

Bunostomum

(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 stronglyloid 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, esp. humans and companion animals. 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. Larvae undergo pulmonary migration through the lungs (sometimes causing pneumonitis) before developing into blood-feeding adults in the small intestines. Some larvae may also undergo arrested development (hypobiosis) and vertical transmission may occur (transplacental and transmammary). *Bunostomum* spp. cause mild-severe hookworm disease (anaemia and diarrhoea) in cattle and sheep 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, Phasmeida) (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: *Bunostomum* (parasitic in small intestines of ruminants)
Species: various species cause anaemia/diarrhoea in cattle and sheep

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 IH)
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
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
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
Bunostominae						
<i>Bunostomum</i>	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
<i>Gaigeria</i>	1	artiodactyls	small intestines	10-45 mm long, buccal capsule with pair ventral cutting plates, elongate lancets and teeth, larval pulmonary migration	108-115 x 58-61 µm, ellipsoidal, thin-shelled	transdermal
<i>Necator</i>	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
Ancylostominae						
<i>Ancylostoma</i>	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
<i>Globocephalus</i>	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
<i>Uncinaria</i>	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

The subfamily Bunostominae contains 12 genera classified in 2 tribes: Bunostominae containing worms with anterodorsally directed heads with pronounced dorsal inclination, oral opening with well-developed cutting plates, no buccal collar, long oesophagus (*Bunostomum* (syn. *Bustomum*, *Monodontus*), *Bathmostomum*, *Bunostomoides*, *Brachyclonus*, *Cameronecator*, *Gaigeria*, *Grammocephalus*, *Monodontus*, *Necator*, *Rhinoceronema*) in elephants, rhinoceros, procyonids, ruminants, rodents, tayasuids, tapirs, and primates; and Acheilostominae containing worms with anterodorsally directed heads with slight dorsal inclination, oral opening with inconspicuous or no cutting plates, buccal collar, short oesophagus (*Acheilostoma*, *Tetragomphius*) in rodents, mustelids and procyonids. The genus *Bunostomum* comprises hookworms with globular buccal capsules with subventral lancets, large dorsal cones, males with asymmetrical dorsal rays and filiform spicules, and females with an anterior vulva. Nine species have been described from ruminants and elephants, most species being stenoxenous and found in a small range of related hosts. Infections by *Bunostomum* spp. occur worldwide, but with a patchy distribution favouring regions with warm moist climates more suitable for the development of exogenous stages in the environment. *B. phlebotomum* is a major enteric parasite of cattle (dairy and beef), while *B. trigonocephalum* mainly infects sheep and goats, although cross-infections can occur. Infections may cause severe disease involving anaemia, hypoproteinaemia and diarrhoea, even death. Infections in abnormal hosts (such as guinea pigs, mice and occasionally humans) usually lead to incomplete worm development, although migrating larvae may still cause transient cutaneous lesions (larval migrans).

