Călin Mircea GHERMAN

# Textbook of Veterinary Parasitology

## Acanthocephala and Nematoda

AcademicPres

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**Some terms and abbreviations**

| Abbreviations | Explanation |
|---|---|
| IH, I.H. | intermediate host |
| DH | definitive host |
| bw | body weight |
| $L_1$, $L_2$, $L_3$, $L_4$, $L_5$ | larval stages, from $L_1$ to $L_5$ |
| mg | milligram |
| kg | kilogram |
| sc | subcutaneously |
| im | intramuscular |
| po, PO | per os |
| antibodies | Ab |
| antigen | Ag |
| EPG (epg) | eggs per gram feces |
| wpt | weeks post treatments |
| syn. | synonym |
| R.H., r.h. | relative humidity |
| s | seconds |

# 1. Acanthocephala

## 1.1. General considerations

Acanthocephalans are a relatively small group of helminthes grouped in phylum Acanthocephala, exclusively parasitic as adults in the intestine of all vertebrate classes. The name of the phylum derives from Greek: *akantha*, spines or thorn + *kephale*, head. The first acanthocephalans were described in 1684 by the Italian physician Franceso Redi, who found white worms with a hooked proboscis in the intestine of the European eels (*Anguilla anguilla*). Since then, about 1,150 species have been described, the vast majority of them parasitizing fish and birds. The highest number of species is found in fish, followed by birds, mammals, amphibians, and reptiles. Their name derives from Greek, *acantho* meaning thorn and *cephala*, head, this association being etymologically translatable as *thorny-headed* worms.

The group resembles both cestodes and nematodes. With the cestodes, they share a well developed anterior hold-fast organ and the lack of a digestive system. With nematodes they share the body shape and the dioecy.

However, there is no phylogenetic proof to show the possible intermediate position of acanthocephalans between cestodes and nematodes.

The phylum is divided into 4 classes (Archiacanthocephala, Eoacanthocephala, Polyacanthocephala and Palaeacanthocephala) and 10 orders which include 22 families plus an unplaced fossil taxa[18]. From a veterinary point of view, there are two important families: the Oligacanthorhynchidae family, which contains the species *Macracanthorhynchus hirudinaceus*, a parasite of swine, and the Polymorphidae family, which includes the species *Polymorphus boschadis*, and *Filicollis anatis*, both parasitizing in web-footed birds.

From a morphostructural point of view, the acanthocephalans are characterized by an unsegmented, cylindrical body consisting of two parts, the praesoma (neck and proboscis) and the metasoma (trunk)[28]. The praesoma represents the anterior part of the body and contains the proboscis armed with rows of hooks. The metasoma is the tubular body where the well-developed reproductive system is located.

The proboscis is an evertable hold-fast organ, used to pierce the intestinal wall of the definitive hosts. In living specimens, the proboscis is usually kept half-invaginated while the "typical" fully evaginated aspect shown in all morphological descriptions is a post-mortem condition. The shape of the proboscis is variable depending on the species, from spherical to cylindrical. The proboscis is an empty structure, filled with fluid. Invagination is actively achieved by inverter muscles while evagination is the result of increased hydraulic pressure.

From the biological point of view, they are biohelminths requiring at least one intermediate host to achieve biological cycle.

## 1.2. Acanthocephalosis of swine (macracanthorhynchosis)

**Definition.** It is an intestinal biohelminthosis with a worldwide distribution affecting pigs, rarely other mammals (humans, muskrats and squirrels), characterized by a chronic evolution that consists in digestive disorders.

**Etiology.** The disease is caused by *Macracanthorhynchus hirudinaceus* included in:

- genus *Macracanthorhynchus*;
- family Oligacanthorhynchidae;
- order Oligacanthorhynchida;
- class Archiacanthocephala;
- phylum Acanthocephala;

***Morphology*.** The adults have a well-developed cylindrical body, stout, pinkish-

whitish, transversely wrinkled. Sexual dimorphism is very pronounced. The males measure between 5.0 and 12.0 cm in length and 2 to 6 mm in width. The females are much longer than males, about 6 times bigger, measuring 30.0-65.3 cm in length and 3-11mm wide[14]. At the anterior end, both sexes have a small organ, called proboscis, used for attachment to the mucosa (figure 1).

**Figure 1.** *M. hirudinaceus* - anterior end, proboscis

It is small, armed, bearing six rows of hooks. This organ is retractable and protractable due to the well-developed sensory nerves and musculature in the proboscis[7,8,10]. Eggs are oval-shaped, brown, measure 110 by 65 μm. They are embryonated when laid, containing the first larval stage called acanthor that is surrounded by a three- (or four, according to other opinions) layered shell, the external layer being pitted[26,27].

***Life cycle.*** (figure 2) The life cycle is indirect, diheteroxenous, with dung beetles (coleopterans from the Scarabaeidae family, *Melolontha vulgaris, Cetonia aurata, Polyphilla fullo, Anomalia vitis,* etc.) serving as intermediate hosts[20]. Intervention of other hosts, such as snails, considered paratenic hosts, is atypical and has not been evidenced in *M. hirudinaceus*. Adult parasites inhabit the small intestine where they are attached to the wall by a thorny proboscis. They feed by an absorption mechanism, the nutrients being acquired through the body surface. They absorb, through their cuticle, the nutrients available in the intestinal contents, sugars, amino acids, triglycerides and nucleotides. Following copulation, the males cover the vaginal opening and posterior end of females with cement from their cement glands, forming a copulatory cap. Its role is to prevent a new copulation made by other males.

The females lay embryonated eggs (containing acanthor) that pass in the feces and are eliminated in the environment. The eggs are ingested by an intermediate host, and hatch, releasing the acanthor. It penetrates the wall of the intestine, using the aclid organ (a spinose structure armed with 6 or 8 hooks). It reaches the hemocoel of the host where it feeds and grows and transforms in acanthella, which is a growing stage. The final stage of development into the intermediate host body is called cystacanth, which is also the infective stage. Definitive hosts are passively contaminated by ingestion of IH which contain cystacanth larvae. The worms develop to the adult stage, in the small intestine of the pig, in two to three months. They attach to the wall of the small intestine and cause nodular lesions. The life span of *M. hirudinaceus* in pigs exceeds one year.

**Epidemiology**

***Geographical distribution.*** The distribution of *M. hirudinaceus* is worldwide, as it is reported from all continents. It was found in pigs, in Belize[9], in the area of Hebei, China (22.52%)[14] and in wild breeding pigs, in the Varzea Amazonian Estuary area, (23%)[22].

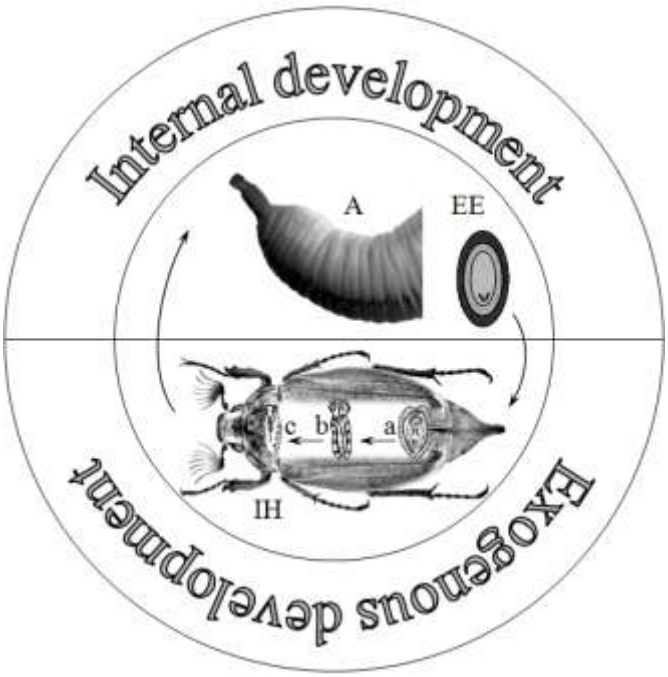


**Figure 2.** *M. hirudinaceus* - life cycle: EE, embryonated egg; A, adult; IH, intermediate host; a, acanthor; b, acanthella; c, cystacanth

Wild boars are highly susceptible to infection and prevalences of 21% in Spain[19], 41.6% in Luristan province, western Iran[25], 19% in the Bursa province of Turkey[24] and 44% in Romania[*] were recorded. The infection occurs also in other species, such as canids. The prevalence recorded was 4.82% in wild canids (stray dogs, red foxes and golden jackals) in the western part of Iran[3] and 45.9% in wild canids (stray and sheepdogs and foxes) in northwestern Iran[31].

***Sources of contamination*.** The sources of environment pollution are usually pigs, but the wild boars may also intervene. Intermediate hosts represent the source for contamination of pigs and exhibit important levels of contamination with cystacanths larvae: 36.6% in the pine chafer (*Polyphylla fullo*), 19.5% in the vine chafer (*Anomala vitis*) and 18% in the common European cockchafer (*Melolontha melolontha*)[11]. The females have an accentuated capacity to pollute the environment, due to their high daily average of egg production, around 260000 eggs and to those 10.000.000 embryonated eggs contained at one time[12]. High density of cystacanths in individual coleopterans (more than 300 in one *Popilla japonica*) ensures a strong source of contamination that exhibits a high potential to induce the development of many adult worms in definitive hosts[17].

***Susceptibility*.** The highest receptivity is recorded in young pigs, aged 8 to 10 months. Probably wild boars are more resistant, but high levels of prevalence are, actually, recorded in this species. This fact may be a response to the increased possibility of wild boars and feral pigs to consume IH compared with domestic pigs.

***The route of contamination*** is oral, by ingestion of infected intermediate hosts.

***Resistance*** of the eggs to the action of temperatures, drying, alternate wetting and drying and ultraviolet irradiation is well-

documented by Kates[13]. The author found that a temperature of 70°C destroys the eggs instantaneously. At 60°C they are destroyed following a 10 minute exposure. At negative temperatures, varying between - 10°C and - 16°C, they survive for as long as 140 days, in water or in dried condition. At temperatures ranging between 5°C and 39°C and 21 to 26°C, for 50 and 265 days, respectively, the author did not record an appreciable reduction in number of viable eggs. Wetting and drying alternation, at 37 to 39°C, destroys the eggs in about one year while at temperatures varying between 2 and 5°C they survive for more than 551 days. Ultraviolet irradiation destroys the eggs placed in a single layer in 10 minutes at a distance of 45 cm.

**Pathogenesis.** Pathogenic actions exercised by *M. hirudinaceus* on the host are mechanical, inflammatory, despoiling, inoculation and toxic-allergenic, complying with the general pattern valid in all helminths.

Mechanical action is due to the large sizes of parasites, especially females, which can cause bowel obstruction or occlusion even in infections with a small number of individuals in the gut. Attachment with the proboscis to the intestinal wall produces pronounced tissue destructions, with the formation of nodules and ulcers at the site of attachment.

Inflammatory action is induced by the proboscis which releases antigens at the attachment sites. Following this release an intense inflammatory response will develop, consisting in predominantly eosinophilic leukocyte infiltration. Combined mechanical and inflammatory actions cause large nodules, visible through transparent serosa, which may be perforated by the proboscis, and peritonitis results[26].

Spoliation is a very accentuated action because of the large sizes of parasites and their food requirements. Acantocephalans absorb the nutrients through their cuticle, each body segment being the site of absorption for a specific nutrient. Triglycerides are taken up at the presoma, and some amino acids are absorbed across the metasomal tegument. Consequently, malnutrition and weakening of animals occurs.

Inoculation is possible in the nodular lesions, which may be, sometimes, invaded by secondary bacterial organisms. Parasitic toxins have a hemolytic effect.

**Clinical signs.** Pig contamination occurs in spring and summer, but clinical signs appear in autumn and winter due to the long prepatent period, between 8 and 12 weeks. The incubation period is 10 days. Symptoms of the disease that may be seen are diarrhoea, weakness, malnutrition, emaciation, abdominal pain.

**Pathology.** Development and attachment of the parasites to duodenal and jejunal mucosa cause nodular enteritis and ulcers. Nodules are visible through the transparent serous; some of them are hemorrhagic and others with tissular necrosis. The worms are attached with the proboscis or are already detached. Ulcers have circular hemorrhagic or fibrotic borders and due to the bacterial superinfections are turned into abscesses. Rarely, the gut wall is perforated by the proboscis and peritonitis results. In chronic forms, the intestinal mucosa is hypertrophied, folded, and the parasites are easily recognizable.

**Diagnosis.** Clinically, it is impossible. Eggs are recovered by sedimentation methods. A positive result reflects the patency of the disease. Parasites attached to the intestinal mucosa are evidenced without difficulty, at necropsy.

***Differential diagnosis*** includes ascariosis, oesophagostomosis, chronic enteropathies due to other causes, solanine poisoning and infectious diseases.

**Treatment.** Avermectins are mainly used with good efficacy:

- Doramectin, given intramuscularly at a dose rate of 0.3 mg/kg bw showed a 62.1% efficacy against *M. hirudinaceus*[29].
- Ivermectin, an in-feed preparation, given at a dose rate of 2 ppm for 7 days had a 13.1% efficacy against *M. hirudinaceus* at 14 days post-treatment (pt), increasing to 76.9% at 36 days pt[21]. At a dose rate of 100 or 200 micrograms/kg of body weight/day, for 7 days, in the same formulation, the efficacy was 100% at 0.1 mg and 85.9% in the case of the second dose[1].
- Flubendazole, at a dose rate of 1.5 mg/kg of body weight, in feed for 5 consecutive days, exerts some activity against *M. hirudinaceus*, but the intensity of infections was too low to make an accurate assessment[2].
- Loperamid hydrochloride, at doses of 1-1.5 mg/kg, given twice daily for 3 consecutive days cures macracanthorhynchosis in pigs[16].

**Control.** The intensive systems of animal exploitation are real barriers against the parasites. The grazing in contaminated areas and feeding the pigs with beetles, in traditional systems of pig production, are forbidden. The use of beetles as food sources is allowed only after their boiling. Removal of feces from pigsties and small runs and bio-thermal sterilization of manure are imposed.

## 1.3. Acanthocephalosis of web-footed birds (polymorphosis and filicolliosis)

**Definition.** These are digestive biohelminthoses that affect domestic and wild web-footed birds (ducks, geese, swans, cormorants). They evolve enzootically, during the summer, and are characterized by a subclinical evolution or a polymorphous clinical picture and nodular enteritis lesions.

**Etiology.** Waterfowl (Anseriformes) are the most susceptible group to acanthocephalans infections due to their high opportunities to ingest aquatic intermediate hosts. Genera *Corynosoma* and *Polymorphus* are the most prevalent in waterfowl. Two species are important for veterinary parasitology of domestic birds: *Polymorphus boschadis* (genus *Polymorphus*, syn. *P. minutus*, *Profilicollis minutus*, *Echinorhynchus polymorphus* and *E. minutus*) and *Filicollis anatis* (genus *Filicollis*, syn. *Echinorhynchus anatis*, *E. filicollis*, *E. laevis* and *E. polymorphus*) both included in the family Polymorphidae.

***Morphology.*** General morphological features of *Filicollis* genus consist in a markedly sexual dimorphism, spherical proboscis of female and orbicular in male and reduced hooks. *Polymorphus* genus is characterized by the presence of an ovoid, cylindrical or pyriform proboscis.

*Filicollis anatis* male has a fusiform, spindle body with spinose anterior part; proboscis is almost spherical, or pear-shaped, continuing with a conical neck. The sizes of males vary between 3.5 to 6.5 mm long, including proboscis and just 3.0 to 5.8 mm the trunk. The armature of proboscis consists in 18-2o longitudinal rows of 9-11 hooks each. The hooks measure between 0.03 and 0.04 mm. The female has an oval body; proboscis is bulbous-like and the neck is long and cylindrical. The total length of females ranges between 10.44 and 14.76 mm and a maximum wide of 1.92-3.24 mm. The proboscis is 1.44 to 1.89 mm long and 1.86 to 2.13 mm width. Eggs are ovoid and measure 60-70 μm length and 20-25 μm wide.

*Polymorphus boschadis* has a small cylindric body, mainly orange but white behind the proboscis, distorted by transverse superficial annulations caused by contractions of the underlying muscle. The male varies in length from 3 to 8.1 mm and the female from 3.5 to 12.2 mm. The trunk has cuticular spines at the anterior end. Proboscis is cylindrical, surrounded by 16 longitudinal rows each

armed with 6 to 10 hooks. Eggs are elongated and measure 110/18-20 μm.

***Life cycle.*** The life cycle is diheteroxenous, similar to that of *M. hirudinaceus* but with the intervention of other intermediate hosts, respectively crustaceans as *Gammarus*, *Asselus* or *Carcinus*. The eggs removed through poultry manure in aquatic environments are ingested by the crustaceans. Infective cystacanths develop in their body within 14 to 40 days in optimal conditions, at 17-26°C. Infective larvae manipulate and modify the behaviour of crustaceans in order to increase their survival related to non-hosts predators and to make them more vulnerable to predation by the definitive hosts[15]. Birds contaminate during the summer by ingestion of infected crustaceans or fish hosts which may intervene as paratenic hosts (in *Polymorphus* spp.). The prepatent period varies between 3 to 4 weeks and longevity is more than 1 year.

**Epidemiology**

***Geographical distribution.*** Acantocephalans infections in domestic and wild waterfowl are widespread, recording different values of prevalence. In domestic ducks from Mymensingh, Bangladesh, *F. anatis* was found in 2.4% of the examined birds[30]. On the Bulgarian Black Sea coast, *F. anatis* was identified in wild birds from the Anseriformes, Gruiformes and Charadriiformes order, namely: garganey (*Anas querquedula*) (33.3%), northern shoveler (*Anas clypeata*), Eurasian coot (*Fulica atra*) (17.5%), common moorhen (*Gallinula chloropus*) (17.3%) and curlew sandpiper (*Calidris ferruginea*) (5.5%)[5]. In the Middle-Bulgarian Region, *F. anatis* was found in the Grey Heron (*Ardea cinerea*)[4]. In Romania, the same species was identified in the Eurasian teal (*Anas crecca*) (5%) and mallard (*Anas platyrhynchos*) (10%)[*]. *P. boschadis* caused mortality in the mute swan (*Cygnus olor*), in Canada[23]. In Hungary, *F. anatis* was diagnosed in the mallard (25%), Eurasian coot (20%) and common goldeneye (*Bucephala clangula*) (33.3%), but infections with *P. boschadis* were absent[6].

***Sources of contamination.*** The reservoir of parasites consists mainly of domestic ducks and geese, and other wild aquatic bird species. All these species represent a source of environment pollution, but their polluting potential is not well known. Crustaceans, as intermediate hosts, are the source of contamination for birds, and paratenic hosts also have a role in bird infections. Migration of waterfowl favors the appearance and dispersal of outbreaks.

***Susceptibility.*** Particular vulnerability is observed in ducks, irrespective to age and sex of ducks and seasons of the year, but geese, wild waterfowl and chickens, all can become infected[30].

***The route of contamination*** is oral, through ingestion of intermediate or paratenic hosts infected with cystacanths.

***Resistance.*** Little is known about the resistance of the eggs laid by the acanthocephalans of birds, but it is estimated that eggs are strongly resistant to the external environment and can survive for more than six months in water at 10 to 17°C. Direct sunlight exposure and prolonged desiccation will destroy them in several weeks.

**Pathogenesis.** The pathogenetic effects of acanthocephalans in birds are very similar to those exerted by *M. hirudinaceus*.

Acute inflammatory action is expressed by multifocal necrotic and ulcerative enteritis while chronic inflammation at the site of attachment causes fibrinous adhesions that involve the viscera, reducing the mobility of the small intestine. Correlated with spoliation caused by the parasites, it will induce emaciation of the birds. Traumatic and inflammatory action consists in the formation of fibrinous nodules on the serosal surface of the intestine. Toxins of parasites act upon the

basal metabolism of the birds and the thermal regulatory system, altering both processes.

**Clinical signs.** There is no correlation between the intensity of parasitism, pathogenic actions, and the clinical manifestation of the disease, respectively Low infections, with a small number of parasites attached to the intestinal wall, may be expressed by severe clinical signs, even death, or massive infections by up to 130 acanthocephalans per bird can evolve subclinically, unapparently. Clinical signs are observed in ducklings and goslings after 4 weeks of age, consisting in a decreased appetite, greenish-yellowish diarrhea, misconduct, adynamia, and in an advanced stage, in astasia, anorexia, weight loss, emaciation, rickets, hypothrepsia, and cachexia.

**Pathology.** Adult parasites attached to the intestinal mucosa cause hemorrhagic and nodular enteritis sometimes with fibrinous nodules on the serosal surface, intestinal mucosal ulcers, perforation of the intestinal wall and peritonitis. Necropsy reveals a large number of parasites, varying between 150 and more than 2000 individuals per bird[23].

**Diagnosis.** From a clinical point of view, the diagnosis is of no value whatsoever. The eggs are identified in feces by sedimentation methods. The presence of nodules at the site of attachment of parasites with proboscis is confirmed during necropsy due to the transparency of the intestinal serosa. The parasites are attached to the intestinal wall, and circular ulcers of the mucosa accompany them.

***Differential diagnosis*** includes histomonosis, trichomonosis, eimeriosis, amidostomosis and acuariosis.

**Treatment.** There is no satisfactory treatment against acanthocephalan infections in birds. Niclosamide at the rate of 250 mg/kg, single oral dose, has expressed a good result, stopping the mortalities in swan flocks in Southern Ontario, Canada[23]. Other medications used are carbon tetrachloride, 0.5 ml per kg bw, per os, mebendazole, 0.5 ml per kg body weight, orally taken for 3 days and fenbendazole, 20 mg / kg bw for 5 days, in the fodders.

**Control.** Measures are difficult to implement due to the intervention of wild birds and practical failure in IH combating. Nevertheless, some remediation measures such as bio-thermal sterilization of manure and limiting the density of the wild waterfowl populations by hunting are recommended. Keeping the birds away from environments that harbor infected intermediate hosts or withdrawal of waterfowl from contaminated ponds are, also, beneficial measures.+

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# 2. Introduction to Nematodes

The former name "helminth" designating a nematode, meant a "*worm living in the digestive tract of humans and animals, and thus was allied with the general concept of parasitism*"[23].

