Opinion

Feline lungworms: what a dilemma

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Aelurostrongylus abstrusus **is regarded as the major lungworm infecting** ***Felis catus*****, although other, albeit poorly studied, nematodes have been described from the respiratory system of domestic cats. Recent records of these neglected parasites have renewed the attention of the scientific community, but their actual role in respiratory disease in cats is blurred. The epidemiology, pathogenic role, and diagnosis of** ***Troglostrongylus*** **spp.,** ***Oslerus rostratus*****, and** ***Capillaria aerophila*** **in domestic cats are far from being clarified. Indeed, recent studies have provided novel information but have also given rise to relevant doubts. We discuss here the state of current knowledge regarding felid lungworms together with the dilemmas recently roused in the scientific literature.**

Felid lungworms – a single star and some co-stars?

The majority of parasitic nematodes belonging to the superfamily Metastrongyloidea reside as adults in the lungs and associated sites (e.g., sinuses, pulmonary veins) of their animal definitive hosts. Thus, metastrongyloids (see Glossary) are commonly regarded as 'lungworms', although parasites ranked within other taxa (e.g., some species of the family Trichuridae) may infect the respiratory system of animals and humans and could be regarded as such. Metastrongyloids of the families Protostrongylidae and Metastrongylidae affect the lungs of large animals, whereas those belonging to families Crenosomatidae and Angiostrongyliidae are mostly associated with small mammals [1]. Few metastrongyloids (e.g., *Angiostrongylus cantonensis*) are transmissible to humans [1].

The most significant nematode infecting the lungs of the domestic cat, *Felis catus*, in terms of species-specificity, current knowledge, geographic distribution, and role played in feline medicine, is the mollusc-borne *Aelurostrongylus abstrusus* (Metastrongyloidea, Angiostrongyliidae), also regarded as the 'cat lungworm' [2–4]. Indeed, *F. catus* is considered the proper definitive host only for this lungworm.

Other metastrongyloids parasitize the respiratory system of wild Felidae, although their sporadic occurrence in domestic cats has also been described [5–8].

Four species are ranked within the genus *Troglostrongylus* (Metastrongyloidea, Crenosomatidae) [5,9–13], which have been found sporadically even in their specific hosts, in other words wild felids (e.g., leopards and tigers). Reports of infection caused by *Oslerus rostratus* (Metastrongyloidea, Filaroididae) are very scant, and little information is available on its biology and species-specificity. Although this metastrongyloid was described for the first time in *F. catus* [5], it has been reported since in bobcats [11] and the domestic cat is considered to be an accidental host [6].

Recent reports of *Troglostrongylus brevior* and *Troglostrongylus subcrenatus* in domestic cats [14–16] have stimulated scientific interest in these parasites. The present article aims to raise attention concerning feline lungworms, with a special focus on recent discoveries about their biology, epidemiology, diagnosis, and, in particular, on the actual role they have in causing respiratory parasitoses of *F. catus*.

Neglected, occasional, sporadic, or misdiagnosed?

Most aspects of aelurostrongylosis, such as the life cycle of *A. abstrusus* and the damage it causes to the lungs, were elucidated in the past [2,17] as well as in more recent studies (e.g., epidemiology and therapy) (reviewed in [4]).

Conversely, even basic knowledge for the other lungworms is incomplete and fragmentary. Both *Troglostrongylus* spp. and *O. rostratus* are also mollusc-borne, and different paratenic hosts (e.g., lizards, frogs, toads, birds, and small mammals) may be involved in routes of transmission [5,7,8]. Thus, these parasites may live in sympatry in the same ecological niches, at least for the immature stages in intermediate and paratenic hosts, that is, the sources of infection for domestic cats and wild felids. However, if *A. abstrusus*, *Troglostrongylus* spp., and *O. rostratus* have similar life cycles and overlapping transmission patterns (Box 1), the question remains as to why only *A. abstrusus* is practically regarded as the 'cat lungworm'.

The epidemiological drivers that might result in bridging of lungworms between wild Felidae and *F. catus* are currently unknown. Apart from a description of *T. subcrenatus* at the necropsy of a domestic cat from Malawi in 1961 [10], no infections of domestic cats by *Troglostrongylus* spp. were reported until recently. An unknown *Troglostrongylus* sp. was found in two cats from the island of Ibiza, Spain, in 2010 [14]. This record has spurred more careful appraisal of lungworm infections in cats; another study reported clinical presentations and pathological features of infection by *T. brevior* and *T. subcrenatus*, respectively, from cases in two domestic kittens on the island of Sicily, which were initially attributed to *A. abstrusus* [15]. *O. rostratus* has been identified infrequently in wild and domestic felids in some countries [8], but cats from the island of Majorca were recently observed to have a high rate of infection [18].

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Glossary

Aelurostrongylosis: the disease caused by nematodes of the genus *Aelurostrongylus*. Cat aelurostrongylosis produced by *Aelurostrongylus abstrusus* is either subclinical or characterized by varying respiratory and general clinical signs: mild to intense chronic cough, sneezing, wheezing, mucopurulent nasal discharge, dyspnea, tachypnea, tachycardia, open-mouthed abdominal breathing, lethargy, depression, loss of bodyweight, and even death. Specific treatment relies on the administration of benzimidazoles or macrolactones.

