Porocephalus, Armillifer
(arthropod: pentastome)

Overview

Arthropods are coelomate metameric invertebrate animals with a chitinous exoskeleton and jointed limbs. They undergo protostomial embryonic development and grow by cuticular moulting (ecdysis). Three main subphyla are recognized: Chelicerata, Crustacea and Hexapoda. Crustaceans have a very strong cuticle strengthened by calcium salts; thus their growth must proceed through repeated moults. Most species are aquatic with internal or external gills, two pairs of antennae, mouthparts comprising one pair of mandibles and two pairs of maxillae, and each heteronomous body segment usually bears a pair of ventral biramous extremities (podia). Maxillipods lack appendages on abdominal segments and the nauplius larval stage has a unique maxillipodan eye. Pentastomatids (tongue worms) are unusual endoparasites with elongate worm-like bodies that have lost virtually all their appendages, apart from two pairs of tiny anterior claws near the mouth (collectively accounting for their penta-stome appearance). Most live in the respiratory systems of reptiles, although a few live in the air sacs of seabirds and the nasopharynx of dogs and cats. Eggs passed into the environment release oval larvae with four stumpy legs and an anterior penetration organ used to invade the tissues of an intermediate host (insect, fish, amphibian, reptile or mammal) where it forms a quiescent nymph which is infective to the definitive host. Porocephalids have their mouths between or below the anterior hooks, the hooks have a fulcrum, and the vulva is posterior. Infections by *Porocephalus* and *Armillifer* spp. are found in the respiratory passages of snakes and they have rodents as intermediate hosts, but may sometimes accidentally infect humans.

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:	Arthropoda (chitinous exoskeleton, segmented body, jointed limbs, haemocoel)
Subphylum:	Crustacea (mandibular mouthparts, gills, two pairs antennae, biramous podia, larval nauplius/zoea)
Class:	Maxillipoda (nauplius with maxillipodan eye)
Subclass:	Pentastomatida (tongue worms, anterior end with mouth and two pairs of tiny claws)
Order:	Porocephalida (horizontally-aligned hooks, posterior genital openings)
Family:	Porocephalidae (cylindrical adults, parasites of snakes)
Genus:	*Porocephalus* (parasitic in respiratory passages of snakes)
Genus:	*Armillifer* (parasitic in respiratory passages of snakes)
Species:	various species may cause respiratory disease in reptiles and visceral lesions 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). Arthropods have small segmented bodies encased in chitinous exoskeletons with articulated limbs. Most species are free-living in terrestrial and aquatic habitats, although a small range are ectoparasitic on other animals, some feeding on the blood or skin of vertebrates. Five subphyla are recognized: Chelicerata, Crustacea, Hexapoda, Myriapoda and Trilobita. Crustaceans have very strong cuticles strengthened by calcium salts, so they moult periodically as they grow and metamorphose through different types of larval stages before forming adults. Most species are aquatic and have internal or external gills, while terrestrial species have internal gills which are kept moist. Crustaceans have mouthparts with two pairs of maxillae (to handle food) and paired mandibles (with opposing biting and grinding surfaces). They have two sets of antennae and each body segment usually gives rise to a pair of ventral biramous appendages (podia). Six crustacean classes are recognized: Brachiopoda, Cephalocarida, Malacostraca, Maxillipoda, Ostracoda and Remipedia. Maxillipods usually have a body plan comprising 5 cephalic, 6 thoracic and 4 abdominal segments followed by a telson. The thoracic segments bear biramous (sometimes uniramous) limbs, but the abdominal segments lack appendages. The carapace is present or reduced, most feed using maxillae, and the nauplius larval stages have unique eyes with three cups, each with tapetal cells (= maxillipodan eye). Six maxillipodan subclasses are recognized: Branchiura, Cirripedia, Copepoda, Mystacocarida, Pentastomatida and Tantulocarida.

Major parasitic crustacean families	Biodiversity	Hosts	Parasitic stages	Patho-genesis	Disease transmission
Class: Maxillipoda					
Subclass: Copepoda (copepods)					
Order: Cyclopoida (open buccal cavity)					
Family: Lernaeidae (anchor worms)	19 genera, 114 spp.	freshwater fishes	copepodids and adults	skin lesions	direct (water)
Former order: Poecilostomatoida (slit-like buccal cavity)[now a "poecilostome" lineage within the Cyclopoida]					
Family: Ergasilidae (gill lice)	27 genera 61 spp.	freshwater and marine fish	adult ♀	gill/skin lesions	direct (water)
Subclass: Branchiura (head with flattened bilobed cephalic fold, carapace expands laterally)					
Order: Argulidea (discoid bodies, attach using hooks, suckers and barbs)					
Family: Argulidae (fish lice)	4 genera 150 spp.	marine and freshwater fish	juveniles, adults	skin lesions	direct (water)
Subclass: Pentastomatida (tongue worms, elongate annulated bodies, 2 pairs tiny anterior claws near mouth)					
Order: Porocephalida (horizontally-aligned hooks)					
Family: Porocephalidae	8 genera, 40 spp.	snakes, lizards (mammal, reptile IH)	adults	lung lesions	indirect (via IH*)
Family: Sebekidae	8 genera, 34 spp.	crocodiles, turtles (fish IH)	adults	lung lesions	indirect (via IH)
Family: Subtriquetridae	1 genus, 4 spp.	crocodiles (fish IH)	adults	lung lesions	indirect (via IH)
Order: Cephalobaenida (obliquely-paired hooks)					
Family: Linguatulidae	1 genus, 4 spp.	carnivorous mammals (mammal IH)	adults	naso-pharyngeal lesions	indirect (via IH)
Family: Cephalobaenidae	1 genus, 1 sp.	snakes (unknown IH)	adults		indirect?
Family: Raillietiellidae	2 genera, 43 spp.	amphibians, snakes, lizards, sugar glider (arthropod IH)	adults	lung lesions	indirect (via IH)
Family: Reighardidae	2 genera, 3 spp.	birds	adults	nasal lesions	direct?