Nematodes belong to the Nematoda phylum and are invertebrate round worms with a worldwide distribution, spread in a large variety of aquatic and terrestrial ecosystems. They can live as free organisms in the environment or cause important diseases for humans, animals and plants. The phylum is one of the most abundant groups of animals, containing 8359 species parasitic in vertebrates, 10 681 free-living species, 4105 species parasites of plants and 3501 species in invertebrate hosts[23].

## 2.1. Systematics of nematodes of veterinary importance

The classification of nematodes is constantly changing due to continuous knowledge acquired on different species. An old classification proposed by Chitwood and Chitwood[13] and revised by Chitwood[11] divided the phylum into two classes: Aphasmidia and Phasmidia (phasmids are small caudal lateral sensory organs, existing in males). Later, the names were changed in Adenophorea, characterized by reduced or absent caudal papillae and an excretory system lacking lateral canals and Secernentea, opposite to previous class, having numerous caudal papillae and an excretory system possessing lateral canals[10].

Blaxter[6] and De Ley and Blaxter[16] proposed a new classification based on an analysis of small subunit ribosomal RNA genes from more than 300 nematode species. Some previous taxa were upgraded in rank, and others were degraded.

More recently, Holterman's et al.[20] researches, based on an analysis of small-subunit rDNA, suggested the presence of 12 clades in the structure of the phylum (table 1).

For an accurate and modern classification of nematodes that cause diseases in domestic animals, we used the system based on the publications of Blaxter et al.[7], De Ley and Blaxter[15,16] and Blaxter[6] (table 2).

**Table 1**. Clade of Nematode phylum based on DNA phylogenetic analysis

| BI Clades | Clade taxa |
|---|---|
| 1 | Enoplida, Triplonchida, Bastianiidae, Rhabdolaimidae (Plectida) |
| 2 | Trichinellida, Mononchida, Mermithida, Dorylaimida |
| 3 | Chromadorida, Prodesmodora (Desmodoridae, Desmodorida) |
| 4 | Desmodorida, Chromadoridae (Chromadorida), Choanolaimidae (Chromadorida) |
| 5 | Monhysterida, Areolaimida, Aulolaimidae (Plectida) |
| 6 | Plectida |
| 7 | Teratocephalidae (Rhabditida, incertae sedis) |
| 8 | Spirurina |
| 9 | Myolaimina, Rhabditina |
| 10 | Tylenchina, Brevibuccidae (Rhabditida, incertae sedis) |
| 11 | Cephalobomorpha |
| 12 | Tylenchomorpha |

**Table 2** The classification of nematodes of veterinary importance used[6,7,15,16] (*Only families of veterinary significance are included)

| Class | Order | Family* | Genus | Disease caused (chapter) |
|---|---|---|---|---|
| Chromadorea | Rhabditida | Ancylostomidae | *Bunostomum* | Bunostomosis in ruminants (2.1.2.) |
| | | | *Ancylostoma* | Ancylostomosis and uncinariosis in carnivores (2.1.1.) |
| | | Uncinariidae | *Uncinaria* | |
| | | Strongylidae | *Strongylus* | Strongylidosis in horses (2.2.) |
| | | | *Triodontophorus* | |
| | | | *Cyathostomum* | |
| | | | *Cylicostephanus* | |
| | | Trichostrongylidae | *Trichostrongylus* | Trichostrongylidosis in ruminants (2.3.1) |
| | | | *Ostertagia* | |
| | | | *Haemonchus* | |
| | | | *Cooperia* | |
| | | | *Nematodirus* | |
| | | | *Hyostrongylus* | Hyostrongylosis in pigs (2.2.1) |
| | | Globocephalidae | *Globocephalus* | Globocephalosis of pigs (2.5.) |
| | | Chabertiidae | *Oesophagostomum* | Oesophagostomosis - Nodular enteritis in ruminants and pigs (2.4.1.) |
| | | | *Chabertia* | Chabertiasis in ruminants (2.4.2.) |
| | | Amidostomidae | *Amidostomum* | Amidostomiasis in aquatic birds (2.6.) |
| | | Dictyocaulidae | *Dictyocaulus* | Respiratory nematodiasis in livestock: dictyocaulosis, protostrongylosis and muellerioses (2.7.; 2.8.1.; 2.8.2.) |
| | | Protostrongylidae | *Protostrongylus* | |
| | | | *Muellerius* | |
| | | Metastrongylidae | *Metastrongylus* | Respiratory nematodiasis in pig (2.9.) |
| | | Syngamidae | *Syngamus* | Respiratory nematodiasis in birds (2.10.) |
| | | | *Cyathostoma* | |
| | | Crenosomatidae | *Crenosoma* | Cardiorespiratory nematodiasis in carnivores (2.11.; 2.12.; 2.13.1; 2.13.2) |
| | | Filaroididae | *Filaroides* | |
| | | Angiostrongylidae | *Angiostrongylus* | |
| | | | *Aelurostrongylus* | |
| | | Strongyloididae | *Strongyloides* | Strongyloidiasis in animals (3.1.) |
| | | Ascarididae | *Ascaris* | Ascaridosis in animals |
| | | | *Parascaris* | |
| | | | *Toxascaris* | |
| | | Toxocaridae | *Toxocara* | |
| | | Ascaridiidae | *Ascaridia* | |
| | | Heterakidae | *Heterakis* | Heterakiosis in birds |
| | | Acuariidae | *Acuaria* | Echinuriasis and Acuariasis in waterfowl |
| | | | *Echinuria* | |
| | | Habronematidae | *Habronema* | Habronemosis in horses |
| | | Onchocercidae | *Onchocerca* | Onchocerciasis in animals |
| | | Setariidae | *Setaria* | Setariasis in animals |
| | | Filariidae | *Parafilaria* | Summer bleeding in horses |
| | | | *Dirofilaria* | Dirofilariosis in dogs |
| | | Thelaziidae | *Thelazia* | Thelaziosis in animals |
| | | Gongylonematidae | *Gongylonema* | Gongylonemosis in domestic animals |
| | | Spirocercidae | *Spirocerca* | Spirocercosis in dogs |
| | | | *Ascarops* | Gastric spiruridosis in pigs |
| | | | *Physocephalus* | |
| | | | *Simondsia* | |
| | | Gnathostomatidae | *Gnathostoma* | |
| | | Oxyuridae | *Oxyuris* | Oxyuriasis in horses |
| | | | *Passalurus* | Passaluriasis in rabbits |
| Enoplea | Trichinellida | Trichinellidae | *Trichinella* | Trichinellosis |
| | | Capillariidae | *Capillaria* | Capillariasis in animals |
| | | Trichuridae | *Trichuris* | Trichuriasis in animals |
| | Dioctophymatida | Dioctophymatidae | *Dioctophyme* | Dioctophymiasis in carnivores |

Further, the content of the book is structured by disease groups, according to their systematization in the main super-families of veterinary interest: Strongyloidea, Strongyloidoidea, Ascaridoidea, Acuarioidea, Habronematoidea, Filarioidea, Thelazioidea, Spiruroidea, Oxyuroidea, Gnathostomatoidea, Trichinelloidea, and Dioctophymatoidea.

On the other hand, the names of diseases from the Standardized Nomenclature of Animal Parasitic Disease (SNOAPAD)[24] are used.

## 2.2. General morphology and structure

Nematodes are invertebrate triploblastic animals, pseudocelomates, with bilateral symmetry and a tubular body plan. They have a cylindrical, unsegmented body, equally or unequally calibrated, with lengths ranging between 1.2 to 100 mm. Most nematodes are dioecious, with an accentuated sexual dimorphism, females being larger than males.

At the anterior end, both sexes show the mouth, with various aspects: simple, rudimentary mouth opening or bounded by a different number of equal or unequal lips. Other species show an oral (buccal) capsule, with different shapes: cupuliform (shaped like a small cup), tronconic (in the shape of a truncated cone) or cylindrical. In hematophagous and histiophagous nematodes, the buccal capsule usually has a very well developed armament consisting in blades, spears, stylets, lancets and teeth.

At the posterior end, females are usually simple, conical, with a subterminal vulvar opening, without ornamental structural elements. The males have different aspects: curled tail with copulatory spicules on the small curvature, or a copulatory bursa, well developed, with two or three lobes, rays (finger-like structures) and spicules.

In a cross section of the body, the following layers are visible: the body wall and pseudocoel that function as a hydrostatic skeleton.

**Body wall** - trilaminar: cuticle, hypodermis and body wall musculature. ***The cuticle*** consists of up to six layers: epicuticle, cortex (inner and outer), medial, fibre and basal[33]. In many species the cuticle has modifications at the anterior end: leaf crowns, vesicles, alae and cervical papillae. Leaf crowns are rows of finger-like protrusions that surround the lips of the buccal cavity. Vesicles are cuticular dilatations around the mouth (cephalic vesicle) or esophagus (cervical vesicle). Alae are lateral expansions of the cuticle similar to wings. Both, vesicles and alae, surround the esophageal region; the alae are located only in the terminal tract of the esophagus, while the vesicles cover almost the entire esophageal region when the alae are missing. Cervical papillae are spiny protrusions, i.e., sensorial structures found in the esophageal region, in pairs. At the posterior end, the cuticle has only caudal papillae and alae. ***The hypodermis*** is a thin tissue layer located beneath the cuticle, usually syncytial; it contains nuclei that thicken in four epidermal cords. These partially divide the pseudocoel and somatic musculature into four quadrants. ***Musculature*** consists of three types of cells: *platymyarian*, wide and shallow, *coelomyarian*, spindle shaped, and *circomyarian*, *which* has contractile fibrils at the periphery[28]. Based on the number of rows of muscle cells per quadrant, there are three arrangements, termed: *polymyarian* (multiple rows), *holomyarian* (1-2 rows) and *meromyarian* (2-5 rows[12].

**The pseudocoel** contains a fluid called hemolymph and there are located the reproductive and digestive systems and other structures. It contains a unique cell type known as coelomocyte and functions as a hydrostatic skeleton.

**The digestive system** is complete: mouth, esophagus, intestine and anus, with the majority of variations occurring in the sizes of each segment.

The mouth was described above, to the aspect of anterior end. The esophagus is an organ with a pump role; it sucks food from the mouth and pumps it into the intestine. It has a variety of shapes, serving as systematic criterion for taxon differentiation. The intestine is a simple, tubular organ that has a wall composed of a single layer of columnar cells. The intestine terminates in a rectum that runs between the anus and the intestine in females, and a cloaca in males. The cloaca is the joint opening of the digestive and reproductive systems and receives their products. The passage of food through the gut is not due to its own peristaltic movements but due to the proximity of the esophagus. Its pumping movements send the food through the intestine.

Depending on their nutrition type, nematodes can be: hematophagous, eating blood; histiophagous, feeding on tissue; or those that eat intestinal content or chyme.

**Reproductive system** - the sexes are separated in most nematode species. Both reproductive systems are solid cords of cells that continue with ducts through which sex cells are eliminated in the environment. These sex cells can proliferate in the inner end of the gonad, and this is called a *telogonic* gonad; when they proliferate throughout the length of a gonad, it is called a *hologonic* gonad.

***The male reproductive system*** is composed of a testis (a single testis in the Rhabditida order and a pair in Enoplea) and a duct divided in a vas deferens and ejaculatory duct that opens into a cloaca. The accessory reproductive organs are the copulatory spicules, almost all nematodes having a pair, and the gubernaculum (telamon in some strongyloid genera), which is a structure that guides the removal of the spicules after copulation.

*Spermatogenesis* is initiated in the distal portion of the testis from cloaca, in the germ cell formation zone, where spematogonia divide mitotically forming primary spematocytes that attach to a support structure called the rachis. Primary spematocytes embedded in the rachis initiate meiosis, detach from the rachis, move into the maturation zone of the testis and become secondary spermatocytes. Meiosis I continues with meiosis II and secondary spermatocytes become round spermatids which remain in the next zone of the testis, toward the cloaca storage zone or seminal vesicle. In the terminal portion of the storage area, the spermatids will be fully developed; mature sperm appear in proximal zone of the testis to the cloaca. Pseudopodial movements of sperm cells are provided by a substance called major sperm protein (MSP) which forms fibrous complexes anchored to the cell[40].

***The female reproductive system*** can be *monodelphic*, having one tract, *didelphic*, which is the most common one, containing two tracts or rarely *polydelphic* (many tracts, up to 10 or 11). The position of the ovaries can be *amphidelphic* (opposed ovaries, one anterior, one posterior to the vulva), *prodelphic* (ovary or ovaries anterior to the vulva) or *opisthodelphic* (ovary(s) posterior to the vulva).

Each tract is composed of an ovary, oviduct and uterus. The ovary is a cord of cells that produce gametes; they move along the ovary, from the upper pole (germinal zone) to the oviduct. The oviduct is tubular; at the limit between the ovary and the oviduct is the storage area or spermatheca. The uterus is a muscular organ with well-developed circular and diagonal muscle fibers. The terminal end of each uterus is muscular and constitutes the ovijector. All ovijectors unite to form the vagina that opens through the vulva, whichhas different locations: at the anterior end, near the mouth, midbody, or it can be posterior, close to the tail.

*Oogenesis* is very similar with spermatogenesis: oogonia situated in the germinal zone of the ovaries become primary oocytes, attached to a rachis. Oocytes increase in size, detach from the rachis and move down

to the maturation or growth zone. Oocytes that enter the spematheca will be penetrated by mature sperm cells. Subsequently, the uterus will take over the fertilized oocytes and the process will continue with egg formation. The peristaltic movements of the uterus will mold the shape of eggs, and the secretory glands from the uterus wall contribute with additional substances to the production of the shell[37].

After mating and fecundation of an oocyte begins the process of *eggshell formation* that is finalized by the forming of a trilamellar structure, generally available in all nematode eggs: an outer vitelline layer, a chitinous layer and an innermost lipid layer (figure 3). In some species, the eggshell contains a fourth layer composed of a muco-polysaccharide protein complex, called the proteinaceous layer.

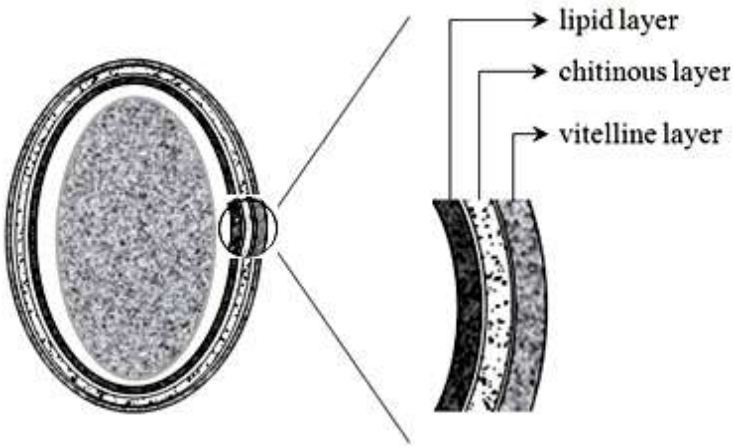


**Figure 3.** Trilamellar eggshell structure of nematode eggs

**Secretory-excretory system** - excretion means the removal of unusable or unnecessary material; secretion is defined as the active release of molecules that convey a survival advantage to the[42]. In nematodes, known for the lack of a recognizable kidney, the main function of this system is secretion in detriment of excretion. The system is not present in all nematode taxa; when it is present, it consists of a singular or double large glandular cell called "renette gland" and a duct that extends to the anterior end, only to open via a ventral pore[5].

In other nematodes, these glands have been replaced by another organ. It consists of two ducts, connected by a single transverse duct that opens into a canal and runs to the excretory pore[2].

**Nervous system** - nematodes have two concentrations of nervous tissues, one of them surrounding the esophagus where it forms the nerve ring, or circumesophageal commissure. The second concentration encircles the rectum, forming the rectal commissure or posterior nerve ring. Each ring serves as a commissure for the ganglia; on either ring there are three ganglia: a ventral, a lateral, and dorsal cephalic one, at the anterior end, and a dorsorectal, a preanal, and s lumbar one on the posterior ring. From each anterior ganglion emanate longitudinal and posterior nerve trunks which embed in the epidermal cords. From the same ganglia emanate anterior nerves which innervate the amphids and cephalic sensory papillae that surround the mouth.

The peripheral nervous system consists of interconnected nerves, originating from nerve trunks, and forming a latticework that provides innervation for the cuticular sensors.
Parasitic nematodes have two types of sensilla: mechanoreceptors and chemoreceptors. Mechanoreceptors consist of two types of papillae: labial and cephalic, located around the mouth and behind the lips, respectively. Many males of different nematode species possess caudal papillae which play a role in copulation. Most nematode species additionally have a pair of cuticular papillae, called deirids or cervical papillae that surround the anterior nerve ring. Chemoreceptors are amphids and phasmids, located at the anterior and posterior end of the nematodes. The amphids may have a secretory function or act as thermoreceptors or mediate thermotaxis[35,31].
Neurotransmission in nematodes (Brooks et al., 2005) is based on two neurotransmitters: acetylcholine, which is the main one[29], and GABA (γ-aminobutyric acid). Acetylcholine acts as an excitant and GABA as an inhibitor of motor neurons. Another substance present in the chemical structures of the nervous system, acting as a neurotransmitter, is glutamate. It is involved in pharyngeal pumping and long-term memory in *C. elegans*[39]. Dopamine, octopamine and serotonin, three biogenic amines found in nematodes, are involved in different processes. Serotonin influences egg laying in *Caenorhabditis elegans*[41], locomotion in *Ascaris suum*[34] and coordination of male copulatory behavior in free-living nematodes[44]. Dopamine and octopamine act as antagonists of serotonin producing movement disorders, decreased eggs laying, disturbances of pharyngeal pump and defecation in some nematode species[22,1,9]. Noradrenalin is also identified in some species of nematodes[18].

## 2.3. Life cycle of nematodes

Despite the accentuated diversity of nematodes, their general life cycle can be related to two basic patterns: geohelminth (or direct life cycle) and biohelminth (or indirect life cycle). Geohelminths are parasitic nematodes with a monoxenous life cycle, without an intermediate host (IH), and all preparasitic stages are found free-living in the environment. Biohelminths involve one (diheteroxenous) or two (triheteroxenous) IH in order to accomplish their life cycle. Other hosts (paratenic, vector) may interfere with their life cycle.
According to the **terminology** proposed by Odening[32], the correct terms that define the types of nematodes in relation with their host number and species are:

- homoxenous parasites (monoxenous) - "parasite transmission via a sequence of hosts of one and the same ontogenetico-cyclic category" (e.g. *Eimeria* spp.). In their turn, homoxenous parasites can be monoxenous (one host species), oligoxenous (two or three host species) or polyxenous (more than three host species).
- heteroxenous parasites need different host categories to achieve their life cycle. The proper terms for the subcategories are diheteroxeny, triheteroxeny and tetraheteroxeny, rather than dixeny and polyxeny.

One of the most important processes that enable the nematode larval development, regardless of the life cycle type, is ***the molting process***. It consists in two steps:

- synthesis of a new cuticle by the hypodermis; this process will continue until the new cuticle will be sufficiently folded under the old cuticle, so that it could be stretched after ecdysis;
- the loss of sheath (exsheathment ) - a process by which the old cuticle is completely destroyed and the new larval stage is released from the old cuticle; the process is facilitated by several enzymes;

***The life cycle of geohelminths*** has two subtypes: "*in ovo*" evolution and *larval development*. Initially, the eggs eliminated in the environment through feces undergo the first stage of embryogenesis resulting in the production of the first larval stage (L1) that remains inside the eggs.

Subsequently, the "*in ovo*" external evolution (figure 4), typical for the Ascarididae, Trichuridae and Oxyuridae families, means that $L_1$ will molt once inside the egg, thus resulting in an infective egg that contains the second larval stage ($L_2$). Contamination of animals, in this case, is achieved orally.

In the *larval development* subtype, characteristic of many families of the Strongyloidea superfamily (Ancylostomidae, Uncinariidae, Strongylidae, Trichostrongylidae and others) $L_1$ hatch in the environment and molt twice, finally resulting in the $L_3$ infective larval stage. Animal contamination is possible in two ways: orally (to the vast majority of nematode species) or by skin penetration (Ancylostomidae, Uncinariidae and Strongyloididae families).

In both subtypes, exogenous evolution is influenced by several abiotic factors, the most important being temperature, humidity and oxygen content.

***The life cycle of biohelminths*** is more complicated and involves a different kind of IH or infective elements for IH, but the internal development or evolution of parasitic forms in IH body is a little bit simplified (figure 5). Depending on the type of infective element for IH, two subtypes can be defined: *contamination with larvae* and *contamination with embryonated eggs*.

*Contamination with larvae* is achieved in species that have viviparous or ovoviviparous females, , and $L_1$ hatch during elimination by the definitive hosts (DH). In both situations, IH will eat $L_1$ directly from the bloodstream (Onchocercidae, Setariidae, and *Dirofilaria*), tears (Thelaziidae), droplets of blood eliminated from skin wounds (Filariidae - *Parafilaria*) or soil (Habronematidae).

*Contamination with embryonated eggs* is common for the Spirocercidae, Gnathostomatidae, Gongylonematidae, Acuariidae and Dioctophymatidae families. Eggs eliminated by females can be embryonated or not; in this case, the first stage of embryogenesis is achieved in the environment with a fast development of $L_1$ inside the egg. Next, these eggs will be eaten by IH.

In both contamination types, $L_1$ will molt twice in IH body, finally resulting $L_3$, an infective element. Animal contamination will be different:

- the inoculation of $L_3$ by hematophagous IH that bites DH, to feed;
- eating the IH that contains $L_3$, by the DH;

Regardless of the contamination route of DH and stage of released larvae ($L_2$ or $L_3$) in both life cycle types, these larvae will follow a tissue migration towards target organs[21]. During migration, larval stages will shed again, once (from $L_3$ to $L_4$) or twice ($L_2 \rightarrow L_3 \rightarrow L_4$) generating $L_4$ which will transform into adults. Sometimes the sexually immature adult stages defined as $L_5$, are developed after new, successive molts.

To conclude, the basic life cycle of nematodes consists of seven stages: an egg, four larval stages ($L_1$, $L_2$, $L_3$, and $L_4$) and two adult stages representing separate males and females.

In the running of the life cycle in many species of nematodes, a state of latent life called hypobiosis or developmental arrest establishes at some point.