Baermann test: the copro-microscopic technique used for the isolation of hydrophilic nematode larvae from different biological samples (e.g., feces and lung tissues). It is the gold standard test for detecting metastrongyloid larvae in the feces of an infected animal.

Capillarioses: a range of diseases caused by nematode species of the genus *Capillaria*. Some species of this genus have synonyms. Feline lung capillariosis caused by *Capillaria aerophila* (also known as *Eucoleus aerophilus*) is a subclinical, severe or potentially fatal disease, with the following clinical signs: general respiratory distress, bronchovesicular breathing sounds, sneezing, wheezing, and chronic dry or moist and productive cough, complicated bronchopneumonia and respiratory failure. Specific treatment relies on the administration of levamisole or moxidectin. The human infection by *C. aerophila* (i.e., human lung capillariosis) is characterized by clinical signs (i.e., cough, mucoid sputum, hemoptysis, fever, dyspnoea, and eosinophilia) and radiology findings (i.e., broncho-pneumonic shadows) mimicking a pulmonary cancer. Specific treatment relies on the administration of benzimidazoles.

Catarrhal exudate: fluid formed by mucus and white blood cells, which is caused by an over-stimulation of respiratory, mucus-producing muciparous cells as a response to inflammatory processes.

Crenosomatids: the nematodes belonging to the Crenosomatidae family.

Egg wall: the external surface of eggs shed by parasites; often characterized by features useful for a specific diagnosis upon microscopic analysis.

First-stage larva: the earlier stage in the larval development of parasitic nematodes, occurring after mating of adult stages.

Hepatization: the transformation of the pulmonary parenchyma into a liver-like tissue, resulting in a marked lung consolidation, which makes the pulmonary alveoli no longer suitable for air exchange.

Lobular flogosis: pulmonary inflammation involving the lobule (i.e., the morpho-functional lung unit).

Lungworm: the common designation used in the scientific literature for nematodes ranked within the Metastrongyloidea superfamily, which are parasitic in the lungs of different animals. In the opinion of the authors this designation should be used also for nematodes infecting the lungs (e.g., *Capillaria aerophila*) other than Metastrongyloidea.

Metastrongyloids: the parasitic nematodes belonging to the Metastrongyloidea superfamily. These parasites are characterized by life cycles typically requiring an intermediate mollusc host for developing to the infective stage. The vast majority of metastrongyloids affect the lungs and associated sites of animals, with few exceptions.

Morphometry: measurement of form, size, and shape of organisms.

Multiplex PCR: a PCR-based assay able to detect different pathogens simultaneously in a biological sample by using multiple sets of specific primers at the same time.

Oslerosis: the disease caused by nematodes belonging to the genus *Oslerus*. Felid oslerosis is caused by *Oslerus rostratus*, a rare metastrongyloid infecting the domestic cat and wild felids. Little information is available on clinical pictures in cats, although a mild bronchitis has been described in experimental infections. No information is available on the treatment of the cat infection.

Paratenic hosts: a host whose presence is not necessarily required for the completion of a parasite's life cycle but which can harbor the stages infective for the definitive host, without them going through further development.

Polar plug: the mucoid extremities located at both ends of the lemon-like or barrel-like eggs shed by nematodes belonging to the Trichuridae family.

Reverse line blot: a PCR-based assay able to detect different pathogens simultaneously by species-specific diagnostic probes on a panel of PCR amplicons obtained from different biological samples.

Sub-pleural nodules: spotted or coalescing lesions located beneath the pleural surface of the lungs.

Sympatry: the ecological condition in which two or more species or populations occupy the same niche or overlapping geographic areas without interbreeding.

Trichurid: a nematode belonging to the Trichuridae family.

Troglostrongylosis: the disease caused by nematodes of the genus *Troglostrongylus* in wild felids. In the domestic cat this occasional condition is often characterized by severe coughing, dyspnoea, polypnea, respiratory failure, and death. No information is available on specific therapy.

Whipworms: the common designation for nematode species of the *Trichuris* genus. Three species, – *Trichuris felis*, *Trichuris campanula*, and *Trichuris serrata* – have been reported from the intestines of cats, but are only rarely reported in limited areas of the world. It is not known whether they are separate species or represent a single species.

Despite these recent records, current knowledge on the epidemiology, distribution, and pathogenicity of *Troglostrongylus* spp. and *O. rostratus* in domestic cats is lacking. This might indicate that these metastrongyloids rarely infect domestic cats or are misdiagnosed as the more common source of infection, *A. abstrusus*.

Metastrongyloid larvae in the feces of a cat

These parasites are diagnosed by detecting first-stage larvae (L1s) upon Baermann examination of cat feces. Hence, the vast majority of information available on feline lungworms is based on copromicroscopic findings rather than by post-mortem examinations.

Several publications report that L1s of *A. abstrusus* are approximately 360–400 μm in length, with a kinked (S-shaped) tail and distinct knob-like or small finger-like projections (a subterminal spine) [6,7,15,19–22]. However, other papers and veterinary textbooks indicate that L1s of *A. abstrusus* may be smaller, with a minimum length of approximately 300 μm [14,23–25]. In addition, we have contributed to this confusion because in two reviews [4,26] we cited earlier erroneous bibliographic references for the length of *A. abstrusus* L1s, although in our laboratory experience in Italy we have not found L1s shorter than approximately 350 μm.