*IH = intermediate host

Morphological and ultrastructural studies on immature and adult stages suggested that pentastomatids (tongue worms) were related to branchiurans, esp. argulids (fish lice). Analyses of mitochondrial DNA gene sequences indicated unambiguously that pentastomatids are a group of modified branchiurans [the name Ichthyostraca has recently been proposed for a 'Branchiura+Pentastomatida' clade]. Pentastomatids are unusual endoparasites with elongate non-chitinous annulated vermiform bodies that have lost virtually all their appendages, apart from two pairs of tiny anterior claws near the mouth (collectively accounting for their penta-stome appearance). Most live in the respiratory systems of reptiles and amphibians, although a few live in the air sacs of seabirds and the nasopharynx of dogs, big cats and deer. Eggs passed into the environment release oval larvae with four stumpy legs and an anterior penetration organ used to invade the tissues of an intermediate host (coprophagous insects, fish, amphibian, reptile or mammal) where it forms a quiescent nymph which is infective to the definitive host. Some species have a direct life-cycle, but this appears limited to the genus *Reighardia* in birds, and possibly the species *Linguatula arctica* in ungulates. Two orders have been recognized: Cephalobaenida (adults with medial genital openings, and a single oviduct); and Porocephalida (adults with posterior genital openings, and 2 oviducts). Members of the order Porocephalida have the mouth positioned between or below the anterior hooks, the hooks have a fulcrum, and the female vulva is located near the posterior end. Several families are recognized: including the Porocephalidae; Subtriquetridae; Sebekidae (now containing the former families Diesingidae and Sambonidae); and Linguatulidae (although recent molecular studies suggest that the linguatulids should be placed in the order Cephalobaenida). Porocephalids are cylindrical pentastomes with horizontally-aligned hooks and reptilian final hosts. Five porocephalid genera (*Armillifer*, *Cubirea*, *Gigliolella*, *Kiricephalus*, and *Porocephalus*) have been recognized as heteroxenous (2-host) parasites with adult pentastomes infecting the respiratory passages of snakes and larval/nymphal stages infecting the viscera of various prey animals (rodents, insectivores, lizards, frogs and some birds). Nine *Porocephalus* spp. have been described from viperid snakes in Africa and the Americas, and 8 *Armillifer* spp. in boid snakes in Africa and elapid snakes in Asia. Four of these species (*A. armillatus, A. grandis, A. moniliformis* and *P. crotali*) have been reported to opportunistically infect humans in Africa and Asia, with larval/nymphal stages encysting in visceral tissues (this is primarily through the ingestion of pentastome eggs via the consumption of contaminated snake meat).