<i>Bunostomum</i> species	Definitive hosts	Location [Clinical signs]	Distribution
<i>B. bhavanagarensis</i>	Artiodactyla: bovid (blackbuck)		Asia
<i>B. brevispiculum</i>	Proboscidea: elephantid (African elephant)		Africa
<i>B. cobbi</i> (syn. <i>B. dentatum</i>)	Artiodactyla: bovid (kafue lechwe, red lechwe, puku, waterbuck, common reedbuck)		Africa
<i>B. floridanus</i>	Rodentia: cricetid (hispid cotton rat)		Americas
<i>B. foliatum</i>	Proboscidea: elephantid (Indian elephant)		Asia
<i>B. hamatum</i>	Proboscidea: elephantid (African elephant)		Africa
<i>B. phlebotomum</i> (syn. <i>B. longecirratum</i> , <i>radiatum</i> , <i>Monodontus</i>) (cattle hookworm)	Artiodactyla: bovid (cattle, zebu, Bali cattle, water buffalo, yak, Indian yak, European bison, sheep, argali, blue wildebeest), cervid (roe deer, fallow deer, Reeve's muntjac, moose); Lagomorpha: leporid (Indian hare) [plus larval infections in Primates: hominid (human)]	small intestines [anaemia, occasionally oedema, diarrhoea, pruritus]	worldwide
<i>B. sangeri</i>	Proboscidea: elephantid (Asian elephant)		Asia
<i>B. trigonocephalum</i> (syn. <i>B. kashinathi</i> , <i>Monodontus</i>) (grassveld hookworm)	Artiodactyla: bovid (sheep, argali, goat, mouflon, chamois, Iberian ibex, cattle, zebu, European bison, impala, blackbuck, blue wildebeest, dorcas gazelle, Arabian oryx), cervid (fallow deer, red deer, roe deer, sambar deer, moose), camelid (camel); Carnivora: canid (dog); Rodentia: caviid (guinea pig), murid (mouse) [plus larval infections in Primates: hominid (human)]	small intestines [anaemia, occasionally oedema, diarrhoea]	worldwide

Parasite morphology: *Bunostomum* hookworms form 3 different stages in their developmental cycles: eggs; larvae (4 successive stages designated L1-L4); and adult worms (sexually dimorphic males and females). Eggs are asymmetrically oval-elliptical in shape (one side being somewhat flattened) measuring 79-117 x 40-70 µm. They are thin-shelled and contain a morula at the 4-8 cell (blastomere) stage of development when laid. L1 and L2 are free-living (preparasitic) stages with elongate tubular bodies, truncated heads, short buccal capsules with cutting plates, rhabditiform (double-bulbed) oesophagi, and hair-like tails. L1 measure from 360-500 µm in length, while L2 are slightly larger measuring from 360-600 µm in length. Infective L3 are larger still, measuring 450-700 µm in length, but they are ensheathed (encased in L2 cuticle) and have bullet-shaped heads, funnel-shaped buccal capsules, long stronglyliform oesophagi with a prominent caudal bulb, intestines comprising 16 cells, and sharply-tapering tails encased in short tail sheath extensions (58-115 µm) that are filamentous for the last 50% of their length. L4 are transient parasitic stages that are developing adult characteristics, particularly with respect to head structures and genitalia. Adult hookworms are stout white-grey worms 10-30 mm long with typically hooked heads and buccal capsules opening anterodorsally. The buccal capsule is large and subglobular, and contains 2 semilunar chitinous cutting plates on the anterior rim, and a large internal tooth-like dorsal cone that contains the duct of the oesophageal gland (in members of the sister subfamily, the ancylostomins, the duct is contained in an elongate dorsal groove). Dorsal teeth are absent but there are 1-2 pairs of small subventral lancets at the base of the buccal capsule. Adult male worms are smaller than females (10-17 mm cf. 16-30 mm) and are readily identified by their well-developed caudal bursa (copulatory clasping organ). The bursa consists of 2 lateral lobes supported by 6 rays formed by muscular elements following nerve channels to terminal papillae (with the externolateral rays arising at different levels from main stem, and the anterolateral rays diverging from other lateral rays) and a dorsal lobe supported by a long asymmetrical dorsal ray (with 4 or 6 terminal branches). Mature males do not possess a gubernaculum (present in the ancylostomins) but have 2 conspicuous spicules, both either short and twisted (e.g. *B. trigonocephalum*) or long and slender (e.g. *B. phlebotomum*). Mature females are didelphic with 2 ovaries and uteri connected to a common vulva located in the anterior half of the body (posterior half in ancylostomins), and their tails do not have a terminal spine (present in ancylostomins). Females are oviparous producing strongyle-type eggs which are passed into the gut lumen of their hosts.

Site of infection: Adult hookworms infect the mucosa of the small intestines, mainly the duodenum and anterior jejunum, while earlier larval stages migrate through host tissues to develop in the lungs (process called pulmonary or tracheal migration). Free-living parasitic larval stages are found developing in host faeces in the external environment.

