

Necator

(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. 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 (some species causing cutaneous larval migrans). Larvae undergo pulmonary migration through the lungs (sometimes causing pneumonitis) before developing into blood-feeding adults in the small intestines. Infections by *Necator* cause New World hookworm disease in humans, characterised by iron-deficiency anaemia and growth retardation in children.

Classification:

Domain: Eukaryota (membrane-bound nucleus)
Supergroup: Amorphea (unikonts with single flagellum, or nonflagellated amoebae)
Kingdom: Metazoa (multicellular eukaryotes, heterotrophs, notably animals)
Group: Protostomia (triploblastic, spiral cleavage)
Subgroup: Ecdysozoa (cuticle moulted = ecdysis)
Phylum: Nematoda (unsegmented, pseudocoelomate roundworms, tubular digestive tract, dioecious)
Class: Chromadorea (spiral amphids, three oesophageal glands, usually annulated bodies, free-living and parasitic)
Order: Rhabditida (Secernentea, Phasmidea) (secretors, with phasmids, bipartite oesophagus, single testis)
Suborder: Rhabditina (free-living or parasitic in invertebrates/lower vertebrates)
Infraorder: Rhabditomorpha ('rod-shaped' buccal cavity)
Superfamily: Strongyloidea (bursate males, prominent buccal capsules, parasites of mammals, birds, reptiles)
Family: Ancylostomatidae (hookworms, buccal capsule bent dorsally, armed with teeth/cutting plates)
Genus: *Necator* (parasitic in small intestines of humans/pigs)
Species: *N. americanus* (causes New World hookworm disease in humans)

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 clasping organ. Many classification schemes group these 'bursate' nematodes into one or more superfamilies in the order Strongylida (with suborders containing the strongyles, trichostrongyles, hookworms and lungworms), although the families essentially remain the same. Many families are recognised on the basis of parasite morphology, biology, life-cycle, host specificity and tissue tropism; including the following which contain many notorious parasites of vertebrates.

Representative Strongyloidea (cf. Strongylida) [with bursate males]				
Family	Characters	Definitive Hosts	Transmission*	No. genera
Ancylostomatina (hookworms)				
Ancylostomatidae (hookworms)	large buccal capsule bent dorsally, armed with teeth/cutting plates	primates, carnivores, artiodactyls	transdermal penetration of L3 (sometimes <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>Necator</i>	7	primates, artiodactyls	small intestines	7-11 mm long, buccal capsule with cutting plates, larval pulmonary migration	55-77 x 35-42 μ m, ovoid, thin-shelled	oral, transdermal
<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 μ m, ovoid, thin-shelled	oral, transdermal, transplacental, transmammmary
<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 μ m, ellipsoidal, thin-shelled	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 μ m, ellipsoidal, thin-shelled	oral, transdermal, transplacental, transmammmary
<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 μ m, 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 μ m, 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 *Necator* comprises hookworms whose buccal capsules contain 2 pairs of cutting plates (subdorsal plates flanking the dorsal cone), females with elongate vestibula in the ovejector, and males with short dorsal rays and deep median fissures in the bursa. Some 7 species that have been described from a small range of mammals from several continents, notably the Americas and Africa. The species *N. americanus* is colloquially called the New World human hookworm, although it probably came to the Americas from Africa with the slave trade. Infections are commonly found in tropical and subtropical regions because the larvae cannot develop below 22°C. They are frequently found in rural areas with high annual rainfall and shaded sandy or loam soils ideal for larval development (not clay or gravel). It is estimated that around 900 million people are infected with hookworms (*Necator* and *Ancylostoma*) worldwide, with 1.6 million suffering from anaemia and 55,000 deaths annually.

<i>Necator</i> species	Oral structures	Hosts	Clinical signs	Geographic distribution
<i>N. americanus</i> (syn. <i>Uncinaria americana</i>) [New World human hookworm]	2 pairs cutting plates (dorsal and ventral)	Primates: hominid (human, chimpanzee, lowland gorilla), cercopithecoid (rhesus macaque, patas monkey, sooty mangabey, Campbells' mona monkey, king colobus, western red colobus, yellow baboon), pithecid (bald uakari); Artiodactyla: suid (pig), rhinocerotid (Indian rhinoceros); Perissodactyla: equid (donkey); Lagomorpha: leporid (rabbit); Pholidota: manid (Chinese pangolin, Indian pangolin); Rodentia: erethizontid (Bahai porcupine), cricetid (Chinese hamster, golden hamster), murid (mouse); Carnivora: canid (dog); Siluriformes: claroteid (bagrid catfish); Cichliformes: cichlid (blackchin tilapia, Guinean tilapia, Nile tilapia)	cutaneous larval migrans, pneumonitis, anaemia	Americas, Africa, India, Asia
<i>N. congolensis</i>	2 pairs cutting plates	Primates: hominid (chimpanzee)	small intestines	Africa
<i>N. exilidens</i>	2 pairs cutting plates	Primates: hominid (chimpanzee)	small intestines	Africa
<i>N. gorillae</i>	2 pairs cutting plates	Primates: hominid (lowland gorilla, bonobo, human)	small intestines	Africa
<i>N. okapi</i>		Artiodactyla: giraffid (okapi)		Africa
<i>N. suillus</i>	2 pairs cutting plates	Artiodactyla: suid (pig)	small intestines	Caribbean
<i>N. urichi</i>	2 pairs cutting plates	Carnivora: procyonid (crab-eating raccoon)	small intestines	South America