Pentastome species	Definitive hosts (adults in respiratory passages)	Intermediate hosts (larvae/nymphs in viscera)	Distribution
Porocephalus (accessory spines on hooks)			
P. basiliscus	Serpentes: viperid (basilisk rattlesnake)		Americas
P. benoiti	Serpentes: elapid (cobra)		Africa
P. clavatus (syn. *Pentastoma didelphis, imperatoris, proboscideum, subcylindricum p.p.)*	Serpentes: viperid (terciopelo, common European viper, common lancehead, rhombic night adder, bushmaster), boid (rainbow boa, common northern boa, red-tailed boa, Paraguay regenbogenboa, green anaconda, Cuban tree boa), colubrid (grass snake, black-striped snake)	Rodentia: murid (house mouse); Didelphimorphia: didelphid (Virginia opossum, Linnaeus's mouse opossum, bare-tailed woolly opossum); Primates: cebid (common squirrel monkey); Sauria: agamid (Oriental garden lizard), teiid (northern caiman lizard), varanid (Nile monitor)	Americas
P. crotali (syn. *P. humboldtii, quadriuncinata, subcylindricum p.p.*)	Serpentes: viperid (Cascavel rattlesnake, Yucatan neotropical rattlesnake, northwestern neotropical rattlesnake, Santa Catalina rattlesnake, basilisk rattlesnake, western diamondback rattlesnake, timber rattlesnake, South American rattlesnake, cottonmouth, water moccasin, fer-de-lance, jararaca), boid (black-tailed python, common boa, northern boa, green anaconda), colubrid (tiger rat snake, Chinese rat snake, spotted desert racer, Rio tropical racer, Wagler's snake, false water cobra)	Rodentia: cricteid (red-nosed mouse, cotton mouse, blackish grass mouse, Florida mouse, muskrat, marsh rice rat, hispid cotton rat), murid (house mouse, black rat); Didelphimorphia: didelphid (Virginia opossum, gray four-eyed opossum, water opossum, bare-tailed woolly opossum, long-furred woolly mouse opossum, Linnaeus's mouse opossum); Cingulata: chlamyphorid (screaming hairy armadillo, southern three-banded armadillo), dasypodid (nine-banded armadillo); Carnivora: canid (dog), mephitid (striped skunk), mustelid (giant otter), procyonid (common raccoon, crab-eating raccoon, white-nosed coati); Chiroptera: phyllostomid (pale spear-nosed bat); Primates: callitrichid (black lion tamarin); Sauria: teiid (gold tegu)	Americas
P. dominicana	Serpentes: boid (Dominican boa)		Americas
P. stilesi	Serpentes: viperid (jararaca, jararacassu, South American bushmaster, Martinique lancehead, fer-de-lance, crossed pit viper), colubrid (brown-banded water snake, tiger rat snake)	Rodentia: caviid (guinea pig); Sauria: teiid (gold tegu); Primates: cebid (common squirrel monkey)	Americas
P. subuliferum (syn. *P. bouvieri, cercopitheci*)	Serpentes: elapid (Indian cobra), lamprophiid (western forest file snake, Congo file snake, Cape file snake), viperid (Gaboon viper, rhinoceros viper, rhombic night viper)	Primates: cercopithecid (green monkey), galagid (Senegal bushbaby), hominid (human); Serpentes: lamprophiid (Cape file snake), psammophiid (hissing sand snake)	Africa
P. taiwana		Primates: hominid (human)	Taiwan
P. tortugensis	Serpentes: viperid (Tortuga Island rattlesnake)		Mexico
Armillifer (annuli raised by muscle bands)			
A. aborealis	Serpentes: boid (green tree python), colubrid (brown tree snake)	Dasyuromorphia: dasyurid (northern quoll); Peramelemorphia: peramelid (northern brown bandicoot)	Australia
A. agkistrodontis	Serpentes: viperid (Chinese moccasin), pythonid (black-tailed python)	Rodentia: murid (house mouse); Primates: cercopithecid (crab-eating macaque)	China
A. armillatus (syn. *Porocephalus, P. moniliformis, Linguatula, L. constricta, diesingii*)	Serpentes: boid (reticulated python, ball python, African rock python, Burmese python), elapid (Indian cobra, rinkhals), lamprophiid (striped house snake, red-black striped snake), viperid (puff adder, Gaboon viper, horned desert viper, rhinoceros viper, rhombic night viper)	Rodentia: murid (black rat), nesomyid (Gambian pouched rat), caviid (guinea pig), hystricid (African brush-tailed porcupine), anomalurid (Lord Derby's scaly-tailed squirrel), sciurid (striped ground squirrel); Carnivora: canid (dog, striped hyena, brown hyena), euplerid (broad-striped Malagasy mongoose), felid	Africa, Arabian Peninsula

		(cat, lion, tiger, leopard, cheetah, serval), herpestid (marsh mongoose, long-nosed mongoose, banded mongoose, white-tailed mongoose, bushy-tailed mongoose, Pousargue's mongoose, Java mongoose, Egyptian mongoose, common kusimanse), mustelid (Eurasian otter, spotted-necked otter, honey badger), nandiniid (African palm civet), viverrid (Asian palm civet, Malabar large-spotted civet, genet, pardine genet); Eulipotyphla: erinaceid (long-eared hedgehog, four-toed hedgehog, desert hedgehog, southern African hedgehog); Tubulidentata: orycteropodid (aardvark); Macroscelidea: macroscelidid (elephant shrew); Artiodactyla: bovid (cattle, southern reedbuck, harnessed bushbuck, white-bellied duiker, Weyns's duiker, roan antelope, royal antelope), giraffid (giraffe), tragulid (water chevrotain), suid (pig, common warthog, desert warthog, red river hog); Chiroptera: hipposiderid (cyclops roundleaf bat); Primates: galagid (southern needle-clawed bushbaby, brown greater galago, Senegal bushbaby), cercopithecid (mandrill, yellow baboon, Chacma baboon, Guinea baboon, sooty mangabey, crab-eating macaque, rhesus macaque, grivet, malbrouck, tantulus monkey, mona monkey, patas monkey, greater spot-nosed monkey), lorisid (potto), hominid (chimpanzee, human); Accipitriformes: accipitrid (European honey buzzard); Strigiformes: strigid (spotted eagle-owl)	
A. australis	Serpentes: pythonid (amethystine python, carpet python)	Peramelemorphia: peramelid (long-nosed bandicoot); Rodentia: murid (Cape York rat)	Australia, Indonesia
A. grandis (syn. *Porocephalus*) (visceral tongue worm)	Serpentes: viperid (Gaboon viper, rhinoceros viper, horned desert viper)	Primates: hominid (human)	Africa
A. mazzai	Serpentes: homalopsid (Macleay's water snake), pythonid (amethystine python)	Dasyuromorphia: dasyurid (quoll)	Australia, New Guinea
A. moniliformis (syn. *Pentastoma, P. aonycis, constrictum, tornatum, wedlii*)	Serpentes: pythonid (reticulated python, black-tailed python, carpet python, royal python, amethystine python, African rock python), boid (Madagascar boa), colubrid (painted keelback)	Rodentia: murid (Cape York rat); Carnivora: hyaenid (aardwolf), herpestid (Javan mongoose), felid (cat, fishing cat, flat-headed cat, tiger, leopard), mustelid (Eurasian otter, Asian small-clawed otter, smooth otter), ursid (sloth bear), viverrid (Asian palm civet, small Indian civet, large Indian civet, binturong); Scandentia: tupaiid (common treeshrew); Artiodactyla: suid (boar), tragulid (Java mouse-deer); Perissodactyla: tapirid (Malayan tapir); Primates: lorisid (red slender loris, Sunda slow loris), cercopithecid (rhesus macaque, crab-eating macaque, southern pig-tailed macaque), hominid (human)	South-East Asia, Australia
A. yoshidai	Serpentes: pythonid (black-tailed python)		Japan