Pathogenesis: Light infections are usually asymptomatic or subclinical, but heavier infections (involving 250 or more worms) may cause significant morbidity and even mortality in domestic animals. The severity of disease depends on a range of factors, including parasite pathogenicity (some species are more virulent), the intensity of infection (number of parasites), host susceptibility (young individuals of permissive species are most at risk), and the stage of infection (peracute, acute or chronic). Three types of disease may be caused during the course of infection: infective larvae penetrating the skin may cause transient cutaneous larval migrans; larvae migrating through the lungs may cause acute pneumonitis; and adult worms feeding in the small intestines may cause chronic manifestations, notably anaemia, enteritis, diarrhoea and illthrift. In normal (permissive) hosts (such as sheep and cattle), penetration

and migration of infective L3 through the skin occurs rapidly (within 45 minutes) and often does not produce significant lesions even though the larvae cause traumatic tissue damage and provoke inflammatory responses. However, in some individuals, particularly those sensitized by previous exposure, the larvae may cause dermatitis with pruritus, usually involving the limbs and provoking foot-stamping. In unusual or abnormal (non-permissive) hosts (including humans and laboratory rodents), the infective L3 may persist in the skin for longer periods leading to cutaneous larval migrans with local dermatitis with cellular infiltrates, oedema and hyperaemia. Larvae subsequently undergoing pulmonary migration in normal hosts often do not produce clinical signs, although they may cause small haemorrhages and pneumonitis when they penetrate into alveolar air-spaces. In contrast, larvae reaching the lungs in abnormal hosts generally do not complete their development but may persist longer causing acute local inflammation with cellular infiltrates, epithelial desquamation, and alveolar consolidation. The most common signs associated with infections, particularly in normal hosts, arise when subadult and adult worms attach to the small intestinal mucosa and feed on tissue plugs and blood using their large buccal capsules and cutting plates. Worms frequently detach to move to new feeding sites leaving behind punctate haemorrhagic lesions, with blood, fluid and protein loss contributing to anaemia (progressing to iron deficiency), oedema (ascites and submandibular bottle-jaw), and hypoproteinaemia (esp. hypoalbuminaemia). The mucosa becomes swollen and covered in mucus with villous atrophy and fusion leading to maldigestion, malabsorption, anorexia, cachexia, alternating diarrhoea (sometimes bloody) and constipation, weight loss, emaciation, collapse and even death. Previous infection has been shown to elicit some protective immunity, so older livestock may be refractory to re-infection although worms may be present asymptotically (concomitant immunity). More severe infections may also occur in stressed hosts experiencing poor nutrition, sometimes coupled with pregnancy.