Parasite morphology: Hookworm developmental stages include eggs, four larval stages and adult worms. Eggs appear as oval thin-shelled bodies, measuring 55-77 µm in length by 35-42 µm in width. Freshly-excreted eggs contain a developing embryo (morula) in the early stages of cleavage with 2-8 blastomeres (cells). The first two larval stages (L1 and L2) are rhabditiform (free-living) and characterised by a long narrow buccal chamber and flask-shaped muscular oesophagus. Third stage larvae (L3) measure up to 600 µm in length and are filariform, non-feeding infective stages characterised by a closed mouth, elongate oesophagus with posterior bulb (strongyloform) and pointed non-notched tail. Fourth-stage larvae (L4) migrate and live in host tissues. Adult hookworms have a creamy-white tough cuticle (synlophe absent), a prominent anterior hook (head deviated dorsally) and a large oval buccal capsule with a pair of dorsal and a pair of ventral cutting plates surrounding the anterior margin. The buccal capsule also has a pair of subdorsal and a pair of subventral teeth near the posterior dorsal cone opening into the oesophagus. Adult worms are sexually dimorphic, with females being larger than males (9-11 mm long cf. 7-9 mm). Female worms have 2 ovaries, an anterior or midbody vulva and their tails lack terminal spines. Male worms have a single testis, 2 needle-like spicules with barbed tips fused distally (gubernaculum absent) and a conspicuous posterior copulatory bursa consisting of two broad lateral lobes and a smaller dorsal lobe supported by fleshy rays formed by muscular elements following nerve channels to terminal papillae (the long dorsal ray has 4 or 6 branchlets).

Site of infection: Adult hookworms use their bent mouths to attach to the small intestinal mucosa. Infective larvae invade dermal tissues, particularly in sites which have come into close contact with the ground (feet, hands and buttocks). Migrating larvae undergo pulmonary migration before being coughed up and swallowed to complete their development in the intestines.

Pathogenesis: Many people infected with hookworms remain asymptomatic. Disease development depends on the parasite species involved, the intensity of infection, and the nutritional condition of the individual. Infections cause three phases of disease; a cutaneous phase where invading larvae may cause dermatitis, a pulmonary phase where migrating larvae may cause pneumonitis, and an intestinal phase where adult worms may cause anaemia. Infective larvae penetrate the skin and invade blood vessels in the dermis, moderate to heavy infections giving rise to an allergic dermatitis with papular, and sometimes vesicular, focal rash and pruritus (condition known as ground itch). The pulmonary phase then occurs when larvae carried to the lungs by the bloodstream break out into airspaces (alveoli) causing focal haemorrhages and allergic pneumonia (severity dependent on numbers). Larvae are coughed up and swallowed and once they reach the small intestines, they attach to the mucosa by ingesting a tissue plug into their mouths and commence feeding on blood. Infections result in significant gastrointestinal haemorrhage, iron-deficiency anaemia, protein malnutrition and intestinal inflammation. The adult worms have voracious appetites and individual adult worms may