Several other species have also been reclassified to other genera: including *A. brumpti = Gigliolella*; *P. bifurcatus = Raillietiella furcocercum*; *P. boulengeri = Raillietiella*; *P. crocodili = Leiperia gracilis*; *P. nematoides = Leiperia cincinnalis*; *P. globicephalus, P. herpetodryados* and *P. seurati = Kiricephalus coarctatus*; *P. pattoni = Kiricephalus*; *P. tortus = Kiricephalus*; *P. indicus = Alofia*; *P. joubini = Sebekia*; *P. kachugensis = Diesingia*; *P. pomeroyi = Cubirea*; and *P. wardi = Sambonia*; while *P. crocidurae* and *P. siamensis* are considered *species inquirenda.*

Parasite morphology: Porocephalid pentastomes form 4 different types of morphological stages during their developmental cycles: namely, eggs, larvae, nymphs, and adults. The eggs are ovoid ranging in size from 100-150 x 70-100 μm (cf. Linguatula eggs average 130 x 80 μm). They are bound by a bladder-like envelope with thin outer shell membrane and thick inner membrane with a unique funnel-shaped facette (thought to deliver sticky secretions from the contained embryo to the outer membrane). Eggs are fully embryonated when mature and contain an ovoid ('mite-like') primary larva with 2 pairs of anterior hooks and budding or short stumpy limbs. When hatched, the primary larvae measure 130-200 x 60-100 μm and have an ovoid non-segmented body with 4 stumpy legs (each with 1-2 retractable claws), a pair of small curved hamuli either side of the mouth, an anterior penetration apparatus on the rostral cephalothorax and a short bifurcate tail. The penetration apparatus comprises a media spear and 2 lateral pointed forks, and dorsal accessory hooks are present. Various studies have reported that larval stages may undergo several moults (ranging from 3-10 depending on species) before metamorphosing into segmented nymph stages that lack larval characteristics (lost legs, penetration apparatus, and tail). Studies have also reported that nymphs may undergo a series of moults (up to 5 depending on species) gradually increasing in size (sometimes up to 15-23 mm long) and segments. Nymphs stages are often described as surrounded by the exuvia of previous stages, and they are reported to form their circumoral hooks and primordial genital organs after 4-5 moults. Generally, they have cylindrical bodies with distinct annulations, the number and orientation of annuli differing between genera. *Porocephalus* nymphs possess 38-40 annuli evident as circular rings, whereas *Armillifer* nymphs have around 20 annuli that are slightly transverse and therefore impart a spiral screw-like appearance. The annuli often have small spines, and the cuticle has many pit-like openings to various glandular elements. The nymphs have small ventral mouths surrounded by a U-shaped sclerotized cadre opening to a simple digestive system with an oesophagus expanding into a blind sac, and sometimes a small hindgut. Mature nymphs are heavily encapsulated in host tissues and they already bear 4 sets of circumoral hooks. Adult porocephalids have elongate vermiform cylindrical bodies (in contrast to *Lingulatula* spp. which have flattened spatulate bodies). They usually grow up to 20-70 mm long, although some species may grow as big as 160 mm long. Like the nymphs, adults are conspicuously annulated with 7-40 ring-like segments, depending on taxa. In additions, the circular and parietal muscles of *Armillifer* spp. are arranged in thick bands, so that the annuli are prominently raised into spiral ridges. Adults have a thin chitinous exoskeleton that is soft enough to allow for peristaltic motion, and they have sclerotized parts around the mouth and accessory genitalia. The body is roughly into a head (or forebody), trunk (or hindbody), and tail (sometimes bifurcated at the tip). The head has virtually lost all appendages, except for the 2 pairs of tiny anterior hooks near the oval mouth (collectively accounting for their penta-stome appearance). The hooks are sclerotized and arc-shaped with a boat- or U-shaped fulcrum. The hooks are horizontally aligned in a straight line with the mouth (not obliquely like *Linguatula*), and those of *Porocephalus* spp. have accessory spines. The mouth is quite muscular and functions as a pump as adults feed on blood. The digestive system is simple and tubular, and now includes a posterior anus. The nervous system comprises a ventral nerve cord with ganglia in each segment (similar to other arthropods). Although adults have a haemocoel, they do not have circulatory, respiratory or excretory organs. The body lacks limbs but may sometimes have vestigial papilla-like outgrowths as well as numerous cuticular pores. Males are commonly smaller than females (*Porocephalus* males 27-36 mm long, females 44-78 mm; *Armillifer* males 12-50 mm, females 70-140 mm). Males have a single tubular testis (2 testes in *Linguatula*) that is connected to a seminal vesicle and a pair of ejaculatory bulbs opening into a long penis (cirrus) located in a dilator organ (cirrus sac). They have distinctive copulatory spicules (not club-shaped) and the genital pore is located near the mouth. Females have a single ovary with bifurcating oviducts that unite into a tubular extensively-coiled uterus with diverticula (including spermatheca). The vagina opens through a ventral posterior gonopore separated from anus by a few annuli (heterogyne condition).