The role of this state is to ensure the survival in adverse environmental conditions. Low temperature, dessication, and a decreasing photoperiod are factors that influence the establishment of this state[27].

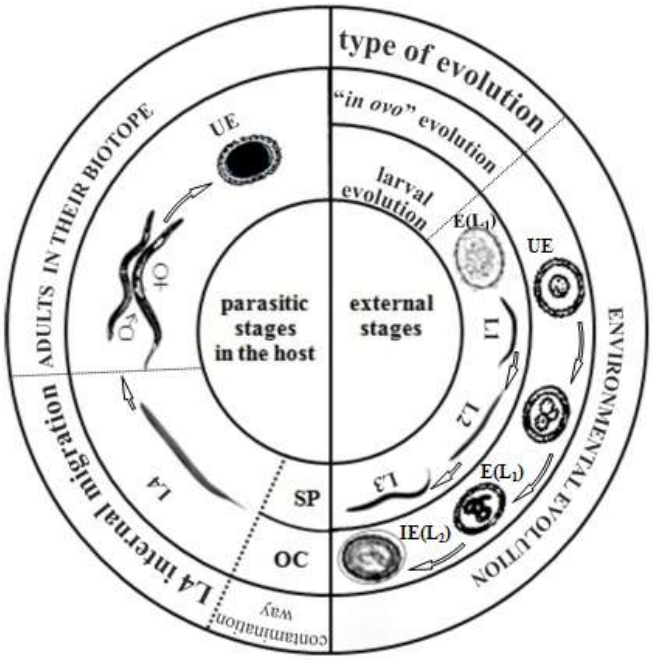


**Figure 4.** Geohelminth type of the nematode life cycle: UE - unembryonated egg; $E(L_1)$ - embryonated egg containing $L_1$; $IE(L_2)$ - infective egg that contains the second larval stage ($L_2$); $L_1$, $L_2$, $L_3$, $L_4$ - larval stages; OC - oral contamination; SP - skin penetration

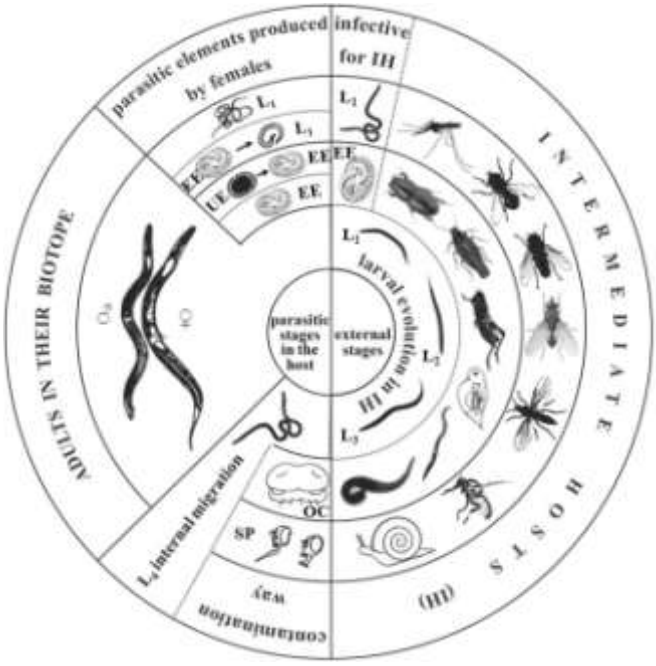


**Figure 5.** Biohelminth type of the nematode life cycle: IH - intermediate hosts; UE - unembryonated egg; EE - embryonated egg; $L_1$, $L_2$, $L_3$, $L_4$ - larval stages; OC - oral contamination; SP - skin penetration

## 2.4. General pathogenesis of nematodes

Despite the variables sizes, different types of nutrition, cuticular armament and endogenous migrations, almost all nematodes exercise the same pathogenic effects: traumatic, nutrition robbing (or spoliation), toxin production, inoculation and interactions of the host immune/inflammatory response.

Some substances serve as chemical communicators in nematodes and help to exercise their pathological actions. These substances are called kairomones and have diverse functions for the receiving organism: hemolysins, histolysins, anticoagulants, antiferments (inhibits host enzymes), attract nutrients towards the parasites, induce protective proliferative reactions around parasites.

The **traumatic action** is dependent on: the size and location of the nematodes, movements in the host body, mouth armament and attachment structures. Because of their size, some species produce compression ***atrophy*** of surrounding tissues (e.g. *Dyoctophyme renale* located in the renal pelvis, causes kidney parenchyma atrophy - medula and cortex). The location of nematodes in ducts associated with their large sizes, causes ***obstruction*** of those canals (e.g. massive infestation with *Ascaris suum* blocks intestinal transit). Movements in the host's body, during internal migrations, and mouth armament are responsible for ***tissues destructions*** (e.g.: migratory larvae of *Ancylostoma* spp. cause lesions to the skin, lung and gut wall; teeth of *Ancylostoma caninum* determine intestinal mucosal injuries; buccal capsule of horse strongyles causes damage at the fixation site).

The **nutrition robbing** (spoliation) is due to the feeding of parasites. The intensity of robbing and the affected components depend on the type of feeding.

Intestinal nematodes, ***eating chyme***, compete with their hosts for nutrition resources because they take nourishment from the digested food. Proteins, lactose, fat, vitamin A and carotene digestion and absorption are the most affected components. Consecutively, characteristic symptoms of malnutrition will set in.

***Hematophagous*** nematodes eat blood causing iron losses and anemia. The daily blood loss, in hookworm infections, may range between 0.03 to 0.15 ml per worm[14], while whipworms can eat 0.2 to 1.5 ml per day[38]. At the same time, this type of nutrition is responsible for loss of blood plasma and its constituents, hypoalbuminemia and other nutrient deficiencies. Achieving hematophagous nutrition is favored by certain parasitic secretions, and namely nematode anticoagulant proteins (NAPs), which inhibit the clotting of blood at the feeding site[17]. Nematodes are also equipped with different structures (blades, lancets, teeth) needed for sectioning mucous membranes, capillary walls and blood sucking.

Other nematodes, so-called ***histiophagous***, feed on host tissues, dead cells, and secretions, which are ingested through several mechanisms, the most common being mucosal scraping.

**Toxic action** is due to the production of two types of toxins: ***exotoxins***, proteic molecules released following the metabolic activity of parasites and ***endotoxins***, resulting from the death of nematodes. Both types of toxins can have a local or a systemic effect.The local, intestinal action of toxins consists in inhibiting the activity of digestive ferments, causing diarrhea/coprostasis and malabsorption by altering membrane permeability. Absorption of toxins from the gut is expressed by blood circulation alterations, convulsions, epileptic seizures and altered hematopoietic mechanisms.

The best-known toxin produced by nematodes is ascaron, released by the ascarid species

following the death of large numbers of parasites. It is a toxic peptone and causes poisoning with symptoms similar to those of anaphylactic shock.

**The inoculation action** consists in taking of pathogens belonging to other groups (bacteria, viruses) by nematodes from the place of penetration into the body (gut, skin), and their circulation through the tissues and organs of the body of the host. These infectious agents are able to cause severe infection on the nematode's migratory route. Migration of ascarid larvae through the lungs of animals is often accompanied by pneumonia, sometimes complicated by bacteria spread by larvae.

Another way to express the relationship between nematodes and infectious agents consists in the creation of access points on the lesions caused by parasites. Subsequently, at these levels, infectious agents will penetrate and disseminate in the host organism. Thus, the associations between accentuated parasitism conditions with ascarids in young animals and the evolution of dysenteric syndromes with bacterial or viral etiology are well known.

The most important pathogenic action of nematodes against their host is alteration of the immune response and **inflammation**. The hypothesis of inflammation caused by nematode aggression is controversial, the reaction being considered, however, as a defense mechanism of the host. In cattle infected with gastrointestinal strongyles, resistant animals can better maintain inflammatory responses at the site of infection, suggesting a mechanism of resistance[30]. Moreover, some nematode's secretions act as anti-inflammatory agent (e.g. filarial product ES-62) and have a therapeutic potential[19]. Another aspect of the interaction between nematodes and the immune response of the host consists in suppressing innate and adaptive pro-inflammatory immune responses by nematodes, while the mechanisms involved in the induction of anti-nematode responses of hosts regulate colitis (inflammatory bowel disease)[43].

Irrespective of the relationship expression between nematode - inflammation - immune response, it is clear that in organs and tissues parasitized by nematodes there appear different types of inflammatory responses: exudative, granulomatous or alteration.

## 2.5. Immunity of host to nematodes

"*Despite an intense effort over 30 years by immunologists, it is still not possible to define exactly how the immune response removes parasites from the host, because of the high degree of complexity and redundancy among various immunological responses*"[26].

However, the types of immunity which are installed in the host due to the aggression of nematodes are known. The ability to acquire specific immunity exists only in vertebrates, and differs from the resistance of the host, which means the susceptibility of the host to the aggression of the nematodes. Generally, two types of immunity are common to all vertebrate animals: innate immunity and acquired immunity. Both involve two categories of substances: antigens and antibodies.

**The innate immune system** comprises: anatomical structures acting as natural barriers, chemical and biochemical barriers, mechanisms and cells that protect the host from infection with a large number of pathogen species.

***Anatomical structures*** are the skin and epithelial surfaces; both form physical and mechanical barriers against nematode aggression due to the contaminant elements at larval stages.

***Chemical and biochemical barriers*** are represented by the low pH and hydrolytic enzymes that create a hostile environment for infective larvae of nematodes. Also, increased mucus production in the digestive tract acts as a trap for nematodes. It is demonstrated that

intestinal mucus is involved in the trapping and rapid expulsion of *Trichinella spiralis* from the gut of rats[4].

The inborn immune ***mechanisms*** are inflammation and complement system activation. The acute *inflammation* is initiated by different types of cells existing in host tissues: macrophages, mastocytes, and histiocytes. These cells have receptors that recognize the pathogens' own molecules and are activated in order to release chemical mediators responsible for the setting in of inflammation. The *complement system* involves more than 25 proteins and protein fractions that help antibodies and phagocytes to eliminate pathogens from the host. Proteases activated by an aggressor, cleave specific proteins to release cytokines and subsequently induce a cascade of further cleavages. The final result will be a massive activation of cell-killing membrane attack complex.

The ***sentinel cells*** involved in innate immunity are: mast cells, phagocytes, macrophages, neutrophils, natural killer cells, basophils and eosinophils.

The **acquired immunity,** or adaptive immune system, is responsible for differentiation of foreign "non-self" from own "self", to generate responses against pathogens and to develop an immunological memory. It comprises highly specialized cells and processes that prevent or eliminate pathogens. The cells involved are T and B lymphocytes, derived from the hematopoietic stem cells. B cells play a role in the humoral immune response, interfering with the synthesis of antibodies, whereas T cells are involved in cell-mediated immune responses, having multiple functions: cytotoxic, helper, regulatory, memory or natural killer. Even if it is a specific immune response, it can be activated by the innate components.

Classification of acquired immunity as active or passive is more or less correct because both types can be natural or acquired[3]. However, systematization of acquired immunity is accepted as active (post-infection or post vaccination) or passive (maternal antibodies transfer or after immunoglobulin administration), according to the manner of development, and sterile or non-sterile (premunition), depending on the persistence or absence of the parasitic agents in the body of the host.

The **antigens** of nematodes are particularly complex and can be included in general classes of these substances, depending on their origin: somatic or metabolic. ***Somatic antigens*** are related to the body structure of live parasites and are released after their death. They exist in all parasites but do not show strong antigenicity and are rarely immunogenic. Depending on their chemical structure, somatic antigens are lipoproteins, glycoproteins or polysaccharides, coupled to other compounds and having a haptenic role. The ***metabolic antigens*** are composed of secretions and excretions resulting as a consequence of parasite activity. These have a great antigenicity and immunogenicity and are specifically immunogenic. Their chemical structure is close to that of proteolytic and lipolytic enzymes.

The nematode **avoidance mechanism** is another aspect of the host-parasite interaction. Despite the various possibilities for the immune system to defend the host body against nematode aggression, the nematodes possess the means by which to eschew this system. The ways to evade are: successive molts that change the antigenic structures of the worm's cuticle, migrations through diverse organs and tissues, presence of a large, cuticular surface that cannot be phagocytosed.

## 2.6. Diagnosis pattern of nematodiasis

The diagnosis of nematodiasis usually involves the corroboration of several methods in order to achieve a diagnosis of certainty. Epidemiological and clinical examinations are

only indicative, being associated with necropsy and fecal examination, to confirm a presumptive diagnosis. In particular situations, when the enunciated methods are inefficient, laboratory methods (mainly immune diagnosis) may be applied for confirmation.

***Epidemiological data*** can reveal aspects of disease seasonality, species and breeds affected, most sensitive age group, and risk factors that favor the occurrence and evolution of the disease.

***Symptoms*** that accompany the evolution of a nematodiasis may exclude a certain group of diseases, uncharacteristic for the clinical picture shown. For instance, intestinal strongyles in horses produce almost exclusively digestive disorders (diarrhea, colic). Other nematodes (hookworms) cause a wide variety of cutaneous, respiratory, digestive and metabolic symptoms, limiting the indicative value of the clinical exam.

The ***necropsy*** allows a diagnosis of certainty, showing location of parasites and lesions caused by them. Regarding the individual, it is a tardy diagnosis, being made after the death of the animal. However, in large collectivities it is useful, often being thefastest and surest method.

***Coprological examination*** means to examine the feces of animals in order to identify eliminated parasitic elements (eggs, larvae), for a definitive diagnosis of the disease. The used methods aim to find and identify helminth eggs, both light (strogyles, ascarids) and heavy (*Fasciola hepatica*), using flotation and sedimentation tests. Another goal of the examination aims to highlight the larvae of pulmonary nematodes (*Dictyocaulus* and *Protostrongylus* genera) and their identification.

***Immune diagnosis*** aims to identify the presence of antibodies, or antigens, in the diseased animal. Common serological methods used in immune diagnosis are: complement fixation, the agglutination and precipitation tests, immunofluorescence and ELISA.

For a high accuracy diagnosis, other laboratory methods involving blood examination can be performed. The values of some biochemical parameters (serum pepsinogen, albumin, globulins, and liver enzymes) or hematological constituents (erythrocytes, leukocytes, total eosinophils) are determined. Particular methods of diagnosis will be described separately, in the case of each disease.

## 2.7. Groups of substances used against nematodes

Nematode infestations are harmful to domestic animals and, which has led to, an active search for nematicide drugs. A wide range of these substances were developed over the past few years, the most modern and active of them being the avermectins. Table 3 presents the systematization of nematicides, including active substances, their mechanism of action and anthelmintic spectrum.

**Table 3**. Classes of nematicide drugs

| Class | mechanism of action | active substances | effective against |
|---|---|---|---|
| Benzimidazoles | Compromise the cytoskeleton through a selective interaction with b-tubulin | albendazole | threadworms, roundworms whipworms, hookworms, lungworms |
| | | mebendazole | |
| | | fenbendazole | |
| | | flubendazole | |
| | | thiabendazole | |
| | | oxfendazole | |
| | | oxibendazole | |
| Diphenylsulfides (Pro-benzimidazole) | Binds to tubulin subunit and interferes with microtubule formation | febantel | roundworms, hookworms, whipworms |
| Amino-acetonitrile derivatives (ADDs) | Paralyzes worms by attacking a previously undiscovered receptor HCO-MPTL-1, present only in nematodes | monepantel | gastrointestinal nematodes of sheep |
| Octadepsipeptides | Binding to a group of G-protein coupled receptors called latrophilins, first identified as being target proteins for α-latrotoxin that can cause paralysis and subsequent death in nematodes | emodepside | gastrointestinal nematodes (cat) |
| Spiroindole | Blockade of cholinergic neuromuscular transmission. | derquantel | gastrointestinal nematodes |
| Hexahydro-pyrazines | Inhibitor of arachidonic acid metabolism in filarial microfilaria, and become more susceptible to immune attack. | diethyl-carbamazine | filariasis in both, dogs and cats |
| | Piperazine paralyses parasites by its agonist effects upon the inhibitory GABA (γ-aminobutyric acid) receptor. | piperazine | ascarids in dogs, cats, horses, swine and poultry |
| Salicylanilide derivatives | Inhibiting oxidative phosphorylation in a parasite | closantel | anti-trematode, anti-nematodes, anti-arthropods |

| Class | mechanism of action | subclass | active substances | effective against |
|---|---|---|---|---|
| Macrocyclic Lactones | stimulate the release of gamma-aminobutyric acid (GABA) at the level of nerve endings and block the transmittance of electrical activity in nerves and muscle cells (Pong et al., 1980) | avermectins | ivermectin | worms, arthropods |
| | | | doramectin | roundworms, lungworms, eyeworms |
| | | | eprinomectin | roundworms, lungworms |
| | | | abamectin | anthelmintic |
| | | | selamectin | heartworms, hookworms, roundworms |
| | | milbemycins | milbemycin oxime | anthelmintic, insecticide, acaricides |
| | | | moxidectin | |
| | | | milbemectin | |
| | | | nemadectin | |
| Nicotinic agonists | acts on the roundworm nervous system as agonists at nicotinic acetylcholine receptors of nematodes causing spastic paralysis | imidazothiazole derivatives | levamisole | roundworms |
| | | | tetramisole | |
| | | tetrahy-dropyrimidines | pyrantel | roundworms, pinworms |
| | | | morantel | |

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# 3. Strongyloidea

**General features.** Generically called strongyls (or strongyles), members of this super-family are characterized by a cosmopolitan distribution, throughout the world, causing diseases primarily in herbivores, but also parasitizing in other species: birds, rabbits and carnivores. Strongyles are, generally, parasites in the digestive or respiratory tracts of animals, but they can be found in others various organs of vertebrate hosts, being responsible for severe diseases in domestic animals and humans.

**General morphology.** A morphological character, highly specific in strongyls, is the presence of copulatory bursa at the posterior end of males (figure 6). The bursa is also called the peloderan, meaning caudal alae that meet posteriorly with the tip of tail. It is a structure composed of three lobes arising from the cuticle as cuticular expansions. The lobes are, typically, unequally calibrated, the lateral ones being more developed, while the medial one is smaller. They are supported by muscular ribs (or rays).

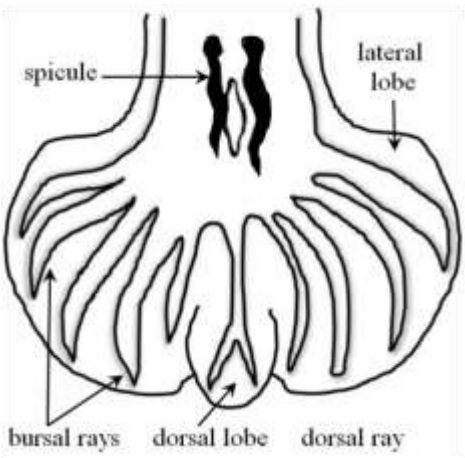


**Figure 6.** Copulatory bursa

The disposition of rays is of great taxonomical value in the classification of strongyles. At the posterior end, strongyles have, in addition, two spicules which may be: equally or unequally calibrated, long or short, thick or thin, and are copulatory organs.

At the anterior end, most of them have large mouth openings and well-developed buccal (oral) capsules which may contain a strong armament, represented by teeth, blades or lancets (figure 7).

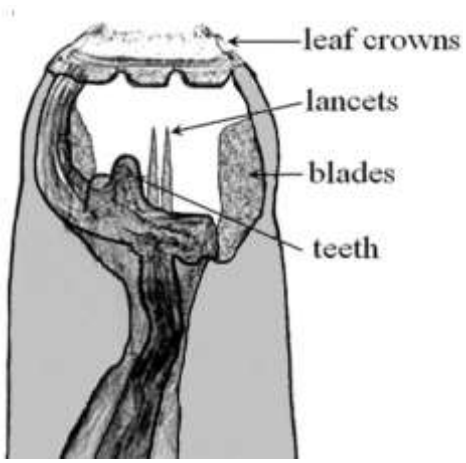


**Figure 7.** Buccal capsule

**General life cycle** (figure 8). Most strongyles have a monoxenous life cycle, but there are some taxa (i.e. Protostrongylidae, Metastrongylidae families) with a diheteroxenous cycle, involving IH.

The typical monoxenous life cycle involves: egg laying by oviparous females (so-called strongyle-type eggs), external environmental evolution of eggs which embryonate, followed by hatching of larvae ($L_1$), two molting processes and finally, development of $L_3$ infective larvae (figure 8a). External development may register some exceptions, consisting in the remaining of $L_1$ inside the eggs where they molt one or two times, ultimately hatching $L_2$ or $L_3$ (*Nematodirus*, Syngaminae) (figure 8b).

