infection of pigs by ingestion of earthworm/molluscan IH carrying L3)
Genus: *Metastrongylus* (parasitic in lungs of pigs, earthworm IH)
Species: various species cause respiratory signs in pigs

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)]
<i>Incertae sedis</i> 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 clasp 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)				
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
Dictyocaulidae (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 <i>per os</i>)	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); Skjrjabyngylidae (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).

Genus	No. spp.	Definitive Hosts	Location	Adult worms	Worm eggs
Metastrongylidae					
<i>Metastrongylus</i> (lungworms)	8	artiodactyls	respiratory tract	10-60 mm long, small buccal capsule, 2 trilobed lips, reduced male bursa, indirect cycle, eggs laid in lungs swallowed, voided, L3 develop in invertebrate IH	41-61 x 26-43 µm, ovoid, thick-shelled

The family Metastrongylidae is monotypic containing a single genus (*Metastrongylus*) characterised by large lungworms with 2 large lateral trilobed labia, thick-shelled sculptured eggs, an atypical bursa, earthworm intermediate hosts and predominantly suid definitive hosts. Some 8 species have been described in domestic, wild and feral swine around the world, many in association with respiratory disease typified as verminous bronchitis. Clinical infections by *M. apri* and *M. salmi* have occasionally been observed in humans.

<i>Metastrongylus</i> species	Definitive Hosts	Location [Clinical signs]	Intermediate Hosts	Distribution
<i>M. apri</i> (syn. <i>M. elongatus</i>) (pig lungworm)	Artiodactyla: suid (pig, wild boar, central European boar, Japanese boar), bovid (cattle, sheep, goat), cervid (deer); Carnivora: canid (dog); Primates: hominid (human)	bronchi [coughing, dyspnoea, nasal discharge]	Clitellata: lumbricid (<i>Allolobophora calliginosa</i> , <i>Aporrectodea</i> , <i>Bumastus</i> , <i>Dendrobaena rubida</i> , <i>Eisenia austriaca</i> , <i>Helodrilus caliginosus</i> , <i>foetidus</i> , <i>Lumbriculus variegatus</i> , <i>Lumbricus rubellus</i> , <i>terrestris</i>), megascolecid (<i>Diplocardia</i>)	worldwide
<i>M. asymmetricus</i>	Artiodactyla: suid (wild boar, Japanese boar)	Bronchi		Eurasia
<i>M. confusus</i>	Artiodactyla: suid (wild boar)	Bronchi		
<i>M. madagascariensis</i>	Artiodactyla: suid (pig)	Bronchi		Africa
<i>M. pudendodectus</i> (syn. <i>M. brevivaginatus</i>)	Artiodactyla: suid (pig, wild boar, central European boar, Sardinian wild boar, Japanese boar)	bronchi [coughing, dyspnoea, nasal discharge]	Clitellata: lumbricid (<i>Lumbricus rubellus</i> , <i>terrestris</i>)	worldwide
<i>M. pulmonalis</i>	Artiodactyla: suid (central European boar)	Bronchi		Europe
<i>M. salmi</i>	Artiodactyla: suid (pig, wild boar, Japanese boar), tayassuid (white-lipped peccary); Primates: hominid (human)	bronchi [coughing, dyspnoea, nasal discharge]	Clitellata: lumbricid (<i>Eisenia phoetida</i>)	Africa, Asia, Americas
<i>M. tschiauricus</i>	Artiodactyla: suid (wild boar)	Bronchi		Russia