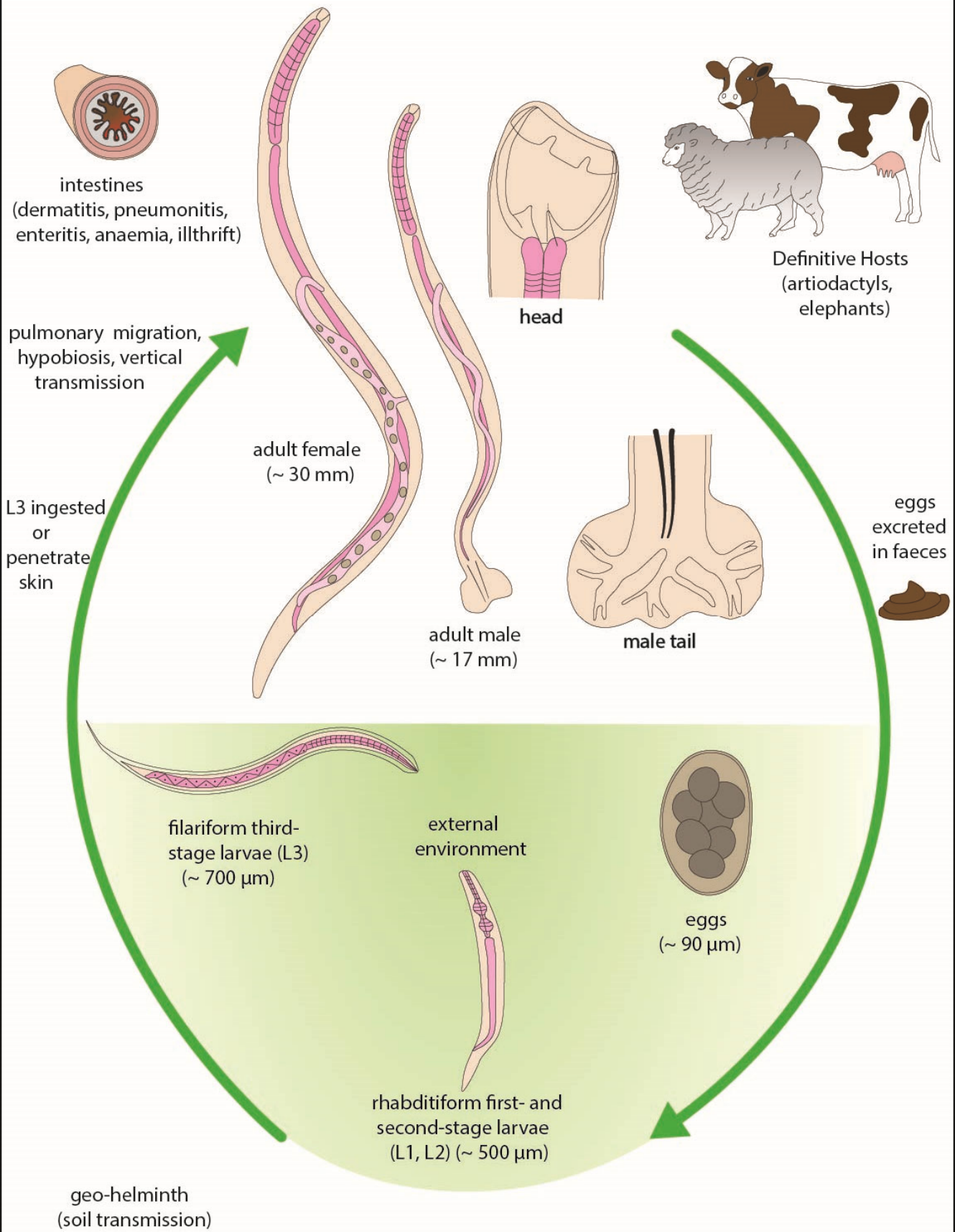
Developmental cycle and mode of transmission: These hookworms have direct monoxenous life-cycles, with hosts becoming infected by the oral ingestion or transdermal penetration of infective larvae contaminating the external environment. Gravid female worms lay eggs (up to 600-1,200/day depending on season) which are excreted with host faeces. The eggs embryonate and hatch releasing free-living (preparasitic) rhabditiform L1 which feed on bacteria in the faecal material. These larvae moult to form similar rhabditiform L2 which also feed on bacteria before they moult forming strongyliform L3 which are ensheathed (encased in L2 cuticle) and are unable to feed. The time taken for embryonation and larval development depends on prevailing environmental conditions, with L3 being formed after several days in warm moist conditions. Development takes longer in cooler conditions but the larvae are highly susceptible to desiccation and cold (< 10°C) conditions. Unlike other hookworms, *Bunostomum* L3 remain in faecal material (surviving for 5-14 days) and do not climb vegetation. Definitive hosts become infected mainly when infective L3 contact and penetrate the skin (percutaneous or transdermal transmission), although infections can sometimes occur when L3 are ingested (oral transmission). Ingested L3 exsheath in the gut and then undergo 2 moults (without any extra-intestinal migration) to form adults which mature and mate producing eggs after 7-10 weeks. However, L3 penetrating the skin undertake a pulmonary migration moving to the lungs via the circulation and possibly the lymphatics. Here, they invade the alveolar air-spaces and moult to L4 which ascend the mucociliary escalator to the trachea to be swallowed reaching the small intestines in 10-12 days. L4 moult to subadult stages (sometimes designated L5) which mature to adults that begin egg production 5-6 weeks after infection. Adult worms may survive in the intestines for 1-2 years. Aberrant migrating larvae are also thought to facilitate transmammary (transcolostral) infections in some hosts. Infections are more prevalent in temperate and subtropical regions supporting wet or habitually moist pastures, particularly in animals which regularly camp at particular sites over winter. Many infections also demonstrate seasonal transmission coincident with the first rains after the dry season (although desiccation during the dry reduces pasture larval survival, high worm burdens may develop in animals at the end of the dry, presumably due to maturation of hypobiotic larvae, with peak egg production occurring early in the rainy season).