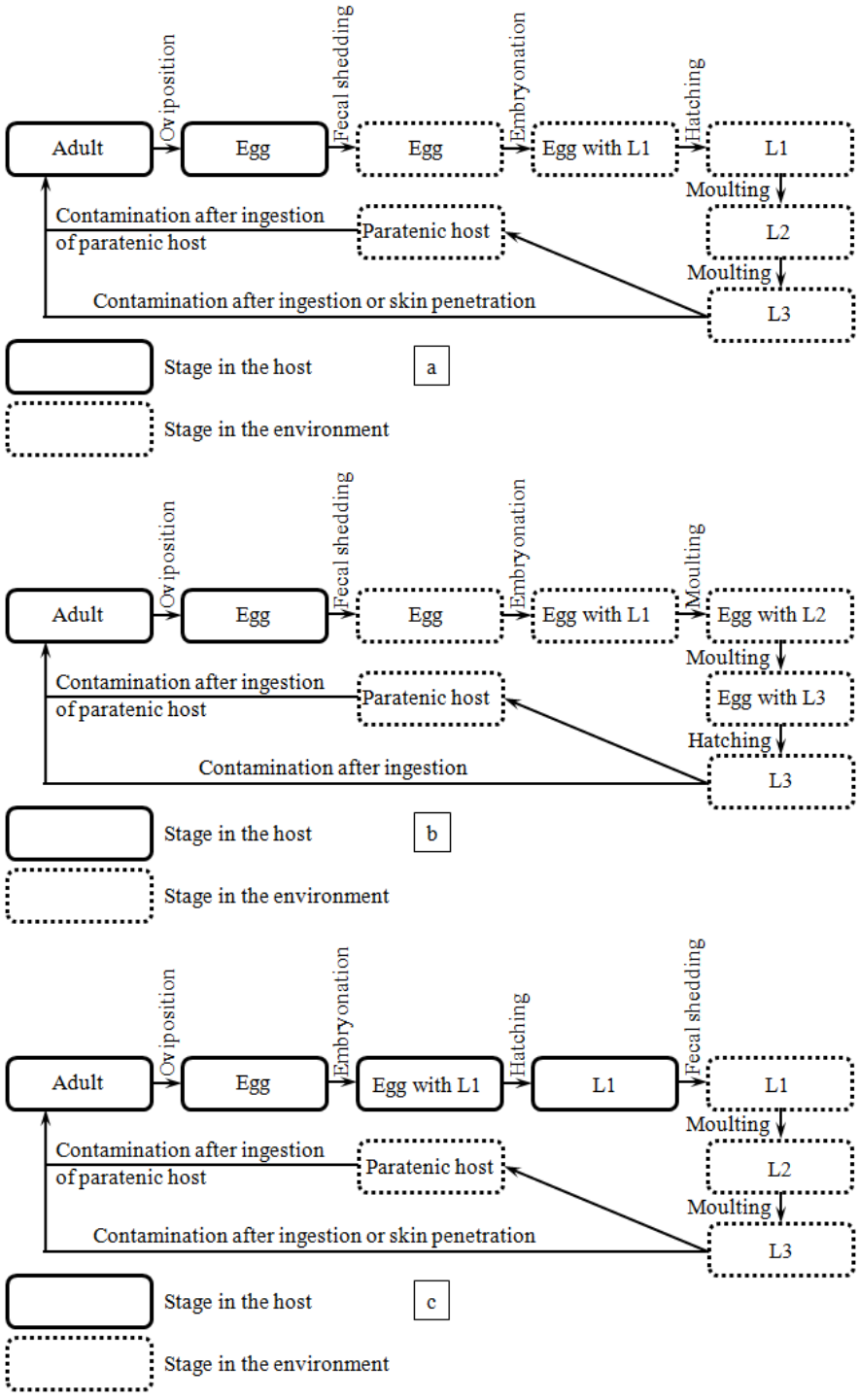


**Figure 8** Life cycle patterns of homoxenous strongyles: a. Eggs embryonate in the environment; $L_1$ hatch and molt to $L_2$ and $L_3$ (i.e. *Strongylus*, *Ancylostoma*); b. Eggs embryonate in the environment; $L_1$ molt to $L_2$ and $L_3$ within the egg; $L_3$ hatch (*Nematodirus*); c. Eggs embryonate and $L_1$ hatch within the host (*Dictyocaulus*).

In other strongyles (i.e. *Dictyocaulus*), eggs embryonate and hatch while still in the host, and $L_1$ are shed in the feces (figure 8c). External stages $L_1$ and $L_2$ feed on bacteria in the environment, or are able to develop and persist without feeding due to sufficient nutrient reserves in their cells (*Dictyocaulus*).

The diheteroxenous life cycle involved IH (earthworms, snails) who eat eggs from the ground and, develop the infective $L_3$ stage in their bodies, by successive molts.

Regardless of the external evolution of thw larvae, animal contamination is achieved by swallowing larvae (Strongylidae), by active penetration of the host skin (Ancylostomatidae), or by eating IH (Metastrongylidae). Following contamination, the larvae of some species accomplish extensive migrations through the bodies of their hosts so that, eventually, the adult stage develops in the target organ.

## 3.1. Ancylostomidae and Uncinariidae: ancylostomatidosis

The families include the so-called hookworms that cause a disease called ancylostomatidosis. Members of the two families are characterized by a cylindrical body, equally calibrated with sizes ranging from 5 to 30 mm in length and color varying from white-gray to red-brown, depending on the stage of feeding. The anterior third of the body is dorsally bent (Ancylo = curved; stoma = mouth). The cephalic extremity presents a buccal capsule, large, lobular and armed; at the posterior end, males have a copulatory bursa with short lateral lobes and two spicules, while females are simple and conical.

The life cycle is monoxenous, with a typical "strongyl" evolution in the external environment where $L_1$ hatch the eggs, then molt twice, the result of which being the $L_3$ infective stage. Contamination is done through the skin followed by internal migration which involves the lungs and trachea and will be completed in the intestine.

### 3.1.1. Ancylostomosis and uncinariosis in carnivores

**Definition.** Nematodosis, known as pernicious anemia, affects carnivores, especially dogs, and manifests itself by a triad of symptoms: digestive, skin, and lung disorders. Both are cosmopolitan diseases, with a zoonotic character and severe outbreaks in tropical and subtropical areas, in precarious health conditions.

**Etiology.** The parasites involved belong to the genera *Ancylostoma* and *Uncinaria* with the next species and host range (domestic and wild species):

Genus *Ancylostoma*

- *A. caninum* (small intestine of dogs, wolves, foxes, jackals, other carnivores, cosmopolitan);
- *A. tubaeforme* (small intestine of domestic and wild felids, worldwide);
- *A. braziliense* (small intestine of dogs and cats in southern Asia - Malaysia, Borneo and Indonesia, Africa, Central and South America and southern United States);
- *A. ceylanicum* (small intestine of dogs, cats, and humans, in Asia: Sri Lanka, India, Philippines);
- *A. duodenale* (small intestine of primates including humans, in Europe, Africa, India, China, Asia, North and South America);

Genus *Uncinaria*

- *U. stenocaphala* (small intestine of dogs, cats, wolves, jackals and foxes, rarely humans, in cool and temperate climates - northern canine hookworm);
- *U. criniformis* (small intestine of mustelids and red fox in Europe);

***Morphology*** (figure 9)

*A. caninum* - the body length ranges between 10 to 20 mm: males measure 10 to 12 mm, and females 15 -20 mm. At the anterior end, the buccal capsule contains the mouth opening and teeth: one pair of teeth, each tooth having three points, located in the ventral area of the capsule, one pair of triangular teeth situated

deep inside the capsule, on its dorsal side, and the last pair of teeth, disposed ventro-laterally. At the posterior end, the males possess a copulatory bursa with developed lateral lobes and the median one atrophied, supported by rays with particular and visible arrangement. The spicules measure 0.73 to 0.96 μm, are equally calibrated and brownish. The posterior end of the female is conical, long and broad, and the vulvar opening is located near the junction of the second and last thirds of the body. The eggs (strongyls type) are oval and contain up to 8 blastomere cells when laid; their sizes range from 63 to 70/39 to 47 μm.

*U. stenocephala* - is smaller than the previous species; the body is equally calibrated, dorsally curved at the anterior end with a large buccal capsule which contains chitinous cutting plates at the ventral edge and two small teeth at the basis of the capsule. The egg is oval in shape and measures 65 - 80/40 - 50 μm; it contains a segmented ovum at the 4 or 8 cell stage.

*A. tubaeforme* - the sizes of males range from 9.5 to 11/0.3 to 0.35 and those of females from 12 to 15/0.38 to 0.43 μm. They have a buccal capsule, smaller than *A. caninum*, with the same armament but more curved dorsally. The copulatory bursa is small and the spicules are longer than those of *A. caninum*, measuring 1.10 to 1.47 μm. The tail of the female is short and narrow. The ranges of eggs are: 55 to 75/34.4 to 44.7 μm.

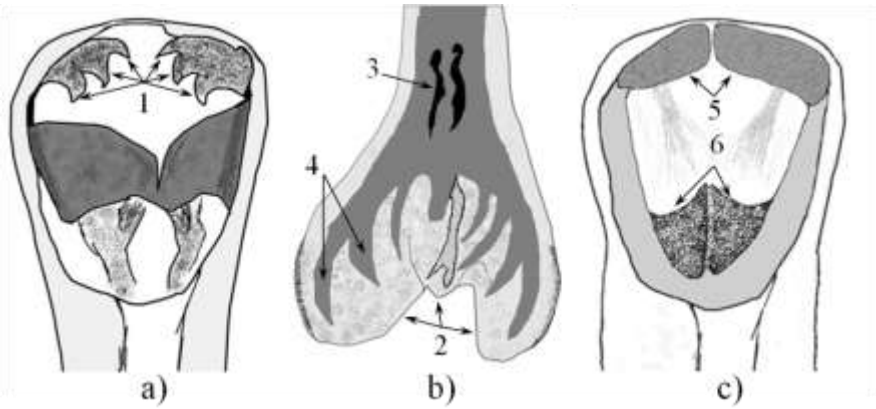


**Figure 9** Head and tail of ancylostomids; a) Anterior end of *A. caninum*; b) Posterior end of males; c) Anterior end of *U. stenocephala*; 1. teeth; 2. lobes of posterior end in males; 3. spicules; 4. rays; 5. cutting plates; 6. small teeth;

***Life* cycle.** The life cycle is direct, monoxenous. Adult parasites are located in the small intestine, predominantly in the posterior third of the jejunum and ileon[213]. They live fixed to the wall and have hematophagous nutrition. After copulation, females lay eggs that pass through the feces into the external environment. The eggs hatch into the first larval stage which molt twice and then emerge into the infective third stage, $L_3$. The egg hatching is influenced by external abiotic factors such as temperature (the most important), humidity, and direct action of sunlight. At 12°C is the eggs hatch in 6-12 days; this perioddecreases as the temperature increases, so that at 23 - 30°C, the eggs only require 9 - 12 hours to hatch. The optimal ambient temperature for larval evolution is about 30°C, when accomplished in 2-3 days, but exogenous development failed at 15°C and the majority of larvae die at temperatures above 37°C.

Contamination is done either by ingestion or via the skin. In the first case, $L_3$ will migrate

through the dermis, enter into the circulatory system and, via the bloodstream, will reach the lungs. At this level they molt again and $L_4$ leave the capillaries and move through the tracheal lumen to the pharynx where they are swallowed. Finally, the larvae reach the intestine where the adults will develop. If contamination is via ingestion, $L_3$ will exsheath in the stomach or intestine followed by the invasion of the gut wall. After a few days $L_3$ emerge into the lumen where they molt, and $L_4$ result, which develop and reach the adult stage.

The third way of transmission is represented by transplacental contamination. The prerequisite that makes it possible consists in skin or oral contamination of adult animals, especially pregnant bitches, which are resistant to the infestations. The migratory larvae will not finish their migration in the adult bodies; they will pass the placental barrier and will remain in an arrested unsheathed third-stage larvae, until the puppies are born. Then, the larvae mature in 10-12 days. During the lactation period, the larvae can locate themselves in the mammary gland of bitches, which allows them to be transmitted via the milk. The transmammary or transplacental transmission of *A. tubaeforme* in cats has not been proven.

The prepatent period in milk and intrauterine transmission ranges between 12 to 16 days; in transcutaneous contamination, followed by tracheal migration, it varies from 18 to 20 days, and in the case of somatic migration, it takes several weeks.

Sometimes, in the ancylostomid life cycle can interfere paratenic hosts (i.e. rodents), in whose body the larvae may remain and survive for intervals of time until they reach the body of definitive hosts. The hookworm larvae have zoonotic potential, causing the human syndrome called "*Larva migrans cutaneous*".

**Epidemiology**

***Geographical distribution***. The diseases caused by hookworms in carnivores have a worldwide distribution, being diagnosed on all continents. Severe outbreaks, with high mortality in puppies and kittens, are registered in those areas where optimal conditions for exogenous evolution are accomplished.

S***ources of contamination*** are the infected dogs, puppies with clinical forms and wild carnivores (foxes, wolves) that pollute the environment. Environmental pollution rate is accentuated, the eggs production of an *A. caninum* female exceeding 16,000 eggs / day[39]. For the animals, $L_3$ infective larvae and paratenic hosts represent the sources of infection.

***Susceptibility***. Different dog breeds and age categories are sensitive, but puppies and young farmed fox do more severe clinical forms of diseases. The prevalence of infestations is higher in stray dogs and cats, than in animals with owners, in kennels with unsanitary conditions as well as in hunting dogs which are more frequently in contact with infective larvae from the environment. Some risk factors influence the receptivity: the access of dogs in pastures and wet ground, the deficient diet (vitamins, important minerals and proteins); the age (adults are more resistant than youth); the sex (bitches are significantly less susceptible than males); category of dog (hunting dogs are the most susceptible compared with pet dogs which are more resistant)[353].

***Route of contamination***: transcutaneous and oral with infective $L_3$ from the external environment; transplacental and trans-mammary with migratory, unsheathed $L_3$ from the pregnant or lactating bitches.

***The resistance*** of parasitic elements in the external environment is influenced by the action of abiotic environmental factors: temperature, humidity, direct sunlight. On grassy pastures, *A. caninum* infective larvae ($L_3$) survival ranges from 1 to 49 days in

summer to late autumn being favored by moderate to high temperature and abundant rainfall. The low temperatures in winter reduce larval resistance, which does not exceed one day, and between March - mid summer, it varies between 0 to 21 days. The materials used to build a kennel affect, in turn, infective larvae survival. On the bare ground and pea gravel, $L_3$ survives between 1 to 7 days and survival is shorter on concrete, from 0 to 2 days. Inside the fecal mass located on these substrates, the survival increases on average by 1 to 3 days. The rain has significant positive effects, while sunlight is lethal[334,335].

**Pathogenesis**. The pathogenic actions refer to the aggression of larval forms when they penetrate the skin and during migration, as well as to those performed by adult parasites in the intestine.

Skin penetration by larvae is accompanied by local inflammatory action consisting in erythema, papules or vesicles. The toxins removed by larvae aggravate local inflammation accentuating itching and dermatitis. During pulmonary migration the larvae act traumatically, causing lung tissue destruction, microbleeds and bronchitis. The larvae also exert an inoculum action consisting in the engagement of other pathogens (bacteria, fungus) from the skin and their circulation during migration, thus aggravating the larval injuries.

In the case of adult hookworms, spoliation is the most accentuated action among the pathogenic effects of nematodes. It is demonstrated that the amount of blood consumed daily by an *A. caninum* female ranges between 43.1 to 46.1 microliters (µl), and 12.9 to 15.8 µl in the case of the male, depending on the blood loss mechanism. These mechanisms are: active sucking and loss through laceration caused by parasites at the attachment site[567]. *U. stenocephala* is less predatory, causing only about 0.3 µl of blood lost per worm a day and the blood lost due to a single *A. tubaeforme* is not measured. Some salivary components [a detergent soluble, haemolytic factor, actually a protein; two proteins: Ac-slp-1 and Ac-slp-2, belonging to the saposin-like protein (SAPLIP) family; *A. caninum* anticoagulant peptide (AcAP)] of ancylostomids have strong anticoagulant and hemolysis effects, favoring nutrition of worms and anemia[143,144,94].

Adult parasites in the intestinal mucosa cause hemorrhagic inflammation and injuries (traumatic action) due to the buccal capsule fixation and sections produced by blades and lancets.

**Clinical signs**. Two clinical evolutive forms can be differentiated: acute, common in puppies with transplacental or transmammary contamination, and chronic, which evolves in young animals, rarely in adults. Both forms are characterized by the symptomatic triad: skin lesions, respiratory symptoms and digestive disorders that occur in dynamics, subsequent to migration of the larvae and development of adults in the intestine

The acute infections are expressed by severe anemia, anorexia, prostration, respiratory embarrassment, bloody diarrhea followed by coma and death.

Chronic forms can be inexpressive, or can evolve pododermatitis, depilation in the lower regions of the body, regional peeling, skin without elasticity, dull hair, dermatitis, oedema of subcutaneous tissues, eczema followed by severe anemia. The weakening is accentuated, youth development is delayed, they lose their liveliness, are adynamic and tired after little effort. The appetite is altered; constipation alternates with diarrhea and the feces contain mucus and blood. The muscle masses are emaciated, and kyphosis and repeated defecation appears. The disease is complicated by intercurrent diseases (rickets, infectious gastroenteritis) and can be fatal in untreated subjects.

The disease is usually accompanied by changes in blood: severe anemia, with

microanisocytosis, polychromatophilia, leukocytosis and eosinophilia in the first months followed by an accentuation of anemia and a mitigation of the other changes.

**Pathology (lesions)**. The evolutive pattern of lesions overlaps with larval migration and adult development, being correlated with the clinical signs, distinguishing three groups of lesions: skin, lung and digestive.

The cachexia is evident in corpses, with serous effusion into the body cavities, ascites, hypertrophy of the mesenteric lymph nodes and liver degeneration. The skin changes are often subtle or sometimes appear as erythema, vesicles, bleb and dermatitis. The pulmonary lesions consist in bleeding, bronchitis and parasitic granulomas. The intestinal lesions are: catarrhal to hypertrophic enteritis, with abundant mucus, hemorrhage and ulcers of the mucosa caused by the parasites' fixation with the buccal capsule; intestinal content is hemorrhagic.

**Diagnosis**. The case history, correlated with epidemiological data and clinical examination, has an indicative value. The coprological exam, using flotation tests, confirms the diagnosis by highlighting the strongyles egg type. It has no value in the prepatent period, in massive infections, when symptoms are severe, but the eggs do not appear in feces because adults are not completely developed in the intestine. Necropsy also has a certainty value, allowing the highlighting of parasites fixed in the gut mucosa.

***Differential diagnosis*** will be done with other helminthiasis (toxocariasis, strongyloidiasis, and trichocephalosis), coccidiosis and nonspecific gastro-enteritis. Ancylostomosis will be differentiated by skin acariosis (scabies, demodicosis, and cheyletiellosis), allergic dermatitis and dermatosis caused by the larvae of the free-living saprophytic nematode *Pelodera strongyloides*. Pulmonary symptoms can be confused with cardiopulmonary and tracheobronchial strongylidosis.

**Treatment**. Good results are obtained with:

- Mebendazole, 20 mg/kg body weight (bw)/day for 3 consecutive days, per os (PO), 95% effective against adult hookworms, but has no effect on migratory larvae[68].
- Fenbendazole, 25 mg/kg bw, 3 consecutive days, orally, active against larval and adult forms.
- Pyrantel pamoate, 14.5 mg/kg bw, PO.
- Nitroscanate, 50 mg/kg of body weight, PO, 99.6% efficacy against *A. caninum*[121].
- Avermectins, 0.2 mg / kg, subcutaneous and PO, with maximum efficiency[350].

In severe cases, symptomatic therapy based on rehydrated medication, general tonic, vitamin therapy ($B_{12}$), parenteral iron and a protein-rich diet, is associated.

**Control**. Preventive measures are based on general rules of hygiene associated with the application of a prophylactic deworming program.

Hygiene in kennels aims: create a smooth floor kennel, without crevices; keep it clean and dry; remove litter and feces, daily; wash the cages and, periodically, treat the soil with sodium borate, lethal to larvae.

Regular anthelmintic therapy (chemo-prophylaxis) differs depending on the age of animals and their physiological status in relation to reproduction, but it is valid in all nematodoses in dogs. Three categories can be distinguished, each including one or two subgroups: adults before mating (i) and pregnant females (ii), newborn puppies between 0-2 months (iii) and 2-6 months (iv), and youths and adults (v) from 6 months to reproductive period.

Adults, males and females before mating (i); this deworming targets all helminths (cestodes and nematodes) parasitizing the animals at this time, and the migratory or encysted larvae in the female body. Useful drugs are those that contain a combination between a cestodicide (praziquantel) and one or two nematocides (benzimidazole derivatives and/or tetrahydropyrimidines - pyrantel, morantel).

The treatment should be administered 10 or 14 days before mating.

During pregnancy (ii), the goal of deworming is to destroy all larvae that migrate towards the body of the fetus, or those that crossed the placental barrier and are localized in the liver of fetuses. It is better to avoid the use of benzimidazoles derivatives at this point because of their adverse reactions (mutagenicity, abortion). The levamisole expresses a good larvicidal effect and tolerance and is indicated for use in pregnant bitches, but only in the second period of gestation.

In newborn puppies (iii), between 0-2 months of age, the deworming targets the migratory larvae in their bodies, consecutive to transplacental or transmammary contamination. Levamisole remains the best option at this point because of its tolerance. The first treatment must be applied at 3 weeks of age, before the adults' development in intestine. Further, until the age of 2 months, the deworming program is correlated with vaccination; each vaccine must be preceded, at 7 days, by an anthelmintic treatment, using the same levamisole.

In puppies, 2 to 6 months of ages (iv), youths and adults (v) from 6 months to the reproductive period, the target of prophylactic deworming is similar with that of the first category: all helminths (cestodes and nematodes) parasitizing the animals. Consequently, commercial products with a broad anthelmintic spectrum, cestodicide and nematocide, can be used

**Notes**: In humans, the "visceral larva migrans" syndrome can be determined by L3 larvae of A. caninum, with a high frequency in people whose skin is in contact with water or soil contaminated with infective larvae.

### 3.1.2. Bunostomosis in ruminants

**Definition**. It is a geohelminthosis of large and small ruminants, manifested by skin, digestive, respiratory and general disorders, caused by nematodes included in the *Bunostomum* genus. The disease, common in pasture season, has a cosmopolitan spread, being often associated with trichostrongylidosis and oesophagostomosis.

**Etiology**. The species involved belong to the genus *Bunostomum*:

*B. trigonocephalum* (small intestine of sheep and goats, particularly in lambs, worldwide distribution);

*B. phlebotomum* (small intestine, usually in the anterior jejunum and/or duodenum, especially in calves, cosmopolitan);

***Morphology***. Both species have a cylindrical body, equally calibrated, with variable color, from whitish to grayish. The length ranges from 1 to 3 cm and they are anteriorly hooked.

*B. trigonocephalum* - at the anterior end, it has a large buccal capsule, cup-shaped, armed with a pair of chitinous cutting plates, a pair of lancets at its base and an internal cone (figure 10).

*B. phlebotomum* is very similar to the previous species, but has two pairs of lancets at the base of the capsule. In the males of both species, the caudal bursa is well-developed, and has two lateral lobes and an asymmetrical median lobe. The spicules differ in the two species: short and twisted in *B. trigonocephalum* and very long and slender in *B. phlebotomum*. The posterior end of females is simple, conical, and the vulvar opening is located close to the middle of the body. The eggs, oval-shaped, measuring 79–117/47–70 μm, have a double and thin shell with a roughened surface, and contain four to eight, even 16 blastomeres.