Besides earlier morphological descriptions, the only recently available data on L1s of *T. brevior* and *T. subcrenatus* [14–16] have given rise to major doubts. In two cats from Ibiza, two larval morphotypes were identified; the first belonged to *A. abstrusus*, which was confirmed by genetic characterization of the 18S rRNA gene, and the L1s had a length of 326–350 μm and possessed the typical tail (Figure 1D) [14]. L1s of the second morphotype were much longer at 435–521 μm and were initially designated as *Troglostrongylus* sp. upon genetic examination. In particular, these larvae were found to be most genetically homologous to *Troglostrongylus wilsoni* from bobcats in the USA. Even though no sequences for other *Troglostrongylus* spp. were present in the GenBank database at that time, the authors did not consider their larvae to be *T. wilsoni* given the conserved nature of the 18S rRNA gene and the similar levels of genetic variability in other well-separated species of metastrongyloids [14]. The tails of these larvae lacked a dorsal kink and had a less pronounced knob-like structure (Figure 1B). Subsequent genetic analysis identified these as *T. brevior* [15]. The molecular data and an image (Figure 1A) of a L1 showing a pointed tail with a pronounced dorsal cuticular spine and a shallower ventral one [14] are consistent with *T. brevior* [15]; however, the morphometric information contrasts with this latter paper which described *T. brevior* L1s from Italy. In fact, those larvae were much smaller, with an average length of 339.3 μm [15]. Interestingly, the paper [5] used for comparison in Brianti *et al.* [15] reports a length of no more than 310 μm. These discrepancies were later reinforced by the L1s from Italy described in 2013 of 311–357 μm in length that were genetically confirmed to be *T. brevior* [16]. Furthermore, L1s of *A. abstrusus* from Ibiza [14] were shorter than larvae described in the comparative study of Brianti *et al.*, which was intended to provide 'a clearer delineation of metastrongyloids affecting cats' [15]. Indeed, together with discernment of *T. brevior*, *T. subcrenatus*, and *A. abstrusus* by describing anatomical sites parasitized, characteristics of adult and larval stages, and molecular data, this work [15] has also inspired controversy.

An L1 approximately 300 μm in length teased from the colon of a cat with lungworms was found in the USA [23]. This larva, even shorter than those described above [6,7,14,15,19–22,24,25], was identified as *A. abstrusus* based on size and the kinked tail with a dorsal spine [23]. Indeed, the tail depicted in this article (Figure 1F) is consistent with that of *A. abstrusus* (Figure 1D,E) [2,15].

The length of *A. abstrusus* L1s from Ibiza [14] and the USA [23] could point to misidentification; however, the genetic characterization [14] and the larval tail together with consistent histological findings [23] ultimately support the identification as *A. abstrusus*. The reasons for the discrepancies [14–16] are unknown. In any case, if L1s of *A. abstrusus* are also less than 350 μm, their differentiation from *T. brevior* should rely more heavily on the tail morphology (Figure 1).

Distinction from *T. subcrenatus* appears less complicated, in that L1s are shorter (i.e., ~280 μm) than those of

Box 1. The life of nematodes residing in the respiratory system of felids

Metastrongyloidea

The life cycle is indirect (Figure I). Adult parasites live in the respiratory system of the felid definitive host: terminal bronchioles, alveolar ducts and alveoli (*Aelurostrongylus abstrusus*), bronchial sub-mucosa (*Oslerus rostratus*) or bronchi, large bronchi, and trachea (*Troglostrongylus* spp.) (Figure IA). The females lay eggs which go through embryonic maturation within the parenchyma. After egg hatching, first-stage larvae (L1s) pass up the respiratory escalator to the pharynx, where they are swallowed and released via the feces into the environment (Figure IB). L1s continue their life cycle into mollusc intermediate hosts, in which they reach the third, infective, larval stage (L3) (Figure IC). The definitive host is infected by ingesting the intermediate (slugs and snails) or paratenic (rodents, frogs, lizards, snakes, birds) hosts (Figure ID). After ingestion, the larvae migrate to the lungs via the emo-lymphatic vessels and develop to adulthood in the different parts of the respiratory system according to the species.

***Capillaria aerophila* (syn. *Eucoleus aerophilus*)**

This nematode has a direct biological cycle, although it is hypothesized that earthworms could be involved as a facultative intermediate or paratenic hosts (Figure II). Adult stages live beneath the epithelium of bronchi and trachea of different vertebrate hosts (Figure IIA) and, after mating, the females lay eggs that are coughed, swallowed, and released via the feces into the environment (Figure IIB), where they mature and become infective. The animal acquires the infection by the ingestion of environmental larvated eggs (Figure IIC) containing infective L1s or, possibly, parasitized earthworms (Figure IID). The ova hatch in the intestine, and the larvae migrate via bloodstream or the lymphatics to the lungs, where they invade the mucosa and reach adulthood.