Site of infection: Pentastomes are obligate internal parasites whose larval and nymphal stages are found in small animals (intermediate hosts) infected through consumption of eggs, while the adult stages are found in carnivorous vertebrates (definitive hosts). The intermediate hosts of *Porocephalus* and *Armillifer* spp. include a range of rodents, insectivores, lizards, frogs and some birds, with larval/nymphal stages infecting the viscera. Adult stages are more host specific and only occur in the respiratory tracts (lungs, trachea, nasal passages) of reptiles (namely, viperid, boid, pythonid, lamprophiid, colubrid and elapid snakes). In contrast, adult *Linguatula* spp. are found in the nasopharyngeal passages of mammals. Nonetheless, infections by 4 species (*A. armillatus, A. grandis, A. moniliformis* and *P. crotali*) have been found opportunistically in humans, where larval/nymphal stages have been detected encysting in visceral tissues, usually in the serosa around abdominal organs, abdominal lymph nodes, in the liver parenchyma, the mesenterium and intestinal wall, sometimes the pleura or lung parenchyma, and rarely the heart or eye.

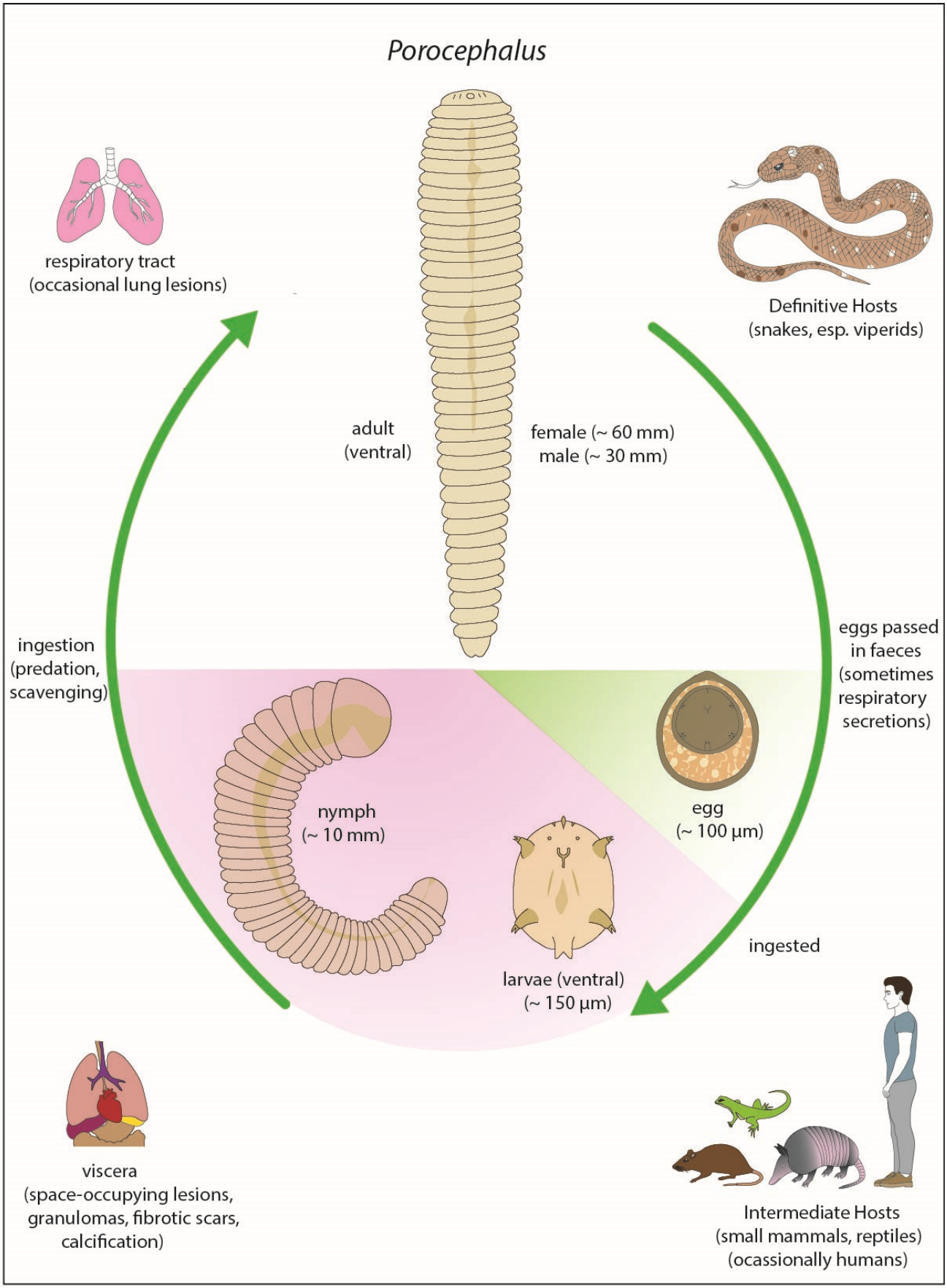
Pathogenesis: Most infections by developing pentastomes in intermediate hosts or by adults in definitive hosts are asymptomatic or remain subclinical, although some may produce morbidity associated with parasites feeding on host blood, larval/nymphal migration and moulting within visceral tissues, traumatic damage to the pulmonary lining by adult hooks, and secondary bacterial and fungal infections. The mouth hooks of both larvae and adults are used to tear tissues during migration as well as to attach to the mucosa when feeding. Both larvae and adults are haematophagous and feed on blood from capillary beds via sucking mouthparts. Morbidity