***Life cycle***. It is monoxenous and consists in the alternation of the endogenous phase with that from the external environment. Adult parasites are fixed with the buccal capsule into the intestinal mucosa and have hematophagous nutrition.

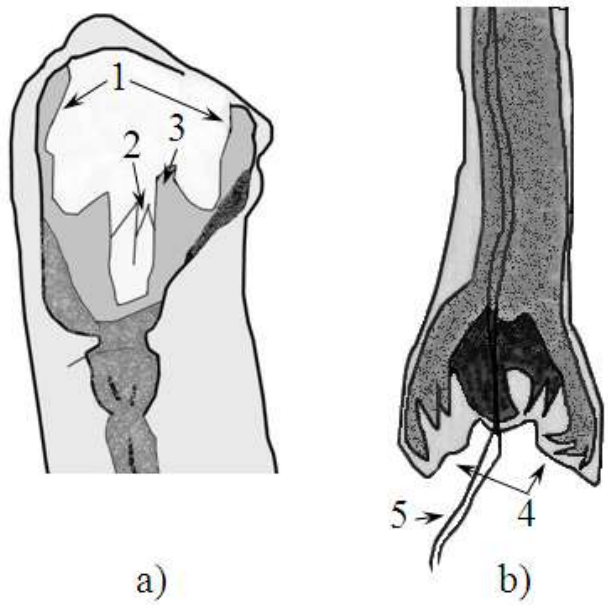


**Figure 10** *Bunostomum* spp.; a) anterior end; b) posterior end (caudal copulatory bursa); 1. chitinous cutting plates; 2. lancets; 3. internal cone; 4. lateral lobes; 5. spicules;

The females are oviparous; eggs eliminated through feces in the external environment will embryonate and hatch in 24 hours at optimal temperature (20-30°C), relative humidity and aeration. The first larval stage ($L_1$) molts twice and develops to 3rd-stage larvae ($L_3$) after 5-6 days.

Contamination is commonly transcutaneous, the larvae having positive histotropism, or oral (rare), with water and feed, when larvae penetrate the bucco-esophageal mucosa. The larvae perform a hematogenous migration, reach the lungs, pass into the alveoli, bronchi and pharynx, then are swallowed and reach the intestine. The migratory larvae molt once and will differentiate sexually. The prepatent period ranges from 6 to 10 weeks depending on the route of contamination.

**Epidemiology**

***Geographical distribution*** is worldwide for both species, but more common in tropical and sub-tropical areas.

***Susceptibility***. The most sensitive category is represented by the ruminant youth, up to the age of 4-12 months, but some risk factors such as malnutrition, with deficiencies in protein, vitamins A and C, minerals (Fe, Ca) accentuate sensitivity. The calves infected during the first year of grazing are resistant to the next grazing season.

***Route of contamination***: skin penetration and ingestion, both achieved by $L_3$ infective larvae.

***The resistance*** of eggs differs compared to that of the larvae, being influenced by temperature, humidity and other factors. The eggs are destroyed in 12 hours at 40°C, but about 25% of them survive for 8 weeks at 5°C and for one hour at -12°C and -17°C. Humidity is very important; 30% of the eggs will embryonate at 100%, but in plain water all $L_3$ infective larvae are inactivated in 34 days at 35°C[41].

**Pathogenesis**. The pathophysiological mechanisms are similar to those of ancylostomosis. Larvae exert a traumatic action when they penetrate the skin and during their migration. They may carry pathogens taken from the skin, causing dermatitis. The aggression of adult parasites consists in a spoliatory action, successive to their hematophagous nutrition, causing acute or

chronic anemia and hypoproteinemia. The traumatic action in the gut, correlated with nutrition of parasites, is expressed by hemorrhagic areas.

**Clinical signs**. In young animals (lambs, kids, calves), the disease begins with skin disorders: dermatitis at the site of penetration, licking the legs, feet stamping, elevated temperature followed by respiratory symptoms (transient cough), and, rarely, even sudden death. After completion of the migration phase, digestive symptoms will appear: inappetence, diarrhea sometimes with melena and animals lose weight even to emaciation. Other clinical signs include anemia, illthrift, submandibular oedema and prostration.

**Pathology**. Initially, dermatitis with a cord-like aspect appears, followed by microhemorrhages in the lung, bronchitis, and even bronchopneumonia. In the intestine, catarrhal or ulcerative enteritis, petechiae and mucosal edema can be observed In the chronic forms the intestinal mucosa is thickened, the parasites are attached with the buccal capsule, and hydrothorax and hydropericardium are present.

**Diagnosis.** It is difficult to establish an intra-vitam diagnosis because of the nonspecific symptoms, common to other helminthiasis and due to the serious disorders in the prepatent phase, when the coprological exam is negative. In the patent period, the coprological exam is positive, but it has a group value (usually, eggs cannot be differentiated from those of the Trichostrongylidae family). Coprocultures are required to identify the species, which involve laborious methods. Necropsy remains the reliable diagnostic method.

***Differential diagnosis*** shall be performed on other digestive parasitosis with similar symptoms: strongyloidiasis, tricho-strongyliasis, trichocephalosis, moneziosis, and even fasciolosis.

**Treatment.** Good results are obtained by using pro-benzimidazole and benzimidazole derivatives or avermectins.

Febantel, at a dosage of 5 mg/kg bw, showed a therapeutic efficacy of 99.4% against experimentally induced *B phlebotomum* infection. In the same trial, the efficacies of ivermectin, paste formulation, at a dosage of 0.2 mg/kg bw were 100 and 99.8%, respectively, at 18- and 60-day post-infections[594]. Albendazole, 5 mg/kg bw, is 96.2% effective against *B. phlebotomum* in cattle[586]. Moxidectin, 0.2 mg/kg bw, subcutaneously injected, was 100% effective against *B. phlebotomum* adults and L4[581].

Levamisole topical at 10 mg/kg bw, thiabendazole paste at 110 mg/kg bw and fenbendazole paste at 10 mg/kg bw have expressed different values of the effectiveness at 7 days post-treatment: 99.1%, 66.7% and 100%, respectively[580].

**Control**. Primary measures involve pasture management and chemoprophylaxis. Secondary measures involve the hygiene of shelters, waterers and feeding pens, which will reduce infection.

The pasture management aims to avoid egg and larva accumulation. The alternation of different species on the pastures, implementation of an integrated rotational grazing system of different age groups within a single host species and alternation of grazing and cropping are management techniques that can provide safe pasture. The reduction of animal contamination chances on pastures can be achieved by keeping pastures well-drained, by avoidance of wet pastures and destruction of infective larvae from the pasture.

Chemoprophylaxis can be achieved by regular deworming or by the use of different types of boluses with large time-release.

Regular deworming involves the periodical administration of a therapeutic dose of antiparasitic substance (the same as the one used in the treatment phase). The periodicity of deworming varies depending on author,

tradition or parasite biology. Suteu and Cozma[521] indicate prophylactic deworming during the spring, 10 to 14 days before going out to pasture, and in autumn, 2-3 weeks after the start stabulation. French tradition claims that deworming must be performed during the new moon, because the worms are more active then. Biodynamic agriculture, developed by the Austrian Rudolf Steiner, recommends deworming in periods of full moon. Considering the biology of parasites, the first deworming is recommended three weeks after the animals have been put out to pasture, to prevent infection by infective larvae ($L_3$ stage) and to kill adult parasites in animals bodies, to avoid the contamination of pastures by egg-laying. The second treatment will be performed three weeks later, when infectious larvae in the pastures will have died as a result of the hot and dry conditions. The best deworming program seems to be quarterly, because it ensures the "free of parasites" preservation status throughout the year.

In terms of large time-release boluses, a variety of devices for administering substances to ruminants are known, containing morantel, levamisole, ivermectin, or benzimidazoles. The principle of their action is to release their contents into the rumen over an extended period. In this way, controlled amounts of medicaments can be administered to the ruminant over a given time period, animals being thus protected against a new parasitic infection.

## 3.2. Strongylidae: Strongylidosis in horses

The family Strongylidae includes roundworms common in equines and is divided into two subfamilies: the Strongylinae (the large strongyles) and the Cyathostominae (the small strongyles). Both groups are some of the most important nematodes of domestic equines throughout the world because of their high level of pathogenicity.

Morphologically, the strongyles are characterized by a cylindrical and equally calibrated body, whitish to brownish, depending on the nutrition status, with sizes ranging between 15 to 50 millimeters. A well-developed buccal capsule, a mouth collar with two leaf-crowns, is present at the anterior end, and a trilobate copulatory bursa at the posterior end,.

Their life cycle is monoxenous, the infective element being the $L_3$ larval stage. Contamination is performed orally, and the larvae migration differs from species to species.

**Definition.** Strongylidoses are cosmopolitan geohelminthoses of equines which frequently evolve subclinically, acutely or chronically, with digestive disorders, colic syndrome, anemia and weight loss. Their incidence is higher in animals at pasture, but they also develop in animals kept in shelters.

**Etiology.** The species involved, divided into large and small strongyles, belong to the Strongylidae family. The subfamily Strongylinae (large strongyles) includes 5 genera: *Strongylus*, *Triodontophorus*, *Bidentostomum*, *Craterostomum*, and *Oesophagodontus*, and contains around 15 species. The 4 major large strongyle species of horses are *Strongylus equinus*, *Delafondia* (*Strongylus*) *vulgaris*, *Alfortia* (*Strongylus*) *edentatus*, and *Triodontophorus serratus*. Their length varies between 25 to 50 mm and they are also known as blood, red or palisade worms. The small strongyles (subfamily Cyathostominae), with lengths between 6-25 mm, include 64 species divided into 14 genera, referred to as trichonemes or cyathostomes: *Cyathostomum* sensu stricto, *Coronocyclus*, *Cylicocyclus*, *Cylicodontophorus*, *Tridentoinfundibulum*, *Cylicostephanus*, *Skrjabinodentus*, *Petrovinema*, *Parapoteriostomum*, *Poteriostomum*, *Gyalocephalus*, *Hsiungia*, *Caballonema*, and *Cylindropharynx* (Lichtenfels et al., 1998). One of the most important species is

*Cylicostephanus longibursatus*, synonymous with *Cylicostomum longibursatum* or *Trichonema longibursatum*.

***Morphology.*** (figure 11)

*Strongylus equinus*: the male measures 25 to 35 mm in length and 1.2 mm in width, while the female size varies between 40 - 50/2 mm. At the anterior end, it has a cup-shaped buccal capsule, armed with 4 teeth at its base and a mouth collar with two leaf-crowns at the anterior extremity of the capsule. The adults parasitize in the cecum and colon, while the larvae ($L_3$ and $L_4$) – in the liver, pancreas and peritoneum.

*Delafondia vulgaris*: the size of males is 14 to 16 mm long per 1 mm wide and that of females, 20 - 25/1.4 mm. The buccal capsule is well developed, equipped with 2 lobate and elongated teeth. The adults parasitize in the cecum and colon and larvae ($L_3$ - $L_4$) in the walls of the abdominal arteries (large mesenteric and iliac vessels and mesenteric lymph nodes).

*Alfortia edentatus*: the male measures 23 to 28/13 mm, and the female 25 to 45/2 mm. The buccal capsule is developed, equipped with a double crown of papillae at the entrance, but it is unarmed, without teeth. The adult parasites have the same location, but $L_3$ and $L_4$ migrate in the liver and peritoneum.

*Triodontophorus serratus*: the anterior end looks like an inverted saucer. The male length ranges from 18 to 20 mm, and the female between 25 to 27 mm. The buccal capsule is round, well-developed and is armed with four (or two split) teeth on the floor of the capsule. The teeth are denticulated on their surface. The caudal bursa has fine scalloped edges and the spicules are long and thick.

The large strongyles eggs have the characteristics of the group, being unidentifiable by species. They are oval, ellipsoidal, thin shell, composed of two dark gray membranes. Their dimensions are 75 to 95/40 to 54 μm and, when females lay them, they are in the morulation phase containing 8 - 16 blastomeres.

*Cylicostephanus longibursatus*: the body length of the male is between 4.3-6.9 mm and that of the female, 4.7-8.0 mm. The buccal cavity is poorly developed, cylindrical or slightly truncated cone-shaped, almost as deep as it is wide, equipped with a leaf crown, non-prominent teeth in the esophageal funnel, and their walls display a compound curve, thicker anteriorly. The caudal bursa is trilobated, with its median lobe developed, elongated and the laterals atrophied; the dorsal ray of the bursa is extremely long; spicules are long (550-970 μm) and thin. The adults are localized in the cecum and colon.

The small strongyle eggs are similar to but larger than those of large strongyles, measuring 80 to 100/45 to 50 μm.

***Life cycle*** is monoxenous and can be divided into three phases according to their location and stage of development: *the luminal phase* when adult strongyles are located in the intestinal lumen, *the environmental phase* consisting in egg and larva development on the pasture, and *the tissue phase,* represented by the migration of the larvae in the different tissues (figure 12).

*The luminal phase*. The adults live in the cecum and colon in horses, donkeys, mules, wild equines and eat blood or tissue, staying tightly fixed with the buccal capsule on the mucous membrane. The females lay eggs, which are dispersed by feces in different biotopes.

*The environmental phase*. On various oxygenated supports, at a favorable temperature of about 26$^{o}$C, embryogenesis is accomplished, and the first larval stage ($L_1$, rhabditiform larvae) hatches the egg in 24 to 48 hours. Under favorable environmental conditions, $L_1$ molt twice within a week and develop into $L_3$ (strongyliform larvae) infective larvae, which are surrounded by protective sheaths.

The free larval populations ($L_1$ - $L_2$) feed while the $L_3$ stage does not feed due to the preserved molting cuticle. All larval stages are mobile in wet environments, climb on the grass and move horizontally to 20 to 30 m from the mass of feces.

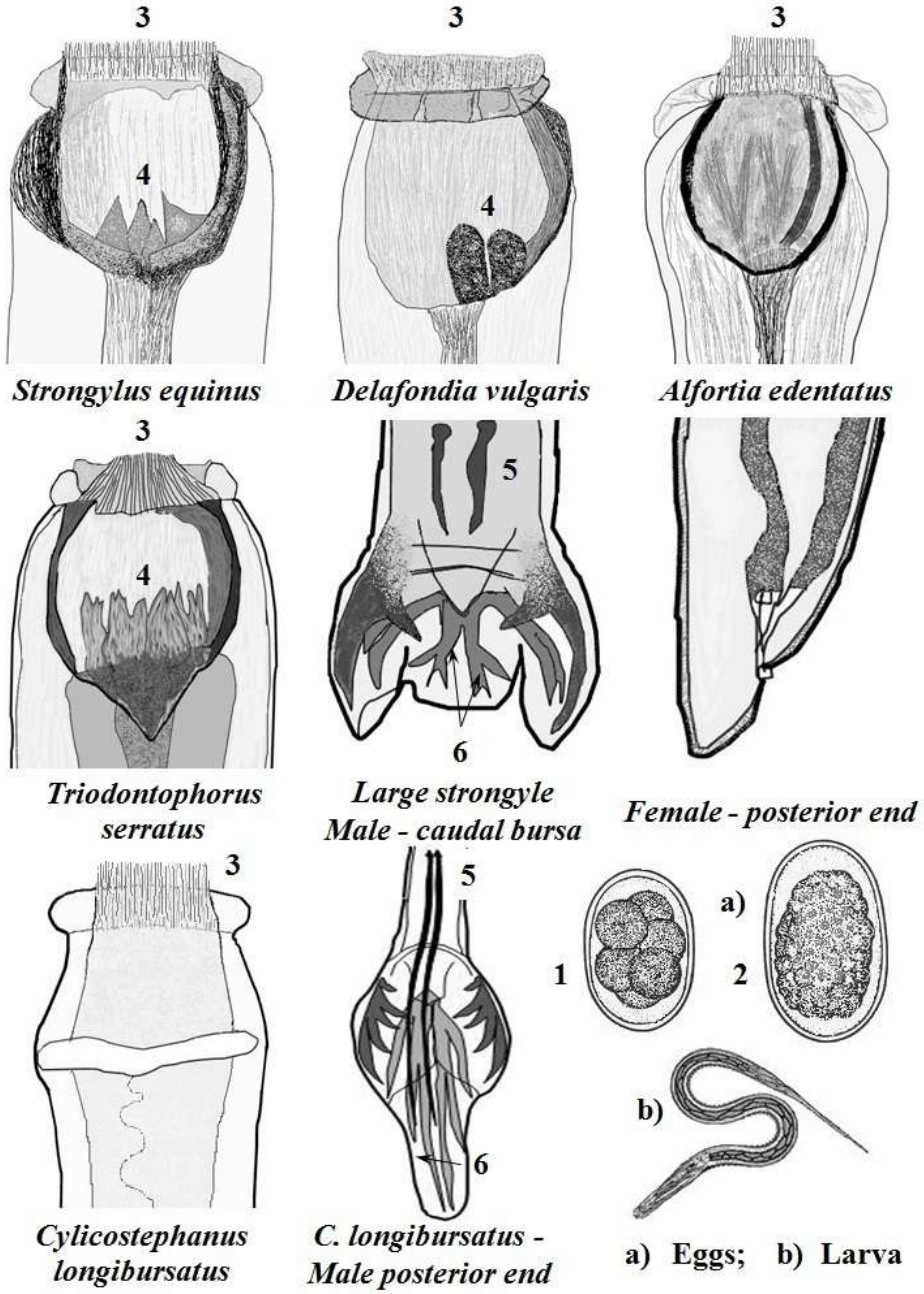


**Figure 11**. Strongyles species in horses; 1. large strongyls egg; 2. small strongyls egg; 3. mouth collar (double crown of papillae); 4. teeth; 5. spicules; 6. rays;

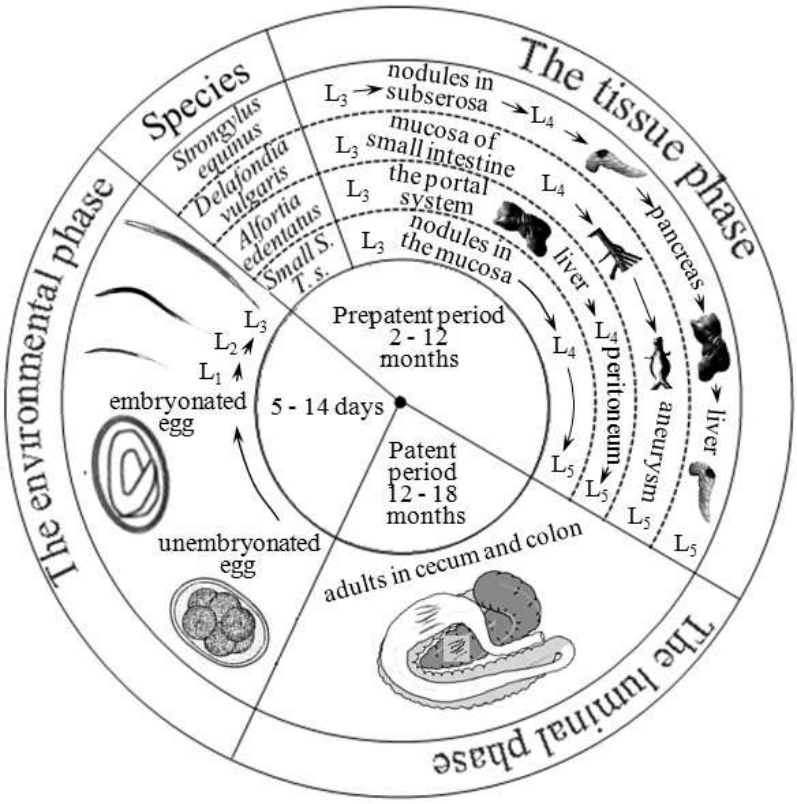


**Figure 12** Life cycle of strongylids from horses

They are characterized by a positive hydrotropism and thermotropism and by a negative phototropism and geotropism. In low thermal conditions, under 12°C, the development of free larvae stagnates. The larvae can find favorable biotopes in wet pastures, paddocks and shelters, on the moist floor and around shelters. Contamination of equines is primarily done on pastures but also in shelters, by ingestion of infective larvae ($L_3$) with grass and/or water.

*The tissue phase*. The $L_3$ stages in the gut have a different histiotropism and will perform specific migrations, during which they feed and develop, pass through $L_4$ and $L_5$ stages by molting, and the latter return to the cecum and colon, where adults are formed.

The $L_3$ larvae of *Strongylus equinus* invade the mucosal layers of the cecum and colon, form the nodules in the subserosa, where in 10 days they molt becoming $L_4$. Then they migrate through the pancreas and finally reach the liver where they stay for several weeks. Next, $L_4$ return to the large intestine again through the pancreas. In the course of their return path, $L_4$ molt in $L_5$, young adult stage, which becomes an adult in the lumen. The prepatent period, from infection to egg-laying, is about 8 - 9 months.

The larvae ($L_3$) of *D. vulgaris* penetrate into the mucosa of the small intestine, cecum, and colon, where they molt in $L_4$. Within 7 days after contamination, $L_4$ enter into the lumen of the arterioles and from there, against the bloodstream, they reach the ileocecal and cranial mesenteric arteries, reaching even the root of the aorta, near the left ventricle, in three weeks. The larvae $L_4$ penetrate the endothelium of these vessels, where they develop into $L_5$, after approximately 5 months.

This causes thrombosis and aneurysm formation. Their intra-arterial stay can last 90 - 120 days. The young adults ($L_5$) return into the bloodstream and, on the same route, reach the intestinal wall, where they form nodules and, following their breakage, will penetrate into the lumen of the colon and cecum. The prepatent period ranges from 5.5 to 7 months.

The third-stage larvae of *Alfortia edentatus* penetrate the wall of the intestine and migrate through the portal system to the liver. Here, they molt once ($L_4$) and will continue their migration following the path of the hepatorenal ligament beneath the peritoneum. There they molt again and generate $L_5$, young adults, who migrate back to the walls of the large intestine where they cause nodules. Following of their rupture, adult worms are released into the lumen. The prepatent period is long, of up to 1 year.

The $L_3$ larval stage of *Triodontophorus serratus* migrate locally. They enter into the mucosa of the intestine where they encyst. Inside the cysts, $L_3$ larvae molt twice ($L_4$ - $L_5$) and become adults who emerge into the lumen of the intestine. The prepatent period is approximately 2–3 months.