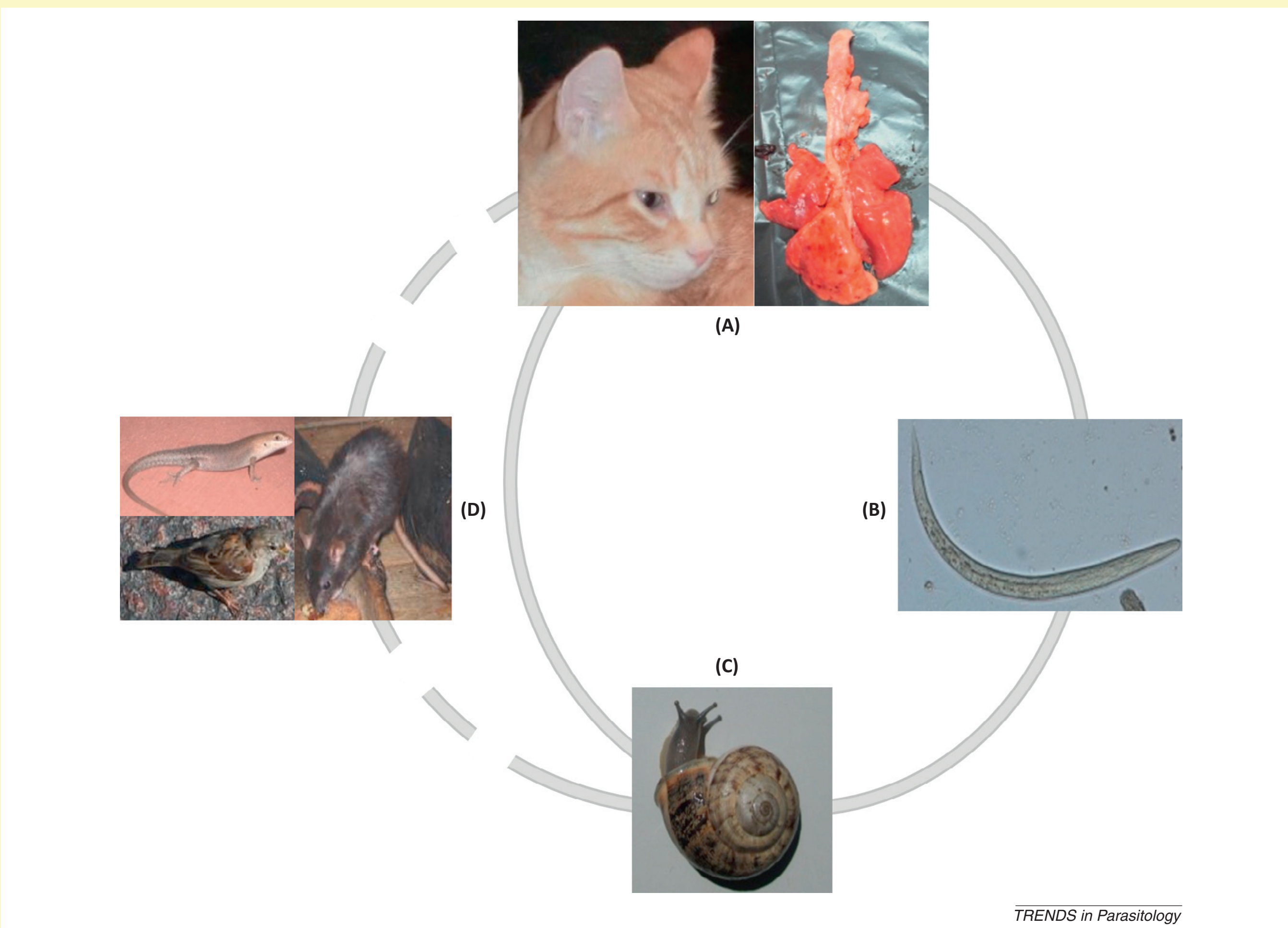

Figure I. The life cycle of felid Metastrongyloidea. **(A)** A cat, the definitive host. **(B)** First-stage larvae are shed with the feces. **(C)** The intermediate host is a terrestrial mollusc. **(D)** Different paratenic hosts may be source of infection.