Parasite morphology: *Metastrongylus* spp. form 3 different types of morphological stages during their developmental cycles: eggs; larvae (4 successive stages designated L1-L4); and adult worms. The eggs are grey-brown in colour, ellipsoidal in shape measuring 41-61 by 26-43 μm , and are surrounded by unique thick sculptured shells (with a rough corrugated-wrinkled surface). When laid, they are embryonated and contain a fully developed larva. Free L1 are elongate stages measuring 275-350 μm , but they may grow to 400-540 μm before moulting. They have bullet-shaped heads, a rhabditiform (double-bulbed) oesophagus measuring 110-120 μm , numerous granular intestinal cells and a tail coiled ventrad. L2 are similar stages but are larger measuring 550-650 μm , and have conical truncated heads and tapering tails. L3 are often ensheathed in the L2 cuticle and they measure from 630-685 μm and have a truncated head with 2 characteristic indentations, a club-shaped oesophagus 150-170 μm long and a tapering tail with 2 deep notches near the tip. L4 are transient stout parasitic stages measuring 530-755 μm and have rounded heads, a club-shaped oesophagus 140-160 μm long, an attenuated tail terminating in a knob-like process, and are beginning to show sexual characteristics (notably a developing male bursa and female vulva). Adults are thin slender white worms measuring from 10-60 mm in length and are characterised by an anterior mouth bearing 2 large lateral tri-lobed lips. The cuticle bears longitudinal ridges (synlophe) and the worms have a small vestigial buccal capsule, a short club-shaped oesophagus, and relatively thick intestines terminating in a caudal cloaca in males and a posterior anus in females. Male worms are smaller than females (10-26 x 0.12-0.25 mm cf. 23-60 x 0.45 mm). Mature males have a distinctive copulatory bursa consisting of 2 large broad lateral lobes divided by deep terminal incision, and a highly reduced dorsal lobe. The lateral lobes are supported by an asymmetrical configuration of up to 5 irregular digitiform rays, and the dorsal lobe is supported by a single reduced dorsal ray with a terminal bifurcation. Males lack a gubernaculum but have a strongly developed genital cone and 2 very long thread-like spicules (400-600 μm) often protruding caudally from the body and ending in a hook (double hooks in *M. pudendotectus* and *M. asymmetricus*). Mature females are didelphic with 2 ovaries and uteri terminating in a posterior vulva usually with a prevulvar swelling. Females of most species also have a well-developed provagina (absent in *M. salmi* and *M. confusus*) and their tails are either straight ((e.g. *M. pudendotectus*) or curved ventrad (e.g. *M. apri*). They are oviparous and produce thick-walled eggs that are fully embryonated when laid.

Site of infection: Infective larvae migrate from the gut to the lungs of their porcine hosts, where adult worms develop to infect the bronchioles and small bronchi, particularly in the posterior lobes, although some species (e.g. *M. apri*) may also extend into the trachea. First-stage larvae contained in eggs or freshly hatched in host faeces are ingested by earthworms where they develop to infective L3 which become encapsulated in earthworm tissues.

Pathogenesis: Most infections appear benign and remain asymptomatic or subclinical in adult pigs which rapidly acquire a natural protective immunity (some animals may develop burdens of several hundred worms without apparent harm). However, young animals with immature immune systems are susceptible to clinical disease, the severity of which depends on parasite pathogenicity (some species are more virulent), host susceptibility (young pigs 4-8 months of age), and the intensity of infection (numbers of larvae and/or adults). Infections may produce respiratory disease during both the prepatent period when only larval stages are present and during patency when adults are feeding and laying eggs. Early larval stages migrating through the lungs may cause traumatic damage with micro-haemorrhages and inflammation resulting in pneumonitis, pulmonary consolidation, and respiratory signs (dyspnoea and developing cough). Adult worms then develop and feed on bronchial exudates, desquamated epithelial cells and mucus, provoking significant inflammation of the airways, all contributing to lumen occlusion, catarrhal bronchiolitis and bronchitis (also known as verminous bronchitis) with alveolar collapse (atelectasis), bronchopneumonia, and compensatory emphysematous areas surrounding lesions. Worm eggs may also be aspirated into smaller air passages and into the lung parenchyma exacerbating pulmonary consolidation and emphysema. Histopathological changes include bronchial and peri-bronchiole cellular infiltrations (esp. by eosinophils), epithelial hyperplasia and metaplasia with goblet cell formation, hypersecretion of mucus, emphysematous areas with alveolar enlargement, and the development of small dense grey miliary nodules containing degenerating parasites (eggs, larvae or adults). Respiratory disease usually develops chronically, rarely acutely, in young animals with persistent cough, initially dry (thumps) and subsequently productive, dyspnoea and sometimes tachypnoea, bronchial fremitus (palpable vibration) and sibilant rales (crackling) on auscultation, muco-purulent nasal discharge, loss of appetite and body condition with impaired growth and weight loss. Lungworm infections can precipitate or enhance other respiratory diseases, particularly those caused by secondary bacterial infections (e.g. purulent staphylococcal infections with congestion and pneumonia). There have also been several reports that lungworm larvae may also be able to transmit viral infections, such as swine influenza, Teschen disease and hog cholera. There have also been several rare reports of infections by *M. apri* and *M. salmi* causing pulmonary disease in human patients, characterised by progressive dyspnoea, chest pain, fatigue and the production of thick bloody sputum.