The $L_3$ larval stage of *Cylicostephanus longibursatus* and generally all cyathostomins invade the lining of the large intestine as early third stage larvae ($EL_3$), which are infective larvae that have shed their protective integument. Inside the mucosa, $EL_3$ encyst and may evolve differently: immediate progression through the next larval stages or they may persist as $EL_3$ into an arrested development stage for one or two years. The progressive development of $EL_3$ consists in a molting process, which results in the late $L_3$ stage ($LL_3$), which will molt in $L_4$. The $L_4$ develop within the cyst, and following the cyst wall ruptures, $L_4$ enter the lumen of the large intestine. The $L_4$ inside the lumen of the large intestine grow in size and eventually molt into the adult, or $L_5$ stage.

**Epidemiology**

***Geographical distribution***. Strongylidosis in horses are widely distributed diseases, but economically important wherever horses are raised. The prevalence varies in some Romanian regions from 67 to 82%[311,374]. Worldwide, the general prevalence ranges between 20 to 62%, exceeding 70% and even reaching 100%, and is influenced by the conditions in which the horses are kept. In horses kept in stalls, the prevalence of strongylid infections was from 46.4% to 77.8% and in horses kept in stalls/pastures, from 95.1% to 100%[307].

***Sources of contamination***. The primary source of contamination is represented by infected animals that pollute the environment. A single horse can remove from 4 - 5 to 100 million eggs daily, the strongyles being prolific egg layers. The older horses remove about 200 - 1200 eggs per gram feces (epg) while in young equines the level increase to 2500 or even 3000 EPG. The mares with foals beside them are the most important polluters of pastures and are subsequently sources of infection for the newly arrived youth on the pasture.

Regarding the seasonal dynamics of pasture contamination, it is generally accepted that, during the year, a peak of egg removal is recorded in the spring, and decrease in the winter. Concerning the maximum flow of infective larvae on the pastures, a marked rise in the concentration is recorded two to four weeks after the peaks in egg output. The pollution of the grasslands in these periods can be over 50000 infective larvae per kilogram of grass[239,177]. The second source of contamination is the water and food that contain $L_3$ infective larvae.

***Susceptibility.*** Generally, many intrinsic factors (sex, age, and breed) influence the prevalence of parasites of domestic animals. However, in the case of equine strongylidosis, the involvement of any of them has not been clearly demonstrated. The studies on age-

related prevalence indicate no difference among different age groups. Nevertheless, a higher proportion of young animals, under 10 years of age, were positive for strongylosis as compared with older horses (more than 11 years of age). The susceptibility of horses to infection and egg excretion are not influenced by sex[447]. The high prevalence of infestation in all horses, regardless of age, reveals the absence of specific resistance after multiple infections.

***Route of contamination***: the route of infection is oral, through the feed and water contaminated with infective $L_3$ larvae.

***The resistance***. The survival of eggs and larvae on the pastures is a complex problem with a high significance in the epidemiology of horse strongylidosis. Both stages are affected, in varying degrees, by the same environmental factors: temperature, moisture, dryness, direct action of sunlight, etc. It is accepted that winter conditions do not kill unembryonated strongyle eggs, especially if they are protected by a coat of snow. In the same conditions, infective larvae already present on the pasture can survive the winter[385]. Under ambient conditions with hot and dry summers only 1% of the larvae survive on herbage for 2-3 weeks and 0.2% are still viable for a further 2-3 weeks; at 1 - 15$^{o}$C and 20$^{o}$C, they remain viable 4 months and half; in an aqueous environment they live for about 30 days; dry heat and direct sunlight destroy the larvae in several days[161,497]. Dryness and desiccation have an ovicidal effect.

**Pathogenesis.** The pathogenic effects are, in most of the cases, a result of the associated aggression of strongylid species, on the one hand, and of the adults and larval stages, on the other hand.

The larval stages exert, during their migrations and shedding, a mechanical action consisting in the traumatization of the tissue of various organs and microbleeds. Depending on the species involved, traumatic action associated with inflammation can be expressed by severe disruption of omental architecture and adhesions involving the intestine (*A. edentatus*), presence of tortuous tracks and white foci on the surface and in the parenchyma of the pancreas and liver (*S. equinus*), thrombi and parasitic aneurysms in abdominal large arteries (*D. vulgaris*) or massive granulomas in the wall of the cecum and colon (*T. serratus* and small strongyles).

The toxic action is determined by metabolic products which act on hematopoietic organs causing hematological changes. The most significant are an early, sharp rise in leukocytes, increased neutrophil: lymphocyte ratio and eosinophilia. They also act on the blood's biochemical parameters causing a progressive increase of the total serum proteins and a higher rate of albumin catabolism[155].

The inoculation action by which the larvae carry on their cuticle or body bacteria, viruses and fungi from the gut may be followed by an intensification of the inflammatory processes, which result in nodular enteritis, hepatitis, pancreatitis, peritonitis.

The cuticles of molting and metabolic antigens from the first infestation can sensitize the animals and, in the case of new infections, allergic reactions may occur expressed by the presence of cecal mucosal edema.

Adult strongyles injure the intestinal mucosa by their well-developed buccal capsule and feed on blood or tissue causing normochromic anemia. Ulcerations sometimes occur at the attachment sites, followed by infections with enteric flora. Toxins secreted by adults cause hemolysis.

**Clinical signs**. Usually, infestation with strongyles in horses evolves subclinically, without symptoms. In adult animals, the parasitism is preponderantly benign, unapparent. The massive infestations and clinically expressed diseases appear especially in young equines. Natural infections are polyspecific, the horses being parasitized

simultaneously by large and small strongyles. Considering these mixed infections, it is difficult to distinguish the signs caused by large strongyles from those of small strongyles.

Whatever the evolutionary type, acute or chronic, clinically expressed or subclinical, the symptomatology is dominated by digestive disorders. Diarrhea is the most common sign, especially in small strongyle infections, but it appears also in large strongyles. Feces may be watery or pasty, with their classical appearance modified, or diarrhea may be intermittent, continuous or may alternate with constipation. Another important clinical sign is the colic, with variable intensity, from mild, repeated colic to violent colic, especially in *D. vulgaris* infestations. The appetite changes from inappetence to a capricious appetite.

The acute form is caused by the migratory larvae and is seen in foals and youth during the first few weeks after infection. Its severity depends on the infective dose, the age and previous infections of the host. Clinically, it is characterized by hyperthermia, loss of appetite, rapid loss of body weight, depression and recumbency, constipation, abdominal distress, and death at 14 to 22 days after infection.

In adult horses, the chronic form evolves. Animals are weak, anemic, present intermittent lameness and get tired easily at normal effort. The hair is dull, dry, with a dirty aspect.

**Pathology.** The lesion pattern varies by species and the developmental stage that causes it.

The adult parasites are fixed to the cecal and colonic mucosa. In the early stage of infestation, they cause catarrhal typhlitis and colitis. In the acute evolution the lesions become worse, having a hemorrhagic character. Subsequently, chronic lesions develop, consisting in hyperplastic typhlitis and colitis and thickened mucosa, with pleats. The crateriform ulcers are present, with limited necrosis or fibrosis.

Larval stages of all species produce, at the beginning of migration, punctiform hemorrhages on cecal and colonic mucosa, and edema in submucosa. Sometimes, haemorrhagic, infiltrative or nodular typhlitis and colitis with the presence of larval forms in nodules can be observed The lymph nodes on the serosal surface of the cecum and colon are enlarged, hard and contain hemorrhagic centers. Thereafter, they produce different injuries, depending on the route of migration and the target organ.

*S. equinus* larvae cause pea-size miliary nodular formations, visible on the surface and in the parenchyma of the liver, pancreas (chronic pancreatitis) and in the peritoneal serous membrane. Parasitic nodules are enucleated. Necrotic content may or may not present larvae. Serous and fibrinous peritonitis is rarely noted. The mesenteric lymph nodes are inconstantly hypertrophied and show microhemorrhages and infiltrations.

*D. vulgaris* larvae cause a thickening and fibrosis of the walls in the cecal and cranial mesenteric arteries with the presence of the $L_4$ and $L_5$ larval stages. The tunica intima surface has a rough or spongy appearance in the variable segments (2-15 cm) with well-organized thrombi (after 2 to 4 months) and fibrous proliferation. The aneurysms formed in the wall of the right cranial mesenteric artery are associated with infarcts of the walls from the large intestine segments.

*A. edentatus* third stage larvae cause on the surface and in the parenchyma of the liver tortuous tracks and white foci. Following their molting, L4 produce nodules and fibrous adhesions involving the greater omentum, in the course of their return to the large intestine.

*T. serratus* and cyathostomin larvae can cause small, gray nodules (1–2 mm) in the mucosa of the large intestine because of their local migration, into the wall.

**Diagnosis**. Clinical examination has no value, indicative symptoms as weight loss, fatigue on exertion, dull hair or diarrhea being common to several diseases. Associated with the colic syndrome, they may guide the diagnosis to the strongyle infestation. The exploration of the rectum can sometimes provide an indication by detection of aneurysms formed near the branch of the aorta.

Coprological examination with the determination of the number of strongyle eggs per gram of feces (EPG) is a diagnosis of certainty. It has two major disadvantages: it is valueless in the prepatent period when eggs are not laid in feces, and has a group value, being unable to differentiate the species involved. Necropsy is a method of certainty, emphasizing lesions caused by parasites and adults presence in the large intestine.

***Differential diagnosis***. The disease will be differentiated from the colic syndrome with other etiology, chronic anemia (digestive helminthosis, gasterophilosis, subacute hemosporidiosis, and infectious anemia in horses).

**Treatment.** For curative purposes, different active substances are used whose efficacy refers to the larval and imaginal forms, or just to the latter. Modern and actual therapy is based on the use of (pro) benzimidazoles and benzimidazole derivatives, tetrahydro-pyrimidines and avermectins:

- Thiabendazole at a dosage of 25 mg/kg bw eliminates the small strongyles (99.5%), *S. vulgaris* (98.1%), *S. equinus* (100%) and *S. edentatus* (87.9%). At 50 mg/kg bw, it showed a 99.8% efficacy against the small strongyles, 99.6 for *S. vulgaris* and 99.5% against *S. edentatus* while the effect against *S. equinus* was 100%[168].
- Cambendazole at 20mg/kg bw had an efficacy of 70% against small strongyles and 98.5% against large strongyles[483].
- Fenbendazole at 7.5 mg/kg bw has an efficacy of 90.7% against the luminal cyathostomes and 95.3% against mucosal $L_3$ and $L_4$ larvae[153].
- The efficiency of oxfendazole at dose-rates of 10 mg/kg bw was 99.8% against adult small strongyles and 97.6% against developing small strongyle larvae. Increasing the dose to 50 mg/kg bw boosted efficacy levels to 99.1% and 100%[154].
- Ivermectin at the rate of 200 micrograms/kg bw removes 100% of small strongyles, *D. vulgaris*, *A. edentatus*, *Triodontophorus serratus* and *T. tenuicollis* irrespective of the injectable and paste formulations[599].
- Doramectin given intramuscularly at a dose rate of 0.2 mg/kg bw showed a 96 % efficacy at two weeks post treatments (wpt)[110].

It must be noted that the most commonly used anthelmintics in equines are the following[321] (table 4):

Current aspects in therapy and particularly in the anthelmintic treatment of horse strongylosis refer to the appearance of chemoresistant populations. The first recorded phenomenon dates back to 1961 when Drudge and Elam[148] isolated small strongyle populations resistant to phenothiazine. The second parasiticide active against strongyles in relation to which the onset of the chemoresistance phenomenon was demonstrated, expressed by a lowered reduction of EPG counts, was thiabendazole[150]. The resistance in small strongyles is demonstrated for many other benzimidazoles or pro-benzimidazole derivatives: febantel, thiabendazole, mebendazole, cambendazole, fenbendazole and oxfendazole[152]. Generally, the chemoresistance is recorded in small strongyle species, the most commonly cited genera being *Coronocyclus*, *Cyathostomum*, *Cylicocyclus*, *Cylicodontophorus*, *Gyalocephalus* and *Petrovinema*[151].

Among non-benzimidazole substances, the chemoresistance is demonstrated for

tetrahydropyrimidines derivatives, namely pyrantel, also to cyathostomin populations[542].

Recently, it has been reported that small strongyle EPG counts revert more quickly than initially, after ivermectin and moxidectin treatment of horses[324]. This reduced activity on small strongyles may signify the gradual installation of chemoresistance in macrocyclic lactone parasiticide group.

Despite the continuous development of the chemoresistance phenomenon of small strongyles, the therapies used against large strongyles are up to 100% effective. The increasingly and frequently therapeutic failure against resistant populations of small strongyles imposed the use of drug associations in order to deworm horses.

The **control** requires the application of general measures during stabulation and grazing period, associated with regular chemoprophylaxis. During stabulation, ensuring hygienic conditions in shelters, maintening dryness on the floor and in litter and respecting feeding and watering hygiene limits the evolution of disease destroying numerous infective larvae.

During grazing period various measures with variable efficiency are recommended:

- Use of cultivated pastures which have a strongyle pollution index lower than perennial pastures. However, it is known that horses instinctively divide pastures into two distinct zones, called roughs and lawns. Roughs are areas with tall grass where horses defecate but do not graze. Lawns are areas with short grass where horses graze but do not defecate. In rough areas, the numbers of strongylid larvae is 15 times greater compared with lawns[239]. Thus, grazing in cultivated pastures, with tall grass, predisposes the horses to create large rough areas on the pasture, with higher contamination risk.
- Implementation of a pasture rotation system. The order in which the different species enter into the pasture is: horses, cattle, and sheep.
- Pasture of mares with foals has not been previously used for other types of equines.
- Application of chemical fertilizers, particularly superphosphate, for pasture fertilization reduces the number of strongyle larvae.
- Chemoprophylaxis – there currently are, as there have been in the past, 4 justifications for implementing periodic deworming in the control of infestation in horses[149,428] (Table 5):
- To develop a program with superior efficacy in equine strongylidosis control, one must answer three major questions: (1) which are the anthelmintics effective on the farm at that time, (2) which are the horses and what level of control is required: minimal, medium or intensive, and (3) what is the interval and anthelmintic substance indicated for each individual to control their own strongyles. Besides those mentioned above, two other factors should also be considered: the seasonal patterns of transmission on the studied farm and evidence-based timing of treatment applications.
- In general, equines are prophylactically treated twice per year starting with foals aged 3-4 months. The first treatment should be applied during spring, 10 to 14 days before grazing season, and the second in autumn, 14 days after re-entry to stalls. A high level of protection is ensured by the application of 4 treatments per year, quarterly, alternating the active substance used.
- The globally adopted strategies aim to reduce the prevalence of strongylidosis, to attenuate pathogenicity and to consequently diminish economic damage, eradication being impossible.

**Table 4** The most used anthelmintics in equines

| Class | Anthelmintic | Administration route | Dose (mg/kg bw)[a] | Duration of action (weeks)[b] | Lethal to major parasites | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | LS | MLS | SS | SSML |
| Macrocyclic lactones | Ivermectin | p.o. | 0.2 | 6 - 8 | √ | √ | √ | - |
| | Moxidectin | p.o. | 0.4 | 13 | √ | √ | √ | √[c] |
| Benzimidazoles | Fenbendazole | p.o. | 5 - 10[d] | 4 - 6 | √ | √[d] | √[d,e] | √ |
| | Mebendazole | p.o. | 8.8 | 4 - 6 | √ | - | √[e] | - |
| | Oxibendazole | p.o. | 10 - 15 | 4 - 6 | √ | - | √[e] | - |
| | Oxfendazole | p.o. | 10 | 4 - 6 | √ | √[f] | √[e] | - |
| | Tiabendazole | p.o. | 44 | 4 - 6 | √ | √[g] | √[e] | - |
| Pyrimidines | Pyrantel pamoate | p.o. | 6.6 (13.2)[h] | 4 | √ | - | √[e] | - |
| | Pyrantel embonate | p.o. | 19 (32)[h] | 4 | √ | - | √[e] | - |
| | Pyrantel tartrate | p.o. | 2.6[i] | Continuous | √ | √[c] | √[e] | - |
| Heterocyclics | Piperazine | p.o. | 88 | 4 - 6 | √[i] | - | √ | - |

p.o., oral; S.C., subcutaneous; LS, adult large strongyles; MLS, migrating large strongyle larvae; SS, adult small strongyles (cyathostomes); SSML, inhibited mucosal larval small strongyles;

[a]Regional differences exist in recommended dose rates and label claims

[b]Duration of action is the time from dosing until worm eggs appear in feces, i.e. the so-called egg reappearance period (ERP)

[c]30 - 40% efficacy

[d]Standard dose rate in USA is 5mg/kg; standard dose rate in Europe is 7.5mg/kg, MLS dose is either 10mg/kg (7.5mg/kg. in Europe) on 5 consecutive days or 50 mg/kg on 3 consecutive days or single dose 60 mg/kg. SSML dose is 10 mg/kg on 5 consecutive days

[e]Anthelmintic resistance may affect efficacy

[f]60 - 75% efficacy

[g]MLS dose is 440 mg/kg on 2 consecutive days

[h]Standard dose rate in USA is 6 mg/kg pyrantel pamoate; standard dose in Europe is 19 mg/kg pyrantel embonate; pyrantel tartrate dose is 2.6 mg/kg daily in feed

[i]50% efficacy

**Table 5** Justifications for implementing periodic deworming program

| Justification | Drudge and Lyons, 1966 | Reinemeyer, 2009 |
|---|---|---|
| Large strongyles (L.S.) are the major targets | L.S. were the most important cause of colic | L.S. practically eradicated from most well-managed herds |
| Rotation of drug class with each treatment | All anthelmintic classes were effective against strongyles | Only one class remains consistently effective |
| Treat perennially at bimonthly intervals | Interval treatment suppressed environmental contamination | Perennial treatment is unnecessary; frequent treatment selects for resistance |
| All horses in the herd treated identically | Contamination by the entire herd was suppressed | Members of a herd should be dewormed as individuals |

## 3.3. Trichostrongylidae

The Trichostrongylidae family belongs to the Strongyloidea superfamily and includes nematodes of cattle, sheep, goats, swine, rabbits, and cats. It is divided into six subfamilies: Trichostrongylinae, Libyostrongylinae, Haemonchinae, Cooperiinae, Ostertagiinae, and Graphidiinae. The most important genera for parasitic pathology in domestic animals are *Haemonchus*, *Ostertagia*, *Trichostrongylus*, *Cooperia*, *Nematodirus*, and *Hyostrongylus*.

The members of this family are cosmopolitan parasites of the small intestine or abomasum mainly of cattle, sheep, goats, and wild animals (Giraffidae, Camelidae and Cervidae).

The etiologic agents of the Trichostrongylidae family are small (0.5 to 30 mm) with an equally calibrated, thin body. At the anterior end is a simple mouth opening without a buccal capsule or with a rudimentary, unarmed one.. At the posterior end males have a trilobated copulatory bursa with two developed lateral lobes and equal spicules of varying sizes. Eggs are of the strongyle type and are of 70 - 200/40 - 100 μm in the morula stage, when laid.

The parasites are geohelminths (or soil-transmitted helminths, STHs) with exogenous development which consists in $L_1$ larval stage hatching and molting in $L_2$. Both stages are rhabditiform larvae with conical pointed tails and valved esophagi. Finally strongyliform $L_3$ infective larvae develop.

### 3.3.1. Trichostrongylidosis in ruminants

**Definition.** Trichostrongylidosis are chronic gastrointestinal nematodoses, rarely acute, with seasonal fluctuations at pasture, affecting domestic and wild ruminants. These are widespread diseases conditioned by climatic and edaphic factors and evolve during the grazing season with anemia, malnutrition, dysmetabolic syndrome, delayed growth in young ruminants and repercussions on productivity in adult animals.

**Etiology.** The species involved in the disease etiology are divided into two groups depending on their location, abomasum and small intestine, the most important being *Haemonchus contortus*, *Ostertagia ostertagi*, *O. circumcincta* and *Trichostrongylus axei* in the abomasum, and *Cooperia oncophora*, *C. curticei*, *Trichostrongylus colubriformis*, *T. vitrinus*, *Nematodirus filicollis* and *N. spathiger* in the small intestine, respectively.

***Morphology***.

*Haemonchus contortus* (figure 13A), known as red worm or wire worm, has a cylindrical, equally calibrated body, tapered at both ends; the length of males varies between 10 to 20 mm and that of females between 18 and 30 mm. The body of the female has a particular appearance called "barber pole" due to the white color of the ovaries that coil as a spiral around the reddish intestine, color determined by hematophagous nutrition. At the anterior end it has a buccal cavity which contains a small dorsal lancet and two small cervical papillae. At the posterior end, males present a well-developed copulatory bursa with acharacteristic asymmetric dorsal lobe supported by a forked ray. The vulvar opening is situated on the posterior half of the body and is covered with a cuticular extension (the vulva flap). Eggs are oval, 65-80/40-46 μm or an average of 94.7/58.3 μm with the limits between 91-101/52-62 μm[261] in size and contain 24-26 blastomeres.

*Ostertagia ostertagi* (figure 13B) parasitize in cattle and occasionally sheep. The adults are small (5 - 9/0.1 mm for males and 10 - 12/0.12 - 0.15 mm for females) with a brownish threadlike body. At the anterior end the cuticle is circular and longitudinally striated, with a pair of conical cervical papillae located beside the esophagus and a tiny buccal cavity. The posterior end of males shows a copulatory bursa equipped with two short, brown and relatively thick spicules

which terminate in 3 stubby hooked processes and a bursal ray. The vulvar opening is covered with a small, cuticular vulval flap. Eggs are 70-85/40-50 μm in size (figure 13C).

*O. circumcincta* (synonim *Teladorsagia circumcincta*) parasitize in the sheep's and goats' abomasum. It is slightly longer than the previous species, reaching 12 mm in length. The body is cylindrical, filiform and dark red. Eggs are 80-100/40-50 μm in size.

*Trichostrongylus axei* is called stomach hair worm because of its slender body, the males reaching 3,8 - 4,8 mm in length/70 - 80 μm in width and the females, 4,9 - 6,7 mm/75 - 87 μm. There is no buccal capsule and it has no morphological structure on the anterior end. The adults have an excretory notch in the cervical region. The lateral lobes of the copulatory bursa are well-developed and the spicules are brownish, stout, of various lengths. Eggs are 79-92/31-41 μm in size.