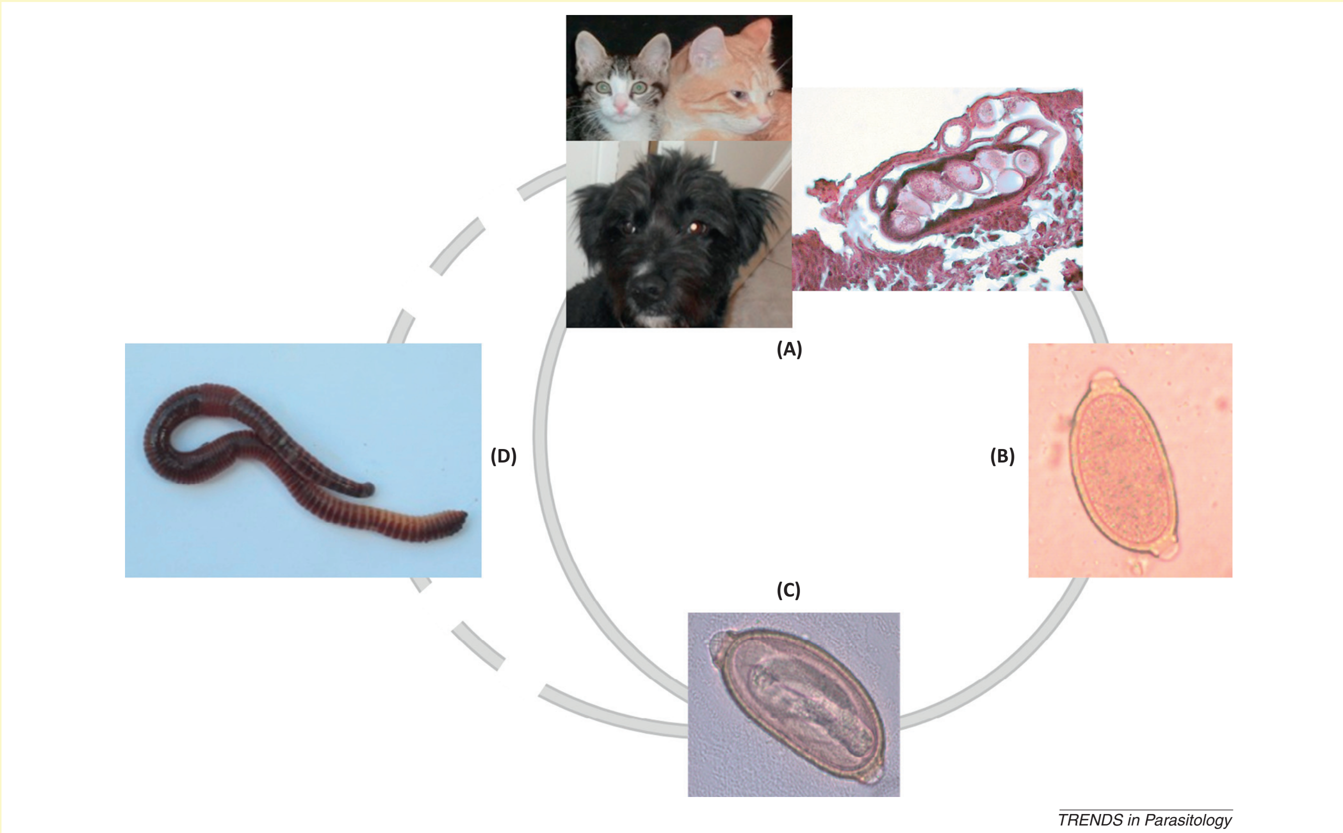

Figure II. The life cycle of *Capillaria aerophila*. **(A)** A carnivore, the definitive host. **(B)** Non-larvated eggs are shed with the feces. **(C)** Eggs become infective in the environment. **(D)** Earthworms are hypothesized facultative intermediate or paratenic hosts.

A. abstrusus and *T. brevior* and have a pointed tail with dorsal and ventral cuticular spines (Figure 1C) [15]. Although one study [15] indicated that morphology and measurements of *T. subcrenatus* in a dead cat were consistent with previous reports [10,27], information on L1s is absent in the older publications. It seems that other than the first description in 1913 of *T. subcrenatus* with a length of 250–270 μm and an undulate tail [28], there is little data available on the L1s [15].

The morphometry of *O. rostratus* L1s is also controversial. The first description of the nematode provided a length of 300–320 μm [5], but a length of 335–412 μm was reported later, thus placing them in the *T. brevior* and *A. abstrusus* range [6,8,22,29]. In any case, the tail with a constriction anterior to the end and tip with a kinked appearance will indicate that such larvae are *O. rostratus* [8,22].

Table 1 summarizes the different information available on key features of metastrongyloid L1s which can be found in

Table 1. Key features of the first larval stage of Metastrongyloidea[a]

Nematode	Tail	Length[b]	Refs
Aelurostrongylus abstrusus	Kinked (S-shaped) with a distinct knob-like or small finger-like projections (a subterminal spine)	306	[23]
		300–390	[4,24–26]
		326–350	[14]
		360–390	[7,22]
		397±10	[6]
		399.1±11.3	[15]
		400±21.3	[19]
Troglostrongylus brevior	Dorsal kink and a less pronounced knob-like structure	300–310	[5]
		311–357	[16]
		339.3±14.1	[15]
		435–521	[14]
Troglostrongylus subcrenatus	Undulate	250–270	[28]
	Pointed with dorsal and ventral cuticular spines	280.7±17.9	[15]
Oslerus rostratus	Constricted anterior to the end and tip with a kinked appearance	300–320	[5]
		335–412	[8,22,29]
		375±17	[6]

[a]Found in the feces of cats.

[b]Measurements in μm.