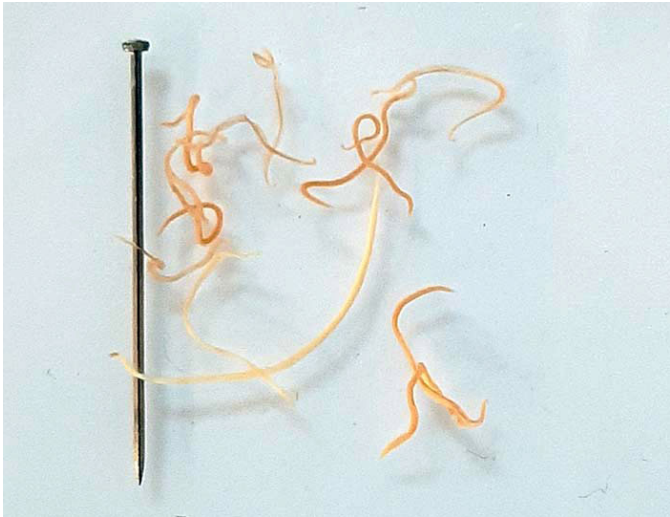
Differential diagnosis: Infections are rarely diagnosed on the basis of symptomatology as most clinical signs (anaemia, diarrhoea) are non-specific (not pathognomic) and may be attributable to other conditions (including fasciolosis in temperate regions and haemonchosis in tropical regions). Coprological examinations may be used to detect and quantitate worm eggs in faecal samples, usually following their concentration by sedimentation in water and floatation in saturated sugar or heavy metal salt solutions. However, faecal egg counts may fluctuate as egg production by female worms is irregular, and clinical disease may be present in some hosts when few eggs are being produced (especially for *B. trigonocephalum* infections). *Bunostomum* eggs are also similar in appearance to those of several trichostrongyles, but are more bluntly rounded than those of *Haemonchus*, and often have sticky eggshells with adherent debris. Faecal samples may be subject to coproculture for several days to harvest L3 which can tentatively be identified by their morphological characteristics (short ensheathed L3 with 16 intestinal cells and short filamentous tails). Adult worms may be detected and quantitated in post-mortem samples of the small intestinal mucosa. Total worm counts of 100-300 worms have been found to cause clinical disease in sheep, goats and cattle, and higher worm burdens have been associated with fatalities. Modern molecular biological techniques have been used to characterize parasite species, examine drug resistance and determine phylogenetic relationships following the polymerase chain reaction (PCR) amplification of nuclear gene sequences (internal transcribed spacers 1 and 2 of ribosomal RNA, beta-tubulin isotype 1) or mitochondrial genomes.