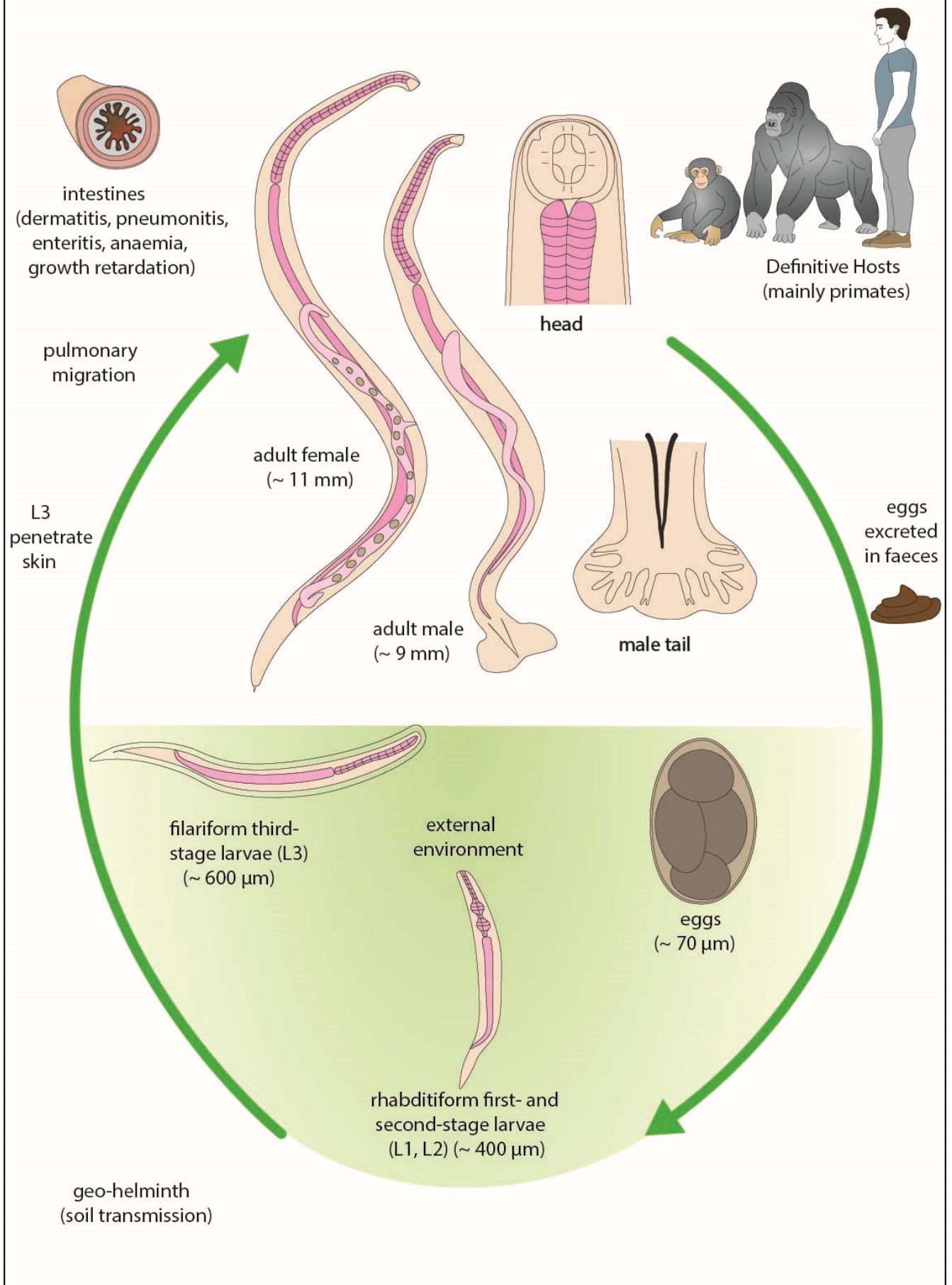
consume 0.03 ml blood per day. Blood loss from the host may result in an initial normocytic, normochromic anaemia that may worsen to a profound iron-deficiency microcytic, hypochromic anaemia with hypoproteinaemia. The worms ingest substantially less blood than adult *Ancylostoma* spp., but they are nonetheless wasteful feeders as not all blood ingested is digested, some is apparently used for respiration and passes through the worm but degrades in the intestines resulting in black tarry faeces (melena). Blood loss is further exacerbated by intestinal lacerations as worms move to new feeding sites from time to time, secreting proteolytic enzymes and anticoagulants, and leaving microscopic ulcers. Infections involving <100 *Necator* are frequently mild whereas >100 worms produce more damage and >1,000 may be fatal. Hookworm infections are a major cause of iron-deficiency anaemia in developing countries, particularly in young children and pregnant women. It is generally considered to be a disease of the poor (low socioeconomic status), with high rates of infection in rural impoverished tropical areas with poor sanitation and barefoot populations. Patients with heavy infections have severe protein deficiency, dry skin and hair, oedema, and potbelly in children with delayed puberty, mental dullness, heart failure and death. Disease is intensified by malnourishment and immunological impairment. Hookworm infections elicit profound humoral and cellular immune responses in their hosts, involving polyclonal antibody production, marked eosinophilia and Th2 lymphocyte proliferation with characteristic cytokine profiles (interleukins 4, 5, 10, 13), but such responses fail to eliminate infections, possibly due to parasites evading immune responses. It is somewhat paradoxical that hookworms elicit allergenic-like responses but survive by modifying those responses.