*Cooperia oncophora* (figure 14A) - are small worms, the male measuring 5-8 mm long and 150-200 μm wide and the female 8-11 mm/150 - 240 μm. At the anterior end, the cuticle has transverse striations and a cephalic vesicle is present, which is a cuticle dilatation, giving the head end a bulbous appearance. At the posterior end, males have a small (but prominent in relation to their size) copulatory bursa with two short spicules, close to their terminal extremity. Eggs are 79.6-89/39.9-44.9 μm in size.

*C. curticei* - is slightly lower than the previous species, the male having 4.6 to 5.4 mm in length and 80 μm wide, and the female 5.8 to 6.2 mm in length/120 μm wide. The body is coiled and the spicules are chitinized and measured, on the average, 153.68 μm. Eggs are 70–82/35–41 μm in size.

*Trichostrongylus colubriformis* (figure 14B) - the sizes vary between 5 to 6.4 mm/80 μm for males and 5 to 7.5 mm in length /90 μm width the females. Copulatory bursa is small and the spicules are unequal in lengths. The egg is oval, with a double thin shell, segmented, 24 to 32 blastomeres when laid and 80-101/39-47 μm in size.

*T. vitrinus* is a parasite of sheep and sometimes infects humans. It has small and straight spicules, tapering to the terminal end and close to each other. Eggs are 93-118/41-52 μm in size.

*Nematodirus filicollis* (figure 14C) adults have a pronounced sexual dimorphism, the sizes ranging between 8-15mm in length and 150mm in width for males and 12-20mm long and 250mm wide for females. At the anterior end they have a small mouth surrounded by six papillae; the cuticle is laterally inflated giving a swollen appearance to the head.

*N. spathiger* is located in the small intestine of goats and sheep. The body is slender, filiform and relatively long, up to 25 mm. At the anterior end, the cuticle is dilated and transversely striated. Eggs are 181-230/91-107 μm in size (figure 13D).

***Life cycle.*** (figure 15) All species included in the Trichostrongylidae family have a very similar monoxenous life cycle consisting in the alternation of the free, pre-parasitic phase which happens in the environment and the parasitic phase. Predilection sites include the abomasum or small intestine of ruminants where adults live attached to the villi. Some of the species have hematophagous nutrition (*Haemonchus* spp., *Ostertagia* spp.) and others feed on the mucosal tissue of the gastrointestinal tract (*Trichostrongylus* spp.). After mating, females lay eggs that pass through feces into the environment.

The pre-parasitic phase begins when the eggs hatch in the environment and the rhabditiform $L_1$ larval stage molt twice generating $L_2$ and infective $L_3$ (strongyliform). The exogenous evolution is achieved in about 4 - 8 days in optimal conditions of ground temperature (20 - 30$^{o}$C), soil moisture (100%) and sufficient air supply in the feces.

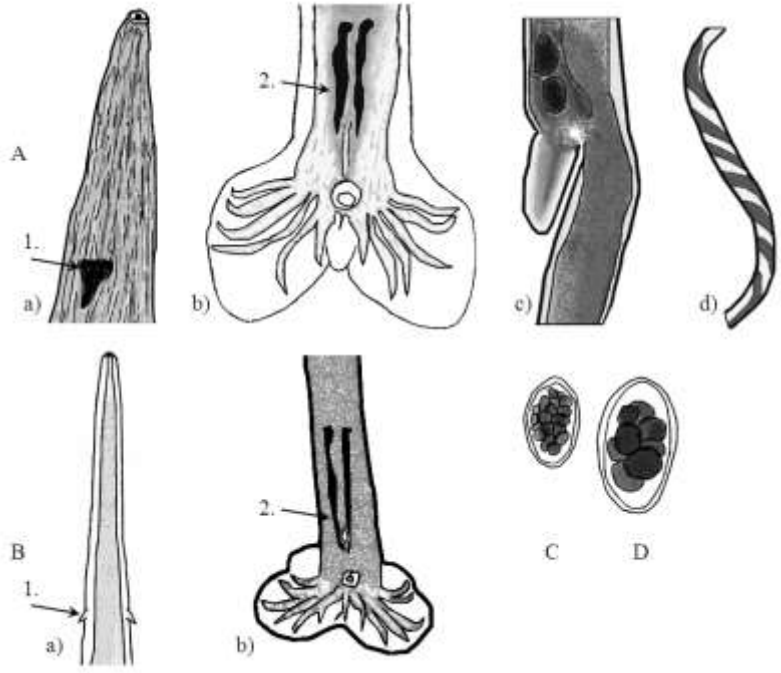


**Figure 13**. A. *Haemonchus contortus*; B. *Ostertagia ostertagi*; C. eggs of abomasal trichostrongylids; D. egg of *Nematodirus* spp.; a) anterior end; b) posterior end; c) the vulva flap; d) "barber pole" appearance of female body; 1. cervical papillae; 2. spicules

The chronology of the exogenous stages consists in hatching that requires 12-48 hours, molting of $L_1$ in $L_2$ which occurs within 1-3 days, and the second molt ($L_2$ in $L_3$), the full cycle requiring the period mentioned above[264]. The $L_1$ and $L_2$ larval stages are microbivorous feeding on bacteria from the feces and ground. The $L_3$ stage is non-feeding because of the preserved molting cuticle.

The species included in the *Nematodirus* genus are an exception to this evolutionary model. They have the same direct and monoxenous life cycle as other trichostrongylids but differ in that $L_1$ larvae do not hatch from eggs. They develop into $L_3$ inside the egg and the parasites overwinter as $L_3$ inside the egg. The $L_3$ larvae will hatch during spring after a "cold shock" and are infective.

All infective $L_3$ larvae migrate in a lateral direction and vertically on herbage. The migratory activity of $L_3$ larvae in a lateral direction depends on the amount and duration of rainfall, ground temperature, and sunlight exposure of pastures.

Vertical migration is influenced by several factors. The morphology of grasses and the presence of a film of moisture are advantageous; 0.65% of larvae climb on wetted blades while only 0.04% on unwetted ones. Higher relative humidity favors the climb, 1.36% of larvae being successful at 95% relative humidity and only 0.06% at 56%. Lower temperature is disadvantageous, only 0.13% migrating upward at 4$^o$C and 2.54% at 26$^o$C. The migration is essentially similar in light and darkness, thus the effect of direct sunlight and its intensity is unclear. In these conditions 59.2, 26.7, 9.9, 3.4 and 0.8% migrate to a height of 2.5, 5.1, 7.6, 10.2, and 12.7 cm from the soil, respectively [476]. Animal contamination is achieved by consuming grass or water which contains infective $L_3$ larvae.

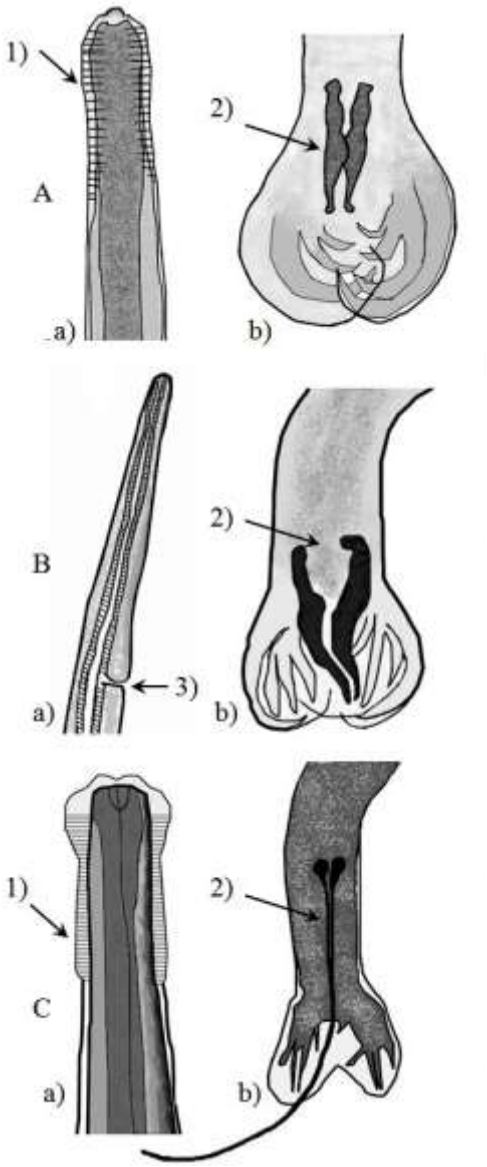


**Figure 14**. A. *Cooperia* sp.;
B. *Trichostrongylus* sp.; C. *Nematodirus* sp.; a) anterior end; b) posterior end; 1. cephalic vesicle; 2. spicules; 3. excretory notch

During the parasitic phase, exsheathment will be the next event after contamination. The sites of the process are species-specific but always situated at the proximal region of the predilection site of each trichostrongylid species.

As examples, *Ostertagia ostertagi* located in the abomasum will exsheath in the rumen, while *Cooperia curticei*, a parasite from the small intestine, will exsheath in the abomasum.

After exsheathment, the $L_3$ larvae move to the predilection site where they grow and develop into adults. The infective larvae ($L_3$) will molt in fourth-stage ($L_4$) which may penetrate deeply into the lining of the stomach, the gastric glands or intestinal crypts, some reaching a histotrophic phase in the abomasal submucosa (*Ostertagia* spp.). A last molt takes place within a variable period after ingestion, resulting in fifth-stage larvae ($L_5$) and finally adults will develop. The prepatent period has a great variability depending on the species (*Haemonchus contortus* 15 days and 28 for *H. placei*, *Cooperia* spp. 15-20 days and *Nematodirus* spp. less than 27), host (in bovines it may be longer) or the hypobiosis phenomenon[225].

The hypobiosis, or arrested development of the early fourth stage ($EL_4$) is a common phenomenon of trichostrongylids and it is presumably a result of the host's acquired immunity. The decline of temperatures in late summer and autumn seems to be another cause of arrested development and is a heritable trait of the larva itself[15]. The presence and accumulation of adult worms is also associated with an increasing number of arrested fourth stage larvae[351].

Another phenomenon that occurs during trichostrongylidae infections in ruminants is the limitation of parasite burdens, which hasmultiple causality. The immune exclusion acts on third stage larvae and mortality of established young parasites acts on fifth stage larvae, both mechanisms acting jointly to reduce the number of worms[485]. In addition, the age of the host[142] as might its nutritional status[46] and interaction between parasites, occurring especially in crowded situations[232] may also have to be taken into account.

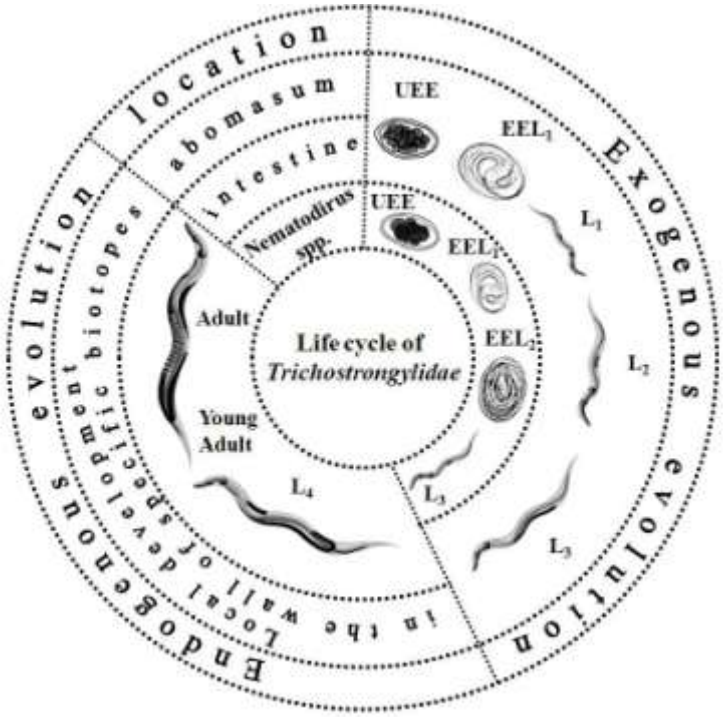


**Figure 15** Life cycle of trichostrongylids from ruminants; UEE unembryonated egg; $EEL_1$ embryonated egg that contains the first-stage larva; $L_1$ - $L_4$ larval-stages;

**Epidemiology**

***Geographical distribution.***

Trichostrongylidoses are cosmopolitan diseases with a higher incidence in sheep and animals kept on pasture, during warm and rainy years when grazing is not adequate in terms of sanitary and animal husbandry conditions.

The prevalence registered worldwide for different species is highly variable. In sheep from western Romania it was 100% for *Ostertagia ostertagi* and 13.33% for *O. circumcincta*, other identified species being *Trichostrongylus colubriformis* (100%), *Nematodirus filicollis* (80%), *N. spathiger* (6.66%), *Cooperia curticei* (33.33%), and *Haemonchus contortus* (26.66%)[260]. In Turkey, gastrointestinal nematodes were encountered in 87.5% out of 104 sheep, the most prevalent species being *Ostertagia circumcincta* (75%), *Nematodirus oiratianus* (75%), *N. spathiger* (65%), and *Haemonchus contortus* (40%)[102]. *Ostertagia circumcincta* was the most commonly detected species on UK ewe and lamb farms in 2010, being diagnosed on all 118 examined farms. *Trichostrongylus vitrinus* was found on 96 and 93% of farms, followed by *T. axei* (96 and 73%), *Cooperia curticei* (79 respectively 53%), and *T. colufriformis* (58 - 47%)[83].

***Sources of contamination***. Sources of parasites are divisible into two categories: pollutant sources of pastures and sources of animal contamination.

Sources of pasture pollution are numerous due to the large parasitic valence of the trichostrongylids which occur in domestic and wild ruminants. The main sources of pollution for grassland habitats, meadows, and paddocks are clinically infected animals, those with subclinical forms or in convalescence. The fecal egg count of trichostrongylids is variable from low indices such as 50-800 epg to high values such as 6400 epg or more[362,134].

The fertile period lasts more than 4-5 weeks and the number of a worm population to an animal can vary from a dozen to a few hundred individuals[362]. Wild ruminants have an important role. Biothermic unsterilized manure used to fertilize pastures also contributes to the pollution.

Pasture contamination displays monthly dynamics influenced by seasonal fluctuations in the number of trichostrongylid eggs removed. This fluctuation is characterized by a gradual increase in the number of eggs per gram of feces from November until spring, with a peak in June-August, followed by a continuous reduction until January. The explanation of this fluctuation consists in fact that the dry weather during late summer and the low temperatures of winter are unfavorable to infective larval development and, consequently, the level of infestation and egglaying of animals will decrease. Another reason is the height of the herbaceous layer. The luxuriant tall grass during spring and summer tends to lower the intake of infective larvae and consequently the number of worms in their habitats decreases. Subsequently, during winter, egg-laying will decrease[529].

Independently of these seasonal fluctuations in the fecal egg count, significant increases in egg-laying are recorded, dependent on a particular season or physiological status. These are the so-called phenomena of "springrise" and "peri-parturient" or "lactating". Both phenomena are characterized by very active egg-laying, daily shedding exceeding by 3-4 times the previous indices. The "springrise" of Trichostrongylidae is present during late winter / early spring, and is frequently followed by a "self-cure" reaction[520]. This reaction may be, in turn, one of the seasonal fluctuation reasons described above and it occurs in the absence of reinfection[6]. The periparturient rise phenomenon consists in an increase in the number of eggs shed in feces in the pre- and post-natal period. It is caused by increased stress levels and/or the relaxation of an acquired immune response by pregnant females associated with elevation of serum prolactin levels[482,100].

Sources of animal contamination are represented by infective $L_3$ larvae from the pastures ingested with food or water.

***Susceptibility.*** Receptivity of animals is characterized by interspecific variations, which depend on age, physiological status, gene pool and aggressiveness of parasites. The highest vulnerability is recorded in sheep followed by goats and cattle. Intraspecifically, the youth aged 2-24 months are the most responsive, the critical phase being during weaning, in the case of immunosuppressive conditions, malnutrition or intercurrent illness[53]. The existence of sheep breeds resistant to Trichostrongylidae infestation has been demonstrated, infestation inherited due to the presence of the anthelmintic factor and the phenotype (BB) of hemoglobin[556,5]. Prehension is another intrinsic factor that influences receptivity. Species which scrape the grass at the ground surface (sheep) acquire stronger infestations. The soil consumption during the spring in the pastures favors sheep and cattle contamination[235].

The species of parasites, intensity of infestation, nutrition, stable and pasture management, climate and polyparasitism are extrinsic factors that influence receptivity.

***Route of contamination***: oral route by ingestion of infective larvae with food or water.

***Resistance***. Temperature and moisture are the major factors which influence the length of the egg in the infective larvae's evolutive stage and their migration and survival ability on pasture. Direct sunlight and dryness destroy 80 - 88% of egg populations during hot seasons. Infective larvae ($L_3$) of some species (*Nematodirus*, *Ostertagia* and *Trichostrongylus*) survive on the pastures over the winter, their longevity reaching 14 months. Larvae of other trichostrongylid

species are destroyed during winter[54,24]. Survival of the $L_3$ during summer varies between one and three months reaching four months in the autumn[12]. The mortality rate is favored by the dryness, heavy rainfall and high salt concentration consecutive to the evaporation. In the hay originating from contaminated hay fields, larval populations will decrease by 44% after three days and their presence will be sporadic (3%) after 21 days. The pollution coefficient will be virtually insignificant after 40 days[395,269]. The larvae of some species of Trichostrongylidae are also sensitive to the action of live agents (earthworms, fungi) on pasture which reduce the number and transmission of infective larvae on grass[226,227]. Irrigation also influences the development of infective larvae on pasture. The maximum number of $L_3$ developed from 100 eggs in feces on irrigated pasture in July was 11.3 for *Ostertagia* sp., 6.99 for *Trichostrongylus* sp. and 10.65 for *Haemonchus* sp.[549].

The main attributes of the exogenous stages of the most important Trichostrongylidae species on their resistance in the environment are presented in table 6 [384].

**Table 6**. Resistance in the environment of the different developmental stages of the ruminant trichostrongilids

| Nematode species | Stage of lifecycle | | | |
|---|---|---|---|---|
| | **Unembryonated egg** | **Embryonated egg** | **Pre-infective larvae** | **Infective larvae** |
| *H. contortus* | Highly susceptible to cold and desiccation. High mortality below 10°C | Susceptible to cold and desiccation. Negligible hatching below 10°C. Low hatching rates in absence of moisture | Highly susceptible to cold and desiccation | Optimum survival in warm, moist weather. Poor survival in cool or warm dry weather and sub-freezing winters |
| *T. colubriformis* | Intermediate susceptibility to cold and desiccation. High mortality below 5°C | Intermediate susceptibility to cold. Low susceptibility to desiccation. | Susceptible to cold. High mortality below 5°C. Susceptible to desiccation | Optimum survival in cool or warm moist weather. Poor survival over sub-freezing winters |
| *O. circumcincta* | Low susceptibility to cold. High egg viability at 0–10°C. Intermediate susceptibility to desiccation | Low susceptibility to cold and desiccation. Hatching below 5°C | Intermediate susceptibility to cold. Susceptible to desiccation | Optimum survival in cool, moist weather and subfreezing winters. Poor survival in warm, dry weather |

**Pathogenesis.** The pathogenic effects of Trichostrongylidae are dependent on multiple factors: affected digestive segment, nutrition of parasites, presence of $L_4$, $L_5$ larvae and adult stages, tissular migratory route, intensity of parasitism and immune status. In the mentioned context, pathogenicity differs from one genus to another. *Haemonchus* and *Ostertagia* are some of the most pathogenic helminths of ruminants in temperate regions while *Trichostrongylus* and *Cooperia* are less or non-pathogenic[322]. Nematodirus was considered non-pathogenic for many years,

but today it is evaluated as one of the most pathogenic to ruminants in a cold climate[14].

The actions exerted on the host are divided into two categories: effects of larval stages and of adult worms. However, the pathogenic mechanisms are those described in section 1.4 1.1 (General pathogenesis of nematodes) having genus or species-dependent particularities.

Larval stages $L_3$ and $L_4$ enter in the abomasum mucosa or secretory glands from the wall and cause a reduction in appetite and in the digestive capability of the abomasum. In the small intestine, mechanical and inflammatory actions are responsible for severe damages of the intestinal mucosa with similar effects.

The effects of adult parasites depend on the number of individuals and the nutritional status of the animals. The inflammatory, mechanical and nutrition robbing actions are expressed by the destruction of the abomasum and small intestine mucosa. The parasites cause a flattening of the villi, enterocyte exfoliation, micro-tunnelling of the mucosa especially in the anterior segments of the small intestine. Consecutive feed intake will decrease, even to the point of anorexia, diarrhoea, inefficient gastrointestinal function, weakening, rickets and/or hypothrepsia (= malnutrition).

The depression in voluntary feed intake (anorexia) is a major factor in the pathogenesis of the disease being caused by elevated blood levels of gastrin and, as a result, reduce the gained live weight[192,193,457].

The gastro-intestinal functions are also affected. The motility of the small intestine is reduced and so is food passage[192]. These disturbances in motility are explained by alterations in gastric hormone levels[222] and effects of substances of parasite origin, as cholinesterases[191].

The secretory activity of the abomasum and intestine is affected, in that the gastric acid secretion decreases and the circulating pepsinogen and gastrin level increases. The increase of the level of plasma pepsinogen occurs within 6 - 10 days pi and persists for a long time (4 - 6 months) and is an important element for laboratory diagnosis[286]. Protein metabolism is altered, their digestion decreasing by 20-30%; fat, minerals and vitamin absorption is affected, emphasizing the maldigestion and malabsorption syndrome.

In *Haemonchus* spp., a strong spoliation action dominates, causing a severe anemia, and a decrease of the red blood cell count (RBCs), pH concentration and packed cell volume (PCV)[406]. A single individual of *H. contortus*, adult or larval $L_4$ or $L_5$ stages, may consume about 0.05 ml of blood per day[440]. The parasites fixed to the abomasum mucosa cause microlesions, sites for bacterial infection. These superinfections determine complications in the parasitized ruminants, which can result in death. Mechanical action and inflammation are moderate because of its location, in close apposition to the abomasal mucosa.