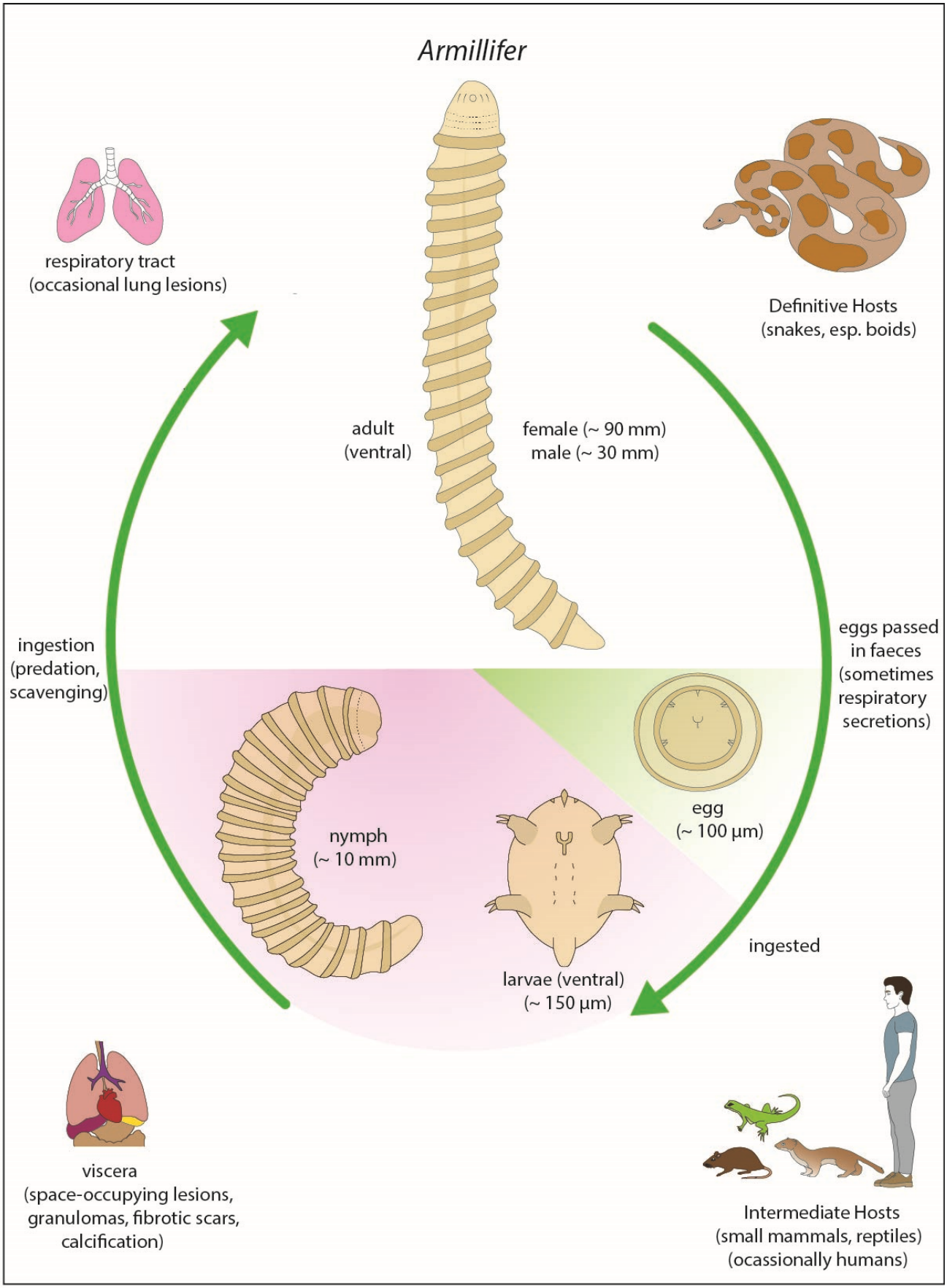
and mortality due to adult pentastome infections in reptiles are usually associated with infected lesions causing septicaemia, enterocolitis and pneumonia. Hosts appear to tolerate these large parasites in their tissues by inflammatory and immunological responses being modified by encapsulation processes (particularly around nymphs which become quiescent for extended periods) and by voluminous parasite excretory/secretory (ES) products that coat the parasites in protective substances. Both nymphal and adult pentastomes are very glandular and produce many different types of coatings that appear to protect them from host cellular and humoral responses. The migration of larvae and the encystment of nymphs can cause distinctive lesions in intermediate hosts, sometimes in accidental definitive hosts. Three types of lesions have been described: progressing from viable nymphs encysted within a thin layer of refractile eosinophilic material with little or no adjacent cellular infiltration; to necrotic granulomas surrounded by fibrotic and hyalinized connective tissues with cellular infiltrates (giant cells, macrophages, lymphocytes, plasma cells, eosinophils) in concentric rings; and finally granulomatous scars (cuticle granulomas) with acellular hyalinized fibrous tissue surrounding a central mass of amorphous calcified material. Humans may act as accidental intermediate hosts for several species of *Armillifer* and *Porocephalus*, with larvae invading visceral organs only to eventually die and calcify as they are unable to complete further development. Most visceral infections remain asymptomatic and are incidental findings during surgery or necropsy. However, they may sometimes cause a range of clinical symptoms and signs, depending on the intensity of infection and the tissues/organs involved. Visceral lesions may be confused with malignancies and infections are more abundant in men (particularly snake handlers or snake-eaters). The initial phase of infection is transient as larvae penetrate intestinal tissues causing pyrexia and colic. Larvae and nymphs are then subsequently found in the serosa around abdominal organs, sometimes within the organs themselves (mainly liver and lungs). Living, intact and encysted nymphs produce few signs, whereas dying and dead parasites may release considerable foreign material contributing to clinical illness, with eosinophilia, abdominal pain, oedema, chronic cough, night sweats, fever, sepsis with acute abdomen, and hepatic or neurological symptoms. In severe infections, death may occur due to disseminated disease, hypersensitivity reactions, intestinal obstruction, enterocolitis and septicaemia. Infections in the eye may cause substantial visual damage with loss of vision, often permanent.