Treatment and control: Clinical infections have been treated effectively using several anthelmintic drugs, including benzimidazoles (albendazole, oxfendazole, fenbendazole, thiabendazole), macrocyclic lactones (ivermectin, doramectin, moxidectin, eprinomectin), imidazothiazoles (levamisole) and tetrahydropyrimidines (moxidectin). Cutaneous larval migrans in humans has often responded well to treatment with similar anthelmintics, and some success has been reported freezing superficial

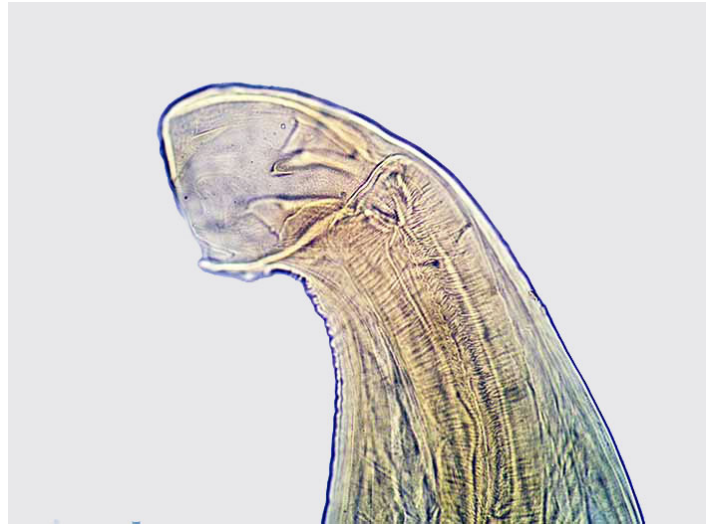
skin lesions with ethylene chloride to kill migrating larvae. Regrettably, most anthelmintics do not have any persistent residual activity, so hosts may be rapidly re-infected when returned to contaminated environments. In veterinary medicine, it has become standard practice to immediately move treated livestock to clean (ungrazed or spelled) pastures, and/or to repeat treatments at regular intervals. Young animals are usually treated before and after weaning, and dietary supplementation should be considered when levels of nutrition are poor (disease is worse in malnourished hosts). To avoid the emergence of drug resistance in parasite populations, it is recommended that strategic dosing be employed on a needs basis, and that drug classes be rotated on a cyclic basis. Various management strategies can be introduced at the farm level to reduce transmission rates by limiting environmental contamination by worm eggs and larvae, either through improved sanitation and hygiene (regularly clean pens, remove faeces particularly from feeding and resting areas, provide dry bedding), stock management (separate cohorts, cyclic or rotational grazing, mixed grazing, avoid overstocking, quarantine new livestock) and pasture management (drain wet pastures, compact soil around water troughs or salt liberally, and spell pastures over hot dry periods).

Bunostomum

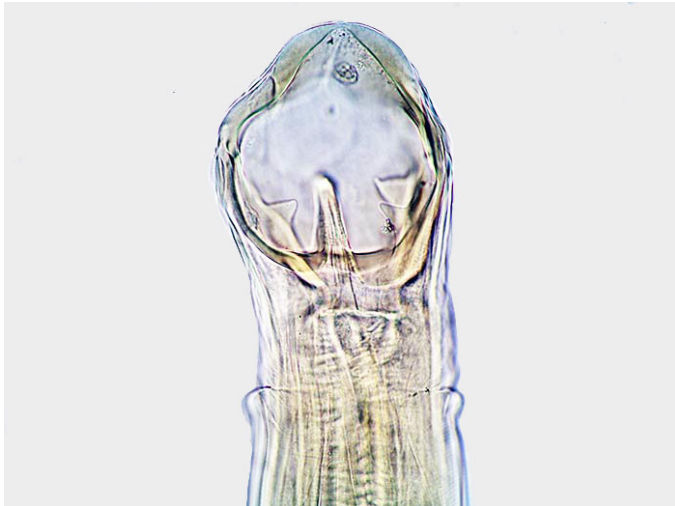




Bunostomum adult worms



Bunostomum adult worm, head, lateral



Bunostomum adult worm, head, ventral