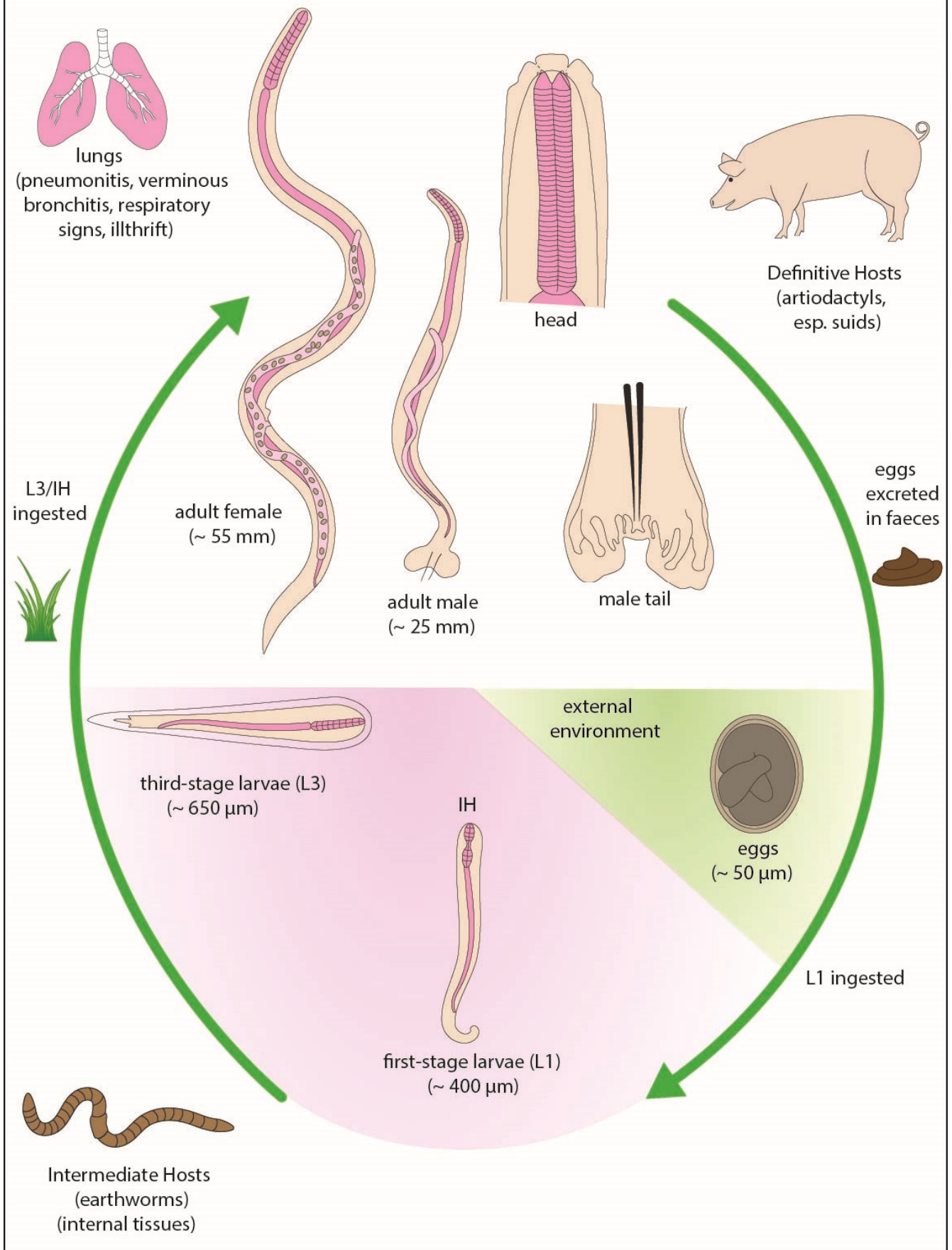
Developmental cycle and mode of transmission: These lungworm parasites have indirect heteroxenous life-cycles involving the development of infective larval stages in invertebrate intermediate hosts which are then consumed by vertebrate definitive hosts. Gravid female worms lay embryonated eggs in the airways which ascend the mucociliary escalator to the trachea to be swallowed and passed in host faeces. While the eggs have been shown to be tolerant of cold temperatures (surviving in manure for 6-8 months and in moist soils for 3-18 months), most eggs hatch almost immediately in humid conditions releasing L1 stages into the surrounding soil. Earthworms act as obligate intermediate hosts in which ingested eggs and/or larvae continue their development to infective L3 stages over 10-30 days. L1 penetrate the wall of the crop and invade the calciferous glands where they moult twice to form ensheathed L3. These larvae spread via the earthworm vascular system to numerous tissues and sinuses where they become