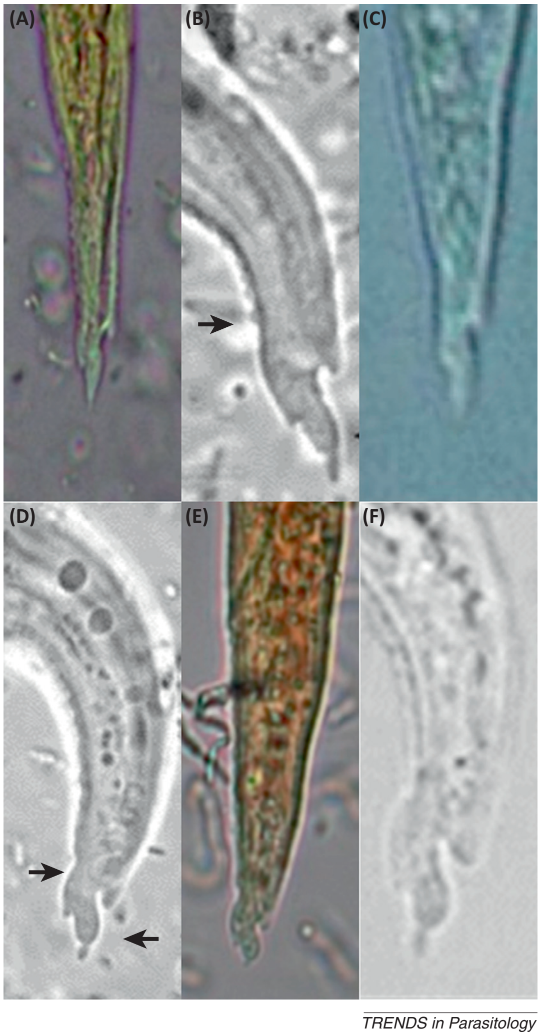

Figure 1. Tail morphology of larval lungworms. **(A)** Image of the first-stage larva of *T. brevior* (reproduced open access from [15]). **(B)** *Troglostrongylus* sp., which was later identified as *T. brevior* (reproduced with permission from [14]). **(C)** *T. subcrenatus* (reproduced open access from [15]). Images of *A. abstrusus* are shown in **(D)** (reproduced with permission from [14]), **(E)** (reproduced open access from [15]), and **(F)** (reproduced with permission from [23]).The arrow in (B) indicates the lack of a dorsal kink, which is present in the tail of first-stage larvae of *A. abstrusus*, as shown by the left arrow in (D). The arrow on the right in (D) indicates the distinct knob-like terminal end of the tail of first-stage larvae of *A. abstrusus*.

the feces of cats. The hypotheses have been put forward that *Troglostrongylus* spp. and *O. rostratus* are more prevalent than currently thought, and that the few records of troglostrongylosis and oslerosis in domestic cats are due to misdiagnosis as a result of overlapping larval features [14,15].

Evidence and doubts

At first glance, general clinical presentations induced by lungworms may appear similar (i.e., infections characterized by the same signs, although of varying degree of severity), thus making definitive etiological diagnosis based on clinical respiratory signs impossible. Aelurostrongylosis is often regarded as subclinical [3], although erroneously, because apparently healthy *A. abstrusus*-infected cats are, in turn, fewer [21,30] than those cats presenting with varying respiratory distress [14,31–34]. Nevertheless, records of fatal aelurostrongylosis are unusual [34,35]. Conversely, clinical signs in cats infected with *Troglostrongylus* are severe, and the infection has been fatal in all cases for which the final outcome of the disease has been disclosed [14–16]. Interestingly, all of the symptomatic cats were kittens less than 6 months of age, with the exception of a subclinical animal aged 1.5 years whose clinical outcome is not known [14]. Hence, it is possible that *Troglostrongylus* spp. establish in young cats, in whom there is perhaps a higher susceptibility to this non-specific parasite, and/or there is an apparent direct route of transmission that is unlikely in adult cats [16]. Only two cats, a queen and a kitten, with troglostrongylosis have been described with no clinical signs; the clinical outcome was not described for either, and in this article [16] the kitten was first reported to be positive for *T. brevior* L1s and was then entirely negative upon copromicroscopy, thus causing confusion to the reader [16].

The clinical severity of troglostrongylosis casts shadows on the hypothesis that *T. brevior* and *T. subcrenatus* have been misdiagnosed in cats for a long time. In fact, cases of fatal aelurostrongylosis in the literature are unusual, even though *A. abstrusus* induces clinical signs worldwide. If troglostrongylosis was frequently misdiagnosed as aelurostrongylosis, records of fatal infections would be more numerous, and this is not the case. Furthermore, necropsy descriptions of cats dead with aelurostrongylosis harboring adult worms larger than those of *A. abstrusus* in the upper airways are lacking. In fact, adults of *A. abstrusus* reside in sub-pleural nodules in the lung parenchyma, affecting bronchioles, alveolar ducts, and alveoli (Box 1), whereas adult *T. brevior* and *T. subcrenatus*, which are bigger than those of *A. abstrusus*, live in upper respiratory airways, that is, the bronchi, large bronchi, and trachea (Box 1). Upon necroscopic gross examination of lungs affected by *A. abstrusus*, 1–20 mm greyish-yellowish sub-pleural nodules containing aggregates of different parasitic stages are found [2,15,35], whereas necropsy of cats infected by *T. brevior* and *T. subcrenatus* showed that they suffered from pulmonary enlargement and congestion, together with multi-spot hemorrhages, diffused hepatization, and lobular flogosis (*T. brevior*), or areas of consolidation and catarrhal exudate in the trachea (*T. subcrenatus*) [15].