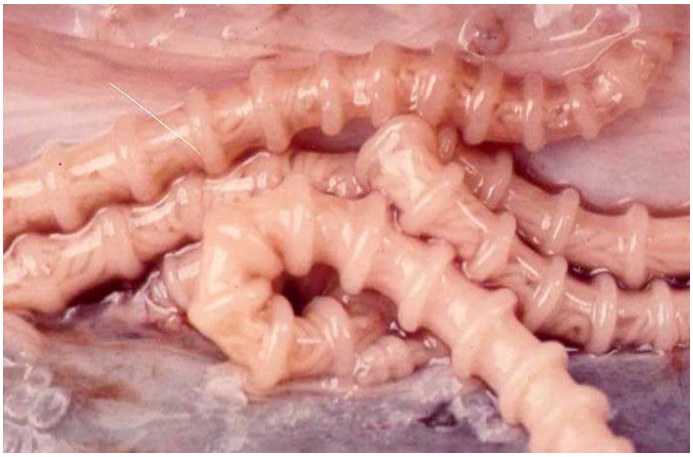
Developmental cycle and mode of transmission: Pentastomes are heteroxenous (2-host) parasites with predator-prey transmission occurring between larval/nymphal stages infecting the viscera of various prey animals (intermediate hosts) and adult stages infecting the respiratory passages of snakes (definitive hosts). Female pentastomes lay fully-embryonated eggs in the respiratory passages which then pass to the trachea and may be coughed/sneezed up but are more likely to be swallowed and subsequently passed in host faeces. The eggs are viscid and often cling together. They may withstand dry conditions for 2 weeks and have been found to remain viable in cool water for up to 6 months. When ingested by a suitable intermediate host (coprophagous or scavenging mammals, lizards or birds), the eggs hatch releasing primary larvae which have 4 stumpy legs and an anterior penetration apparatus used to invade host tissues. They may penetrate the intestines within one hour of ingestion and then migrate randomly in the body cavity for 7-8 days before encapsulating in serosal or soft tissues (they rarely invade striated muscles). Studies on developmental cycles report variable numbers of larval moults before they metamorphose into nymphs (lacking larval features) which grow and also undergo several moults before becoming heavily encapsulated as quiescent (dormant) stages that may persist for months in host tissues. Mature nymphs are recognizable by the presence of genital primordia and the development of 4 sets of circumoral hooks (characteristic for adults). When mature nymphs encysted within prey flesh are eaten by predation or scavenging by suitable definitive hosts (in this case, snakes), the nymphs excyst, penetrate the intestines and migrate by moving up the oesophagus to the nasal passages and then the lungs. Note that if definitive hosts accidentally ingest eggs, they may act as transient intermediate hosts when larvae hatch and penetrate tissues but they are unable to complete their development to adults. Male and female pentastomes mate once within their definitive hosts, but then anatomical changes in gravid females preclude further matings. Both sexes feed on host blood, but males do not live long, so most long-term infections consist of maturing females (which may live for up to 2 years or longer). Patent females lay massive numbers of eggs (up to several million) throughout their reproductive lives. Infections in humans occur when eggs are inadvertently ingested following the handling of snakes or snake products (including meat and bile) or by the consumption of undercooked snake meat or water contaminated with eggs. The eggs hatch releasing larvae which invade host tissues and may cause a range of clinical conditions. Those most at risk are snake owners (including groups that use snakes as totems), workers at snake farms, snake keepers at zoos and pet shops, veterinarians, as well as those that process and eat snake meat. Infections by at least 4 species (*A. armillatus, A. grandis, A. moniliformis* and *P. crotali*) have been found opportunistically in humans mainly in Africa and Asia.