encapsulated within granulomas by fibrous host reactions. L3 have been shown to remain viable in earthworms for up to 7 years (most earthworms only live for 8-9 years) and infections may accumulate over time (up to 600 larvae have been recorded in some individuals). It has also been demonstrated that L3 may leave the bodies of dying or dead earthworms and are able to survive in moist soils for several months. Definitive hosts become infected when they consume infective L3 either in earthworms or free on pastures or water. Ingested L3 burrow through the gut wall and migrate to the mesenteric lymph nodes where they moult to L4 before moving via the thoracic duct or portal venous system to the heart and pulmonary arteries to reach the lungs. The L4 invade alveolar airspaces and moult to subadults (sometimes designated L5) which move upwards to the bronchioles and bronchi to mature into adult worms. The prepatent period (time from infection to first excretion of eggs) ranges according to species from 2-6 weeks, and adult worms are thought to live for 8-12 months.

Differential diagnosis: Clinical infections may be suspected on the basis of respiratory signs (dyspnoea and coughing) in young piglets with access to pastures, but other conditions may also cause similar signs (e.g. pulmonary ascariasis, strongyloidosis, bacterial or viral pneumonia). Infections are conventionally confirmed by the microscopic detection of worm eggs in faecal samples, usually following their concentration by floatation in saturated sugar or salt solutions with high specific gravities. However, eggs may be passed sporadically in low numbers and they are similar in appearance to thick-walled *Ascaris* eggs which embryonate in aged faecal material. Infections may be diagnosed at necropsy by the detection of adult worms in dissected bronchi, in bronchial exudates or by extrusion of material from incised lung lobes (esp. terminal diaphragmatic lobes). Molecular biological techniques have been used to characterize species and determine phylogenetic relationships following the polymerase chain reaction (PCR) amplification and sequencing of nuclear genes (notably internal transcribed spacer 2 (ITS2) of ribosomal RNA) and mitochondrial genes (esp. cytochrome c oxidase subunit 1 (cox1)).

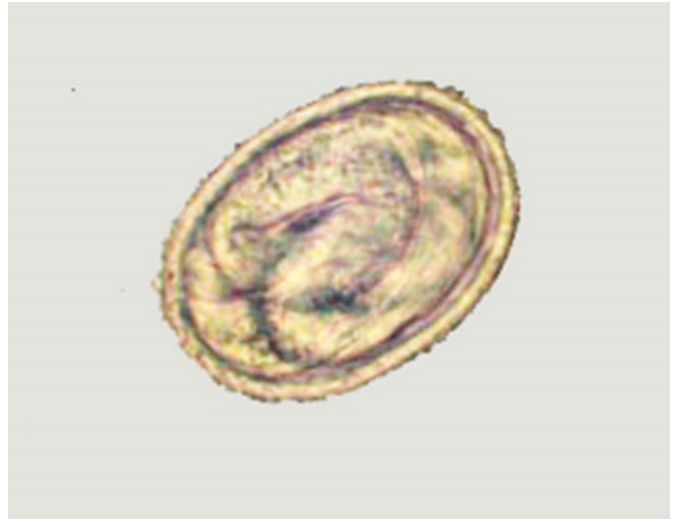
Treatment and control: Clinical infections in pigs have responded well to treatment with various anthelmintic drugs, including benzimidazoles (albendazole, fenbendazole, oxfendazole, flubendazole), imidazothiazoles (levamisole), and macrocyclic lactones (abamectin, doramectin, ivermectin, moxidectin) - the latter also being effective against migrating larvae. Human infections have also been treated successfully with ivermectin. However, treated animals may be rapidly re-infected unless various preventive measures are adopted, particularly on farms where pigs are outdoors and have access to soils containing earthworms. Infections are rarely a problem in intensive piggeries where indoor pens can be regularly cleaned and solid flooring prevents contact with soil. In extensive or semi-intensive systems using outdoor shelters and enclosures, attempts should be made to reduce environmental contamination by pig faeces (raised pens, better sanitation through drainage and/or effluent treatment) and to minimise the uptake of infective larvae in earthworms or soils (provide clean food and water, prevent foraging using barriers or nose rings, pasture rotation involving previously ungrazed areas). Little can be done to control infections in wild or feral pig populations which scavenge widely and tend to congregate around open water sources with moist soils. Epidemiological studies have found infections to be less prevalent in forested areas than open ranges, presumably due to the lower abundance of earthworms.

Metastrongylus





Metastrongylus adult worms



Metastrongylus worm egg



Metastrongylus adult worm, head