Unfortunately, no histological examinations were carried out after necropsy of cats who died from troglostrongylosis, nor is there information available in earlier descriptions on the presence of parasitic stages in the lung parenchyma, rather than in upper airways [5,10]. However, localization of adult *Troglostrongylus* and knowledge of other closely-related crenosomatids [36] might suggest the absence of parasites in alveolar ducts or alveoli and no significant changes in lower airways or pulmonary vessels, although alveoli of cats with aelurostrongylosis present significant and severe histological changes [17,37,38]. Thus, records of eggs and larvae in the parenchyma with the absence of large lungworms in upper airways, together with multifocal sub-pleural nodules distributed throughout the lungs, can be attributed to *A. abstrusus*. Several key examples of necropsy-based studies on aelurostrongylosis from different countries have reported histological findings consistent with *A. abstrusus* and no suggestions of a misdiagnosis [23,34,35,37,39].

Epidemiological and biological drivers

Reports of coinfection with metastrongyloids [6,14] demonstrate that in particular conditions *A. abstrusus* and other lungworms can live in sympatry in the same ecological niches. For these mollusc-borne nematodes this can be explained by the presence of the same molluscs serving as intermediate hosts for different species or by cohabiting of different competent molluscs.

Feral and wild animals have been incriminated as bridging hosts in infections of pets with emergent non-intestinal nematodes [4]. This is also strongly suggested for the trichurid respiratory nematode *Capillaria aerophila* (Box 2) which may be found in coinfections with *A. abstrusus* [40,41]. Although *C. aerophila* is not a metastrongyloid, this parasite is another source of problems in feline medicine, also for its low degree of specificity for animal hosts (Box 2).

It has been suggested that climate changes may nurture the spread of mollusc-transmitted parasitoses [4,42]. A recent climate-matching model has clearly shown evidence both of spread of the mollusc-borne canine lungworm *Angiostrongylus vasorum* within known endemic foci and the appearance of new foci in several regions previously free of infection, together with suitable ecological and epidemiological conditions for a further expansion in the near future [43]. With similar life-cycle patterns, the same factors involved in the spread of *A. vasorum* would likely also have an effect on felid metastrongyloids. In fact, global warming is a potential driver that could promote spread of troglostrongylosis given that *T. brevior* has a shorter development time in *Helicella* spp. [5] compared with *A. abstrusus* in the mollusc *Helix aspersa* [44], at similar temperature ranges. Thus, it could be hypothesized that climate changes may not only favor the dispersion of *A. abstrusus* but indeed also trigger a faster spread of troglostrongylosis than of aelurostrongylosis in the same ecological niches.

Descriptions of *O. rostratus* in cats are few, including studies of single cases [5,6] as well as infections of multiple cats in Sri Lanka [45], Hawaii [46], and Majorca [18]. The hypothesis of a misidentification of *Troglostrongylus* as *O. rostratus* [18] has been put forward [14]. However, no information on the localization of parasites in the lungs or detailed microscopic analysis were provided [18], thus misidentification as *A. abstrusus* could be another possibility considering the unusually high rate of infection described. The assumption that all cats from Majorca were infected with *O. rostratus* provides food for thought on the provenance of most records of infections by metastrongyloids typically thought to only infect wild felids. In fact, case series of oslerosis in domestic cats have been found exclusively on islands [18,45,46], similar to recent reports of *Troglostrongylus* spp. [14–16]. Such apparent geographic confinement could imply that lungworms of wild felids occur mainly in confined regions where they can find suitable epidemiological factors and routes of development and transmission, thus changing their usual host affiliation. If this is true, the descriptions of two single cats diagnosed, respectively, with oslerosis and troglostrongylosis in continental Spain [6] and Italy [16] deserves further epidemiological investigations to unveil their significance.

Box 2. *Capillaria* or *Trichuris*, that is the question

Capillaria aerophila (syn. *Eucoleus aerophilus*) is a nematode living in the trachea, bronchi, and bronchioles of wild animals (e.g., foxes, mustelids), although it has also been described in companion animals, that is, dogs and cats [4,41]. The scant knowledge on the distribution of lung capillariosis in pets is likely due to the misidentification of *C. aerophila* eggs as those of the more commonly known intestinal whipworms. In fact, the bipolar lemon-like eggs of *C. aerophila*, which have the same characteristics (Figure IA) in the feces of dogs and cats [49], may be easily mistaken for the eggs of *Trichuris vulpis*, although this nematode only infects canid hosts. Certainly, it is interesting to mention that recent publications have described cats infected with *Trichuris* sp. or *T. vulpis* without any details of diagnostic features and/or from areas (i.e., Italy) where feline intestinal whipworms have never been recorded [50,51]. This possible erroneous identification of *C. aerophila* eggs is supported by the inability of *T. vulpis* to infect cats and by the absence of feline *Trichuris* spp. in the vast majority of the world, being confined to limited areas of the Americas and a few other regions, where they occur rarely as shown by the number of reports in the scientific literature over the past 40 years [22,49]. In addition, some textbooks report a misleading length of more than 80 μm for *C. aerophila* eggs [22,52], which is more similar to the length of *T. vulpis* eggs rather than *Capillaria* eggs. The actual lengths of *C. aerophila* eggs shed by cats and dogs are less than 70 μm [49], and the differentiation from *Trichuris* spp. should be based on additional features such as wall surface and plug morphology and position [49]. The scenario is more complicated if one considers that cats may shed eggs of rare intestinal or urinary trichurids or trichurid eggs from the birds and rodents on which they prey [22,41]. Although a careful microscopic appraisal allows a definitive diagnosis, limited information and controversial bibliographic sources ultimately indicate the need for a thorough microscopic analysis of any lemon-like egg found in the feces of feline patients. In dogs, conversely, confounding coinfections (Figure I) with *T. vulpis* and *C. aerophila* may occur [41], but this is not the case for cats. It is noteworthy that a pet shedding *C. aerophila* eggs may be a source of dangerous human infection, which can mimic clinical and radiology findings of a lung neoplasia [41,53].