Developmental cycle and mode of transmission: Hookworms have direct life-cycles involving a geo-helminth (soil-transmitted) stage where infective larvae in the soil actively penetrate the skin or oral mucosa of their hosts. Female worms produce numerous unembryonated eggs (3,000-9,000 per day) which are excreted with host faeces. The eggs embryonate rapidly in warm moist conditions and hatch within 1-2 days releasing free-living rhabditiform larvae which feed on bacteria and organic debris. The larvae moult twice over 10 days transforming into non-feeding ensheathed filariform larvae (L3) which are the infective stages. They remain viable for 3-4 weeks in moist temperate soils but do not survive freezing or desiccation. *Necator* larvae penetrate the skin to infect their definitive hosts (transdermal or percutaneous transmission). The larvae enter the circulation and are carried to the lungs where they break into respiratory alveoli and move up the trachea to be swallowed (pulmonary migration lasting several days). Once they reach the small intestines, they moult, attach to mucosa and become sexually differentiated, moult again and grow into adult worms. The prepatent period (time from infection to first egg excretion) ranges from 2-7 weeks and adult worms may live for up to 15 years.

Differential diagnosis: The diagnosis of hookworm disease on the basis of clinical symptomatology (notably chronic anaemia and debility) is highly suggestive, but requires confirmation by the detection of parasite eggs in faecal samples by microscopy, preferably after concentration although they can be found in direct smears or wet mounts. Because the eggs of hookworms (*Necator* and *Ancylostoma*) and threadworms (*Strongyloides*) are virtually identical, faeces should be kept for larval cultures (usually Harada-Mori filter paper technique in closed tubes for a few days) to differentiate genera (hookworm larvae have a larger buccal cavity and smaller genital primordium), since treatment options are quite different for each group. Radiographic findings include intestinal hypermotility, proximal jejunal dilatation and coarsening of the mucosal folds. Several immunoserological tests (enzyme immunoassays and Western blots) have been developed to detect host antibodies against hookworm antigens, but they generally do not discriminate between patent or previous infections and often exhibit some cross-reactivity with other helminths. More recently, several polymerase chain reaction (PCR) tests have been developed to detect specific parasite DNA sequences of nuclear (ribosomal RNA internal transcribed spacers (ITS-1, ITS-2)) and mitochondrial genes (cytochrome oxidase 1 gene, cAMP-dependent protein kinase catalytic subunit).

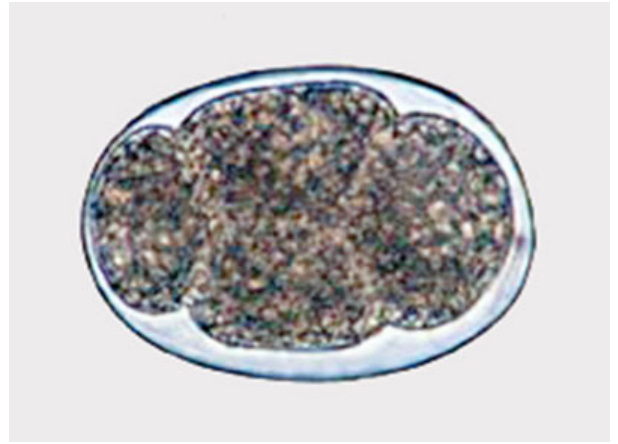
Treatment and control: Various anthelmintic drugs have been used to cure infections, and are best used in conjunction with supportive care involving fluid and electrolyte therapy, dietary supplementation (especially iron replacement), and even blood transfusion if deemed necessary. The most effective drugs are mebendazole, albendazole and pyrantel pamoate. Levamisole is less effective and treatment has adverse side-effects. Older drugs, such as bephenium and tetrachlorethylene, are still used in many areas throughout the world because they are cheap. Regrettably, mass drug treatment programmes are only partly effective as many individuals return to heavily contaminated areas and rapidly become re-infected. Infection appears to stimulate little protective immunity. Control programmes must include prophylaxis to prevent infections as well as environmental management to reduce soil contamination. People should be encouraged to wear solid shoes in endemic regions and to thoroughly wash salad vegetables. Building and education campaigns should be introduced to provide latrines/toilets and improve sanitary conditions, as promiscuous defaecation, associated with poverty and ignorance, keeps soil contamination high. Nightsoil (faecal waste) should not be used to fertilise gardens or vegetable crops. Several countries have successfully controlled infections in human populations, predominantly by using periodic mass treatment programs and encouraging people to wear shoes and use latrines through public education campaigns. Considerable effort has also been made in developing vaccines against hookworm infections, particularly using secreted larval proteins to prevent infections or by inhibiting adult gut enzymes (aspartic proteases, cysteine proteases, haemoglobinases) to reduce worm burdens. Variable results have been obtained, although several formulations are currently undergoing clinical trials.

Necator





Necator adult worms



Necator adult worms



Necator adult worm, male bursa



Necator adult worm, head