Differential diagnosis: Infections in reptiles may be detected ante-mortem by finding pentastome eggs upon microscopic examination of faecal floatations (sometimes lung washes) or by finding adult stages incidentally in lungs upon surgery or necropsy. On occasion, endoscopic techniques have been used to detect adult pentastomes in the lungs of large snakes (mostly pythons). Visceral infections in intermediate hosts may be indicated by radiographic findings of nodular lesions containing calcified C-shaped nymphs in host abdominal tissues, rarely in striated musculature (unlike the calcified cysticerci of tapeworms). More often, visceral infections are detected incidentally at surgery or necropsy, and confirmed by gross or histopathological observations (cuticular structures are readily observed, even in calcified specimens). Several studies have developed immunoserological tests (enzyme-linked immunosorbent assays, Western blots) to detect specific host antibodies against antigenic extracts from larval and adult pentastomes, but they are not widely available. More recently, molecular biological techniques have been used to identify and characterize pentastome species following the polymerase chain reaction (PCR) amplification of nuclear (ribosomal RNA) and mitochondrial (cytochrome c oxidase) gene sequences.

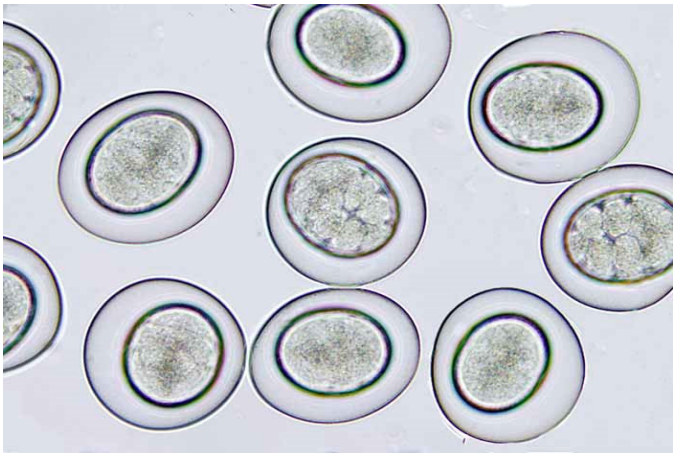
Treatment and control: Clinical infections in snakes may be treated after stabilizing hosts with thermal, fluid and nutritional support, and providing antibiotics in the case of secondary bacterial infections. Adult pentastomes may be removed from large snakes by endoscopic manipulation, taking care not to tear the parasite cuticle. Killing adult stages with antiparasitic drugs has been attempted using diethylenediamines (diethylcarbamazine), isoquinolines (praziquantel), imidazothiazoles (levamisole), benzimadazoles (thiabendazole, fenbendazole, mebendazole) and macrocyclic lactones (ivermectin), but complications have sometimes arisen with the release of large amounts of antigenic material from dying parasites leading to allergic reactions, including anaphylaxis. Asymptomatic infections in humans with larval/nymphal stages are usually not treated as the parasites begin to degenerate and break down after several months. In symptomatic patients with visceral pentastomiasis, surgical approaches may have to be considered as there are no recommended antiparasitic chemotherapies available because the parasites are usually encapsulated in host tissues and coated with ES secretions. Nonetheless, clinicians have sometimes resorted to using diethylcarbamazine, praziquantel, levamisole, thiabendazole, fenbendazole, mebendazole, ivermectin and even fluoroquinolone antibiotics (ciprofloxacin), hematinics (haematopoetic nutrients) and some Chinese herbal medicines. The use of glucocorticoids to moderate allergic or inflammatory responses in contra-indicated. The prevention of infections revolves around personal hygiene (washing after handling snakes), meat hygiene (cleaning and cooking snake meat), good sanitation (disposing of snake faeces) and water treatment (filtration and disinfection).


Porocephalus
respiratory tract
(occasional lung lesions)
adult
(ventral)
female (~ 60 mm)
male (~ 30 mm)
Definitive Hosts
(snakes, esp. viperids)
ingestion
(predation,
scavenging)
eggs passed
in faeces
(sometimes
respiratory
secretions)
nymph
(~ 10 mm)
egg
(~ 100 µm)
larvae (ventral)
(~ 150 µm)
ingested
viscera
(space-occupying lesions,
granulomas, fibrotic scars,
calcification)
Intermediate Hosts
(small mammals, reptiles)
(ocassionally humans)


Armillifer
respiratory tract
(occasional lung lesions)
Definitive Hosts
(snakes, esp. boids)
adult
(ventral)
female (~ 90 mm)
male (~ 30 mm)
ingestion
(predation,
scavenging)
eggs passed
in faeces
(sometimes
respiratory
secretions)
nymph
(~ 10 mm)
egg
(~ 100 µm)
ingested
larvae (ventral)
(~ 150 µm)
viscera
(space-occupying lesions,
granulomas, fibrotic scars,
calcification)
Intermediate Hosts
(small mammals, reptiles)
(ocassionally humans)



Armillifer adults



Armillifer eggs

Porocephalus adult head

Porocephalus egg