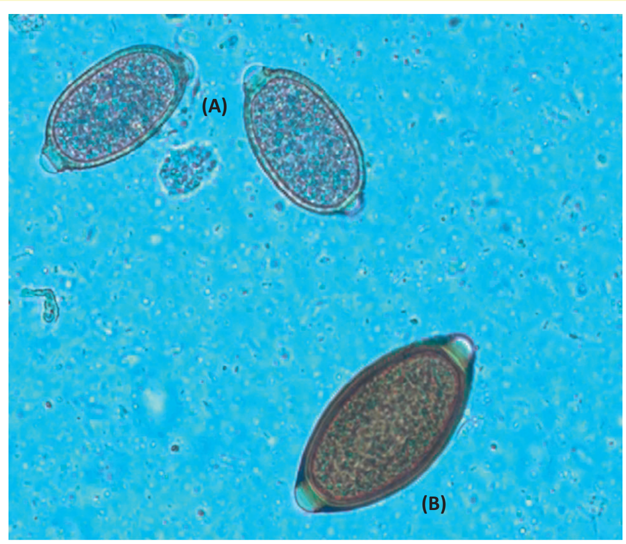

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Figure I. Fecal sample from a dog. **(A)** *Capillaria aerophila* and **(B)** *Trichuris vulpis* eggs are shown.

Box 3. Outstanding questions

- Is *Aelurostrongylus abstrusus* the only species-specific lungworm infecting *Felis catus*?
- When and how do *Troglostrongylus* spp. and *Oslerus rostratus* cause respiratory diseases in domestic cats?
- Do *Troglostrongylus* spp. and *O. rostratus* rarely infect domestic cats, or are they misdiagnosed as *A. abstrusus*?
- Do *Troglostrongylus* spp. always cause life-threatening infection in domestic cats?
- If *Troglostrongylus* spp. are pathogenic but misdiagnosed, why are there few cases of life-threatening lungworm infections in domestic cats in the veterinary literature?
- Is age a key driver in triggering clinical signs in animals infected with *Troglostrongylus* spp.?
- Which epidemiological and biological drivers may nurture bridging respiratory infections between wildlife and *F. catus*?
- Will global warming promote the expansion of feline lungworms?
- Are there differences in the treatment and control of different lungworm infections in *F. catus*?
- How many cats with zoonotic lung capillariosis are erroneously diagnosed with intestinal whipworm infections?
- How many cases of human lung capillariosis remain unrecognized?

Concluding remarks

It is clear that several questions on feline lungworms remain to be answered (Box 3). *Troglostrongylus* spp., *O. rostratus*, and *C. aerophila* (Box 2) are usually considered to be agents of respiratory parasitoses only in wildlife, with a negligible occurrence in domestic cats [3,4,6,15,47]. Therefore, it is unclear whether they have been long neglected, underestimated or, more simply, limited in their geographical distribution and host preferences. This is particularly true for *Troglostrongylus* spp., and it is not known whether: (i) *T. brevior* and *T. subcrenatus* infect domestic cats more frequently than previously thought and are mistaken for *A. abstrusus* due to the close similarity in larval characteristics; (ii) the recent reports are infrequent because of a possible affiliation in domestic felids mostly in confined areas; and/or (iii) some epidemiological drivers may nurture the occurrence of lungworms of wildlife in *F. catus*. A careful and accurate appraisal of key features might allow discrimination of metastrongyloid larvae. In particular, the controversial or absent descriptions of the length of diagnostic stages (L1s) require further investigation and underline the need for careful examination of tail features (Figure 1) for the etiological diagnosis. Although unawareness-driven misdiagnosis in feline metastrongyloid infections cannot be excluded, convincing data suggesting this circumstance are lacking in the veterinary literature. Advances in the molecular knowledge of feline lungworms have been obtained recently with the characterization of diagnostic markers within both ribosomal and mitochondrial DNA of *A. abstrusus*, *T. brevior*, and *C. aerophila* [16,33,41,48], but further characterizations are necessary (e.g., *T. subcrenatus* and *O. rostratus*) together with the validation of DNA-based species-specific diagnostic assays. In fact, genetic assays able to distinguish metastrongyloid L1s simultaneously by the detection of specific sequences in the same target gene (e.g., multiplex-PCR, reverse line blot hybridization) would be powerful to understand which lungworms actually infect hosts on a case-by case basis, even in coinfections. An unequivocal molecular diagnosis would have potential for future trials aiming to evaluate the efficacy of parasiticides against individual lungworms, which at the moment are impaired by the limitation of the microscopic identification. Evidence of misdiagnosis of lung capillariosis is strongly suggested (Box 2) despite: (i) a careful appraisal of trichurid eggs in cat feces ultimately allows the etiological diagnosis and (ii) the recent achievements in innovative diagnostic tests [41].

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