Larval stages of *Ostertagia ostertagi* are localized in the gastric glands of the abomasum where they grow about 100 fold. They cause erosion of the secretory epithelium and swelling of the gland with maximal biochemical consequences when parasites emerge from glands. These consequences consist in the reduction of the functional gastric juice and diarrhea, the primary clinical sign.

*Cooperia* spp. are considered mild pathogens which cause watery diarrhea and contribute to the effects of *Haemonchus* and *Ostertagia*.

*Trichostrongylus* spp. cause irregular thickness of the intestinal mucosa and, consequently, an increase in plasma losses into the gut, hypoproteinaemia and slight anemia[25].

*Nematodirus* spp. infection was considered a mild disease, but sometimes serious effects may result. Profuse diarrhea, weight loss and

growth retardation have been associated with this parasite.

**Immunity.** Trichostrongylidae are somatic and metabolic aggregated antigens, which induce various states of immunity. In the trichostrongyle infection, two types of immune reactions occur: para-immunity expressed by allergy and an acquired immunity process. The latter can be a sterile humoral immunity or an active post-infective non-sterile (premonition) one.

The allergic reaction is induced by liquids and cuticles of $L_3$ exsheatment. These cause hyperhistaminemia and swelling of the digestive tract wall at the fixation sites. Therefore, the self-curing process will be accentuated.

Aquired immunity is humoral mediated, there being involved antibodies that develop in the wall of the digestive tract[587]. The protection period ranges between 3-5 months if not maintained by reinfection, and decreases in winter.

Premonition, or the presence of worms in the digestive lumen, is characterized by the inhibition of the new larvae development from re-infestations. It is encountered in species which develop in the wall of the digestive tract[141].

**Clinical signs**. Incubation corresponds to the prepatent period (it generally ranges between 15 to 27 days), except for species in which the arrested development phenomenon in the gastric or intestinal wall is established. General clinical signs in ruminant trichostrongylidosis consist in digestive disorders: diarrhea, dehydration, polydipsia, progressive weight loss and anemia. The intensity of the symptoms varies from species to species: an acute evolution in youth (lambs, kids and calves) and a chronic, subclinical and latent evolution in adult animals have been distinguished. Despite the clinical signs common to all Trichostrongylidae species, the current trend is for the diseases to be described separately and independently from a symptomatological point of view: haemonchosis, ostertagiosis, trichostrongylosis, cooperiosis and nematodirosis.

***Haemonchosis*** is a common disease of small ruminants, the parasites being more adapted to sheep than to cattle[62]. Even in mixed sheep-cattle grazings, *Haemonchus contortus* will develop in cattle in lower proportions and with a shortened life span than in sheep[230]. Three forms of evolution are identified: hyperacute, acute and chronic.

*The hyperacute form* is prevalent in tropical areas where developmental conditions of the exogenous stages are optimal, thus creating prerequisites of abundant contamination sources. Animals ingest large infective doses, of tens of thousands of worms. As a result, fever, haemorrhage, severe anemia, dark colored feces and death in seven days will occur. The animals may lose about 0.5 liters blood/day[130].

*The acute form* is spread in temperate regions where lambs and youth are affected. Diarrhea, dehydration, severe anaemia, weight loss, reduced growth and production are the main symptoms. Anaemia in sheep caused by *H. contortus* is hypochromic normocytic[60] while in cattle, caused by *H. placei*, it is normocytic normochromic in immunised calves and microcytic normochromic in non-immunised calves[203].

The *chronic form* is more common in practice and has a long-term evolution of between 2-6 months. It is caused by a low number of parasites, between 100-1000 worms. Malnutrition, progressive weight loss, loss of wool or rough hair coat in goats and stopping growth in youth are typical signs of chronic evolution. Hematological parameters may be within normal limits, despite the chronic blood loss.

***Ostertagiosis*** evolves differently in cattle than in small ruminants. Several types and evolutive syndromes are differentiated in cattle.

*Type I* of ostertagiosis affects only weaned calves. It corresponds to parasitic gastritis which manifests itself by profuse diarrhea, dehydration, weight loss and high mortality, between 75-100%, evolving in the first grazing season during the summer and autumn[415]. Pronounced hemoconcentration and a 10 times increase of the plasma pepsinogen characterize the hematology[285].

*Pretype II* of the disease is a subclinical form that affects calves at the end of the grazing season when animals are carriers of a high number of the arrested $L_4$ larvae[415].

*Type II* of ostertagiosis affects two year-olds or older animals which winter outdoors or in the stables. It is expressed by a pronounced and rapid weight loss, profuse and watering diarrhea and hemorrhage in the abomasum, with a severe evolution from December to June. Aging and the emergence of a large number of arrested $L_4$ larvae that turn into adults are responsible for this form. Two variants are known in this type: fasciolosis/ostertagiosis complex and parturient ostertagiosis.

The fasciolosis/ostertagiosis complex affects calves, 12-15 months of ages, from December toMarch, with severe anemia, weight loss, watering diarrhea and edema of the jaw[415]. Parturient ostertagiosis occurs in adult cows, in this period.

*Oedematous ostertagiosis* or gastritis is another original type or syndrome of disease. It was described by Pitre and Quittet[401] in 8 month to 3 year old animals. The clinical signs are rapid weight loss and profuse diarrhea. The edematous abomasum can be observed at necropsy, reaching 4.5 kg or more (2 to 3 times the normal weight).

Ostertagiosis in sheep is a serious disease, especially in lambs and youth up to 1-1.5 years of age. It is characterized by anemia, weight loss, decreased appetite and diarrhea. Type II of the disease from winter to spring (February / March) is described[426].

***Trichostrongylosis*** has two clinical forms: gastric, caused by *T. axei*, and intestinal, which involves *T. colubriformis*, *T. vitrinus*, and other species.

In gastric trichostrongylosis, young animals are most susceptible to infection. Diarrhea, dehydration, bottle jaw, weight loss, poor growth and emaciation are the main clinical signs.

Intestinal trichostrongylosis shows a severe evolution in kids compared with lambs. The minimum lethal dose in kids is 78000 infective larvae of *T. colubriformis*, whereas in lambs, it is 115000. Profuse and continuous diarrhea with a dark green, almost black color of the feces, are the main clinical signs. The animals are depressed with abdominal pain, anorexia and severe emaciation. Hematology is characterized by leukocytosis with increased polymorphonuclear neutrophils and the erythrocytes are in the normal range of the species. Animal death is due to malnutrition[13]. In calves, the minimum lethal dose is 250,000 larvae, anorexia and diarrhea being the developed symptoms[240].

***Cooperiosis*** is caused by *C. curticei* which mainly infect sheep and goats, *C. oncophora*, *C. punctata* and *C. pectinata* being the common species in the case of cattle. Their superficial localization through the intestinal villi without the deep penetration of the mucosa and rapid development of the host resistance cause lack of pathogenicity. Signs of the infection include apathy, intermittent or continued diarrhea with soft feces, reduced feed consumption, weight loss and progressive emaciation. Anemia and changes in other hematological or biochemical constituents are not recorded, suggesting the reduced parasite interference with blood circulation and intestinal absorption.

***Nematodirosis*** predominantly affects lambs, 6-12 weeks of age, causing lethargy, profuse diarrhea with greenish-black or pale yellow and watering feces, dehydration, polydipsia,

abdominal pain, weight loss and sometimes death.

**Pathology.** The pathological pattern varies in intensity from discrete, unobtrusive lesions, , in low infestations with species whose pathogenicity is low to important, to severe lesions, some of which are specific. The lesions are systematized in two categories, depending on the location of the parasites: gastric and intestinal.

*Haemonchosis* in sheep and goats is characterized by an initial congestion of the mucosa and a white spot in the cardiac region followed by the appearance of petechial hemorrhages and erosions similar to ulcers with depressed centees and slightly elevated edges. Next, hemorrhagic abomasitis, congestion, edema of rugae and thickening of the mucosae will develop. In a more advanced stage, the mucosal edema is accentuated and shows pitted areas. The cellular inflammatory reaction consists of eosinophils, mononuclear cells and plasma cells in the mucosa and submucosa. Hyperplastic or granular abomasitis and petechial hemorrhage disseminated between the whitish, large parasitic nodules are chronic lesions[4]. Hemorrhagic lesions of the abomasal mucosa have been recorded in calves.

In *Ostertagia* spp. infection, nodular abomasitis is the most characteristic lesion. The nodules are small, 1–2 mm in diameter, umbilicated, crater-like, and disseminated throughout the abomasum. They may be discrete, well individualized, but in heavy infections tend to coalesce and give rise to a lesion similar in aspect to Morocco leather. The edema of the mucosa is frequently intense and occasionally necrosis and sloughing occurs. As a result of the nodule dropout by the pre-adult larvae and chronicization, the lesion becomes hyperplastic abomasitis. Nodular abomasitis, edema and congestion of the mucosa are common lesions for type I and II ostertagiosis in cattle, and, in addition, a gross distension of folds appears in type II[322].

In *T. axei* infections, catharral abomasitis, superficial erosions and congestion of the mucosa, sometimes covered with a fibrinous exudate, are observed.

In *Cooperia* spp. infection, catarrhal gastroenteritis, patchy necrosis, haemorrhages, edema of the intestinal mucosa, the presence of a profuse, mucous exudate in the lumen and chronic hyperplastic lesions are diagnosed.

*Nematodirus* spp in monospecific infection seems to be of little significance although the larvae cause severe villous atrophy, mucous-cell hyperplasia and necrosis when they penetrate mucosa. In heavy infections, adults can cause severe lesions as tunnels, destruction of tissues and chronic hyperplastic enteritis.

*T. colubriformis* cause mucosal flattening and villous atrophy in lambs[272].

Regardless of the type of infestation, mono- or polispecific, the lesions are associated with the presence of parasites in their characteristic habitat. *Haemonchus* adults can be easily seen because of their large size while the other smaller species are difficult to see.

Gastrointestinal lesions are associated with anemia with a whitish mucous membrane, edematous infiltration of the subcutaneous tissue, muscle wasting, liver degeneration and cachexia condition. The mesenteric lymph nodes are hypertrophied and infiltrated.

**Diagnosis –** in the case of live animals, it requires the corroboration of the results of several methods. The clinical signs and epidemiological data are presumptive, parasitological and biochemical tests being necessary.

The important *epidemiological data* in targeting diagnosis are the appearance of diarrhea mainly in young ruminants, during the grazing season.

*The clinical examination* serves as guidance, the symptoms being common to a large number of digestive diseases in ruminants.

*The coproparasitological exam* aims to highlight fecal egg counts using flotation tests based on dense saturated solutions (salt, sugar or magnesium sulphate). The method presents some disadvantages: it has no value during the prepatent period, caused by the larval form, when eggs are not shed in the feces, and it does not always correlate the number of adult worms present with the clinical forms of evolution. The method has a group value, the eggs of Trichostrongylidae being indistinguishable from those of the *Bunostomum* sp. or *Oesophagostomum* sp. In nematodirosis the exam has a genus value due to the large size of the eggs. To differentiate the genera, coprocultures and biometry of the $L_3$ larval stage are required.

*Necropsy* is a diagnosis of certainty, but the small sizes and slender bodies of these nematodes require a magnifying glass or microscope examination of the gastrointestinal contents. The method of successive washings of the intestinal content and the artificial digestion of the gastric submucosa to detect larvae is recommended.

*The biochemical exam* aims to determine the plasma pepsinogen, which has a diagnosis value between 7 to 60 days pi only in abomasitis (haemonchosis, ostertagiosis, and trichostrongylosis). Pepsinogen level is 2 - 4 times higher than in non-infected animals.

Serology and immunology are mainly used for experimental purposes.

***Differential diagnosis*** - will be conducted for other gastrointestinal helminthiasis (fasciolosis, oesophagostomosis, strongyloidosis, etc.), coccidiosis, foodborne gastroenteritis, bovine paratuberculosis and digestive anaerobiosis which sometimes evolve in association.

**Treatment.** Curative, it is aimed at: the specific treatment of the entire contaminated livestock; limitation of contamination risk removing the animals from the contaminated area; setting of symptomatic adequate adjuvant medications and dietary nutrition in order to improve the animals' state. Highly effective and well tolerated anthelmintics are presented in table 7.

Avermectins demonstrate an increased efficiency, ranging between 98 and 100%, against both stages of trichostrongylids, adults and arrested larvae. Regardless of the active substances used, meat and milk withdrawal conditions after deworming must be respected.

Unsuccessful trichostrongylidosis therapy cases have been recorded in recent decades. The adaptation phenomenon and the increased resistance of worms to the action of anthelminthic substances are the causes of these failures.

Resistance to an antihelminthic is defined as "*a significant increase in the ability of a strain to tolerate therapeutic doses of the drug*"[315].

The phenomenon is registered in all Trichostrongylidae species, parasites of domestic animals, against at least one or more substances. In *Haemonchus contortus*, populations resistant to thiabendazole, parbendazole, mebendazole, cambendazole, oxibendazole, febendezole and albendazole were identified[339,479,241,564].

Some isolates of *Ostertagia* spp are resistant to thiabendazole, morantel tartrate and levamisole[314].

McMahon et al.[348] observed resistance to the benzimidazoles, avermectin and moxidectin across the *Trichostrongylus*, *Ostertagia* and *Cooperia* genera, while only *Trichostrongylus* and *Ostertagia* were resistant to levamisole. Many other studies demonstrated this phenomenon in different strains of gastrointestinal Trichostrongylidae (GIN), but it is important for the three genera of sheep nematodes: *Haemonchus*, *Ostertagia* and *Trichostrongylus* and, to a lesser extent, for *Cooperia* and *Nematodirus*. Alternation of active substances from one deworming to another and association of two or more active substances are the best measures to eliminate deficiencies induced by the Trichostrongylidae resistance.

**Table 7** Anthelmintic substances used in therapy of trichostrongylidosis in ruminants

| substance | dose (mg/kg bw) | Adult worms | | | | | Arrested larvae ($L_3$-$L_4$) and preadults | | | | | spp. | references |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | H | O | T | C | N | H | O | T | C. | N | | |
| levamisole | 10 $L_3$ | | | | | | 72 | 85.5 | | 98.9 | | cattle | Rowlands and Berger 1977 |
| | 10 $L_4$ | | | | | | 99.3 | 38.1 | | 99.9 | | | |
| | 10 $L_5$ | | | | | | 100 | 74.5 | | 100 | | | |
| | 5.8 | | 70 | | | | | | | | | cattle | Lyons et al., 1981 |
| | 8.1 | | 76 | | | | | | | | | | |
| febantel | 5.0 | 98.5 | | | | | | | | | | sheep | Bürger, 1978 |
| | 7.5 | 100 | | | | | | | | | | | |
| | 5.0 | 97 - 100 | 93 - 98 | 97 - 100 | | | | 61 - 96 | | | | cattle | Ciordia et al., 1982 |
| | 7.5 | | | | | | | | | | | | |
| | 10 | | | | | | | | | | | | |
| ricobendazole | 3.75 | 100 | 100 | | | 100 | | | | | | sheep | Sahin et al., 2009 |
| | 3.75 - 7.5 | 100 | | 100 | 100 | | | | | | | cattle | Coronado et al., 1997 |
| thiabendazole | 100.0 | | | | | | +++ | | +++ | | +++ | sheep | Connan, 1976 |
| oxfendazole | 5.0 | 91.8 | | 77.8 | | | | | | | | goats | Sangster, and Rickard, 1991 |
| | | 95.8 | | 90.9 | | | | | | | | sheep | |
| | 10.0 | 97.5 | | 87.8 | | | | | | | | goats | |
| | | 94.5 | | 93.8 | | | | | | | | sheep | |
| | 20.0 | 98.8 | | 94.5 | | | | | | | | goats | |
| | | 100 | | 98.7 | | | | | | | | sheep | |
| | 2.5 | 100 | 100 | | 99.8 | | | 100 | | | | cattle | Downey, 1976 |
| | 5.0 | 100 | 100 | | 100 | | | | | | | | |
| albendazole[1] | 7.5x2[2] | | 94.6 | | | | | | | | | sheep | Baños et al., 1979 |
| | 10.0x2[2] | | 95.1 | 99.3 | 100 | 93.5 | | | | | | | |
| | 7.5 | | 100 | 100 | 100 | | | | | 100 | | cattle | Borgsteede, 1979 |
| | | 94.5 | 93.5 | 100 | | | | 53.4 | | | | | Williams et al., 1981a |
| | 5.0 | > 95 | | | | | 99 - 100 | | | | | cattle | Theodorides et al., 1976a |
| | 10.0 | > 97 | | | | | | | | | | | |
| fenbendazole | 3.5 | 93.4 | 100 | 100 | 100 | 99.5 | | | | | | sheep | Kennedy and Todd, 1975 |
| | 5.0 | 95.3 | 100 | 100 | 100 | 99.6 | | | | | | | |
| | 7.5 | 99.8 | 100 | 100 | 100 | 100 | | | | | | | |
| | 1.0[3] | 100 | 85.9 | 100 | 94 | | | 47.6 | | | | cattle | Williams et al., 1981b |
| | 5.0 | 98.6 | 96.9 | 98.6 | 94 | | | 74.7 | | | | | |
| oxibendazole | 15.0[4] | 83 - 100[7] | | | | | | | | 92-98 | | cattle | Theodorides et al., 1976b |
| | 15.0[5] | > 98 | | | | | +++ | | | | | | Crowley et al., 1976 |
| ivermectin | 100 µg (orally) | | 99 | 99 | 98.6 | 82.3 | | 99 | | 98.6 | | cattle | Armour et al., 1980 |
| | 200 µg sc | | 100 | | | | | 99.8 | | | | | Williams et al., 1981c |
| | 200 µg 300 µg | | | | | | 99 | | | | | sheep | Todd et al., 1985 |
| doramectin | 200 µg | 100 | | 100 | | | | | | | | cattle | Mehlhorn et al., 1993 |

However, incorrect rotation of drugs, with mistakes such as underdosing, repeated at very short intervals, may aggravate the resistance.

**Control** - has several clear goals: application of technological measures which target the pastures and grazing system, destruction of the free parasitic elements from the pasture, and chemoprophylaxis.

Cultivated pastures play an important role in animal husbandry. Besides the advantages induced by quality, quantity and fodder flow, they are real barriers against animal contamination. Deep ploughing of the grassland determines the disappearance of parasitic elements existing at that moment on the surface. All parasitic stages will be buried in the ground by turning of the furrow. High, well developed grass prevents $L_3$ larvae from climbing, thus reducing the cattle contamination opportunities.

Drainage, regulation of watercourses, removing temporary aquatic biotopes (traces of hooves, carts) will reduce the moisture at the level of soil and (tricho)-strongyle larvae evolution is affected.

Rotational grazing is the process whereby livestock are moved from a grazed pasture to a fresh paddock in order to regenerate the herbaceous vegetation in the previous area. For high efficiency, species alternation must be associated with large ruminants grazing following horses in a particular area. The introduction of a new species on the pasture, unreceptive to infective elements present in the soil, correlated with larval resistance and the impossibility for them to continue their biology contributes to animal protection against new contamination.

The inactivation of infective larvae from the pasture is possible by using different chemical, physical or biological methods. Chemical control, based on the application of chemicals (calcium cyanamide) is currently restricted due to adverse effects on other components of biocenosis. The destructive action of physical factors (heat, humidity, solar radiation) is independent and uninfluenced by humans. Biological methods are highly topical because they protect the environment, are not very expensive and are controlled by humans. The classical and modern methods involve the presence of living organisms which destroy infective larvae through various ways: by feeding with larvae, by exerting a toxic action or by induce deadly diseases in them. A modern method, of great interest, is the use of pests such as nematodophagous fungi or toxic plants. Among the fungi, positive results were obtained with *Duddingtonia flagrans* and *Monacrosporium thaumasium* which trap the free-living stages of trichostrongylids[478]. Among toxic plants, promising outcomes were obtained with the *Xanthium strumarium* species, the undiluted juice of its leaves causing 100% inhibition in egg hatching[470].

The chemoprophylaxis is achievable through two major ways: regular deworming and use of retard-boluses. Regular deworming is based on the same substances used in the treatment, but the timetable of doses administration differs. Two prophylactic treatments are generally prescribed per year, first during the spring, 10 to 14 days before grazing season, and the second in autumn, 2-3 weeks after stabulation begins. The best protective results are obtained applying an anthelminthic treatment quarterly. The routes of administration for the substances may be oral, pour-on or spot-on.

The retard-bolus is a device that contains an active substance which is introduced into the rumen of an animal, where it will release the active ingredient. According to the release system, anthelmintic boluses are classified into sustained release systems of active substance and programmed periodic release systems[124]. In the trade there are many products indicated in the prophylaxis of trichostrongylidosis containing albendazole (Albenol-2500 Bolus), morantel tartrate

(Paratect bolus), ivermectin (Ivodac bolus), abamectin (Enzec), levamisole (Chronominthic bolus), oxfendazol (Synanthic multidose bolus, Repidose forte bolus) or fenbendazole (Panacur Bolus). The protective period of these products ranges from 3 to 5 months.

In the context of continuous prohibition of various therapies in animals intended for human consumption due to adverse reactions to drugs, research towards selecting some breeds with increased genetic resistance in ruminant nematodes infestations will provide new ways in preventing these diseases.

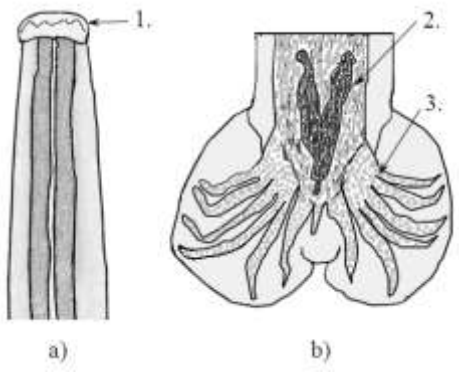


**Figure 16.** *Hyostrongylus rubidus*;
a) anterior end; b) posterior end
1. buccal collar; 2. spicules; 3. rays;

### 3.3.2. Hyostrongylosis in pigs

The *Hyostrongylus* genus is included in the Trichostrongylidae family, Ostertagiinae subfamily and contains parasites of the Leporidae, Suidae and Bovidae families.

**Definition.** Hyostrongylosis is a benign gastritis that affects piglets and young swine expressed by weak or mild digestive disorders, and has been lately reported in several countries.

**Etiology.** The *Hyostrongylus* genus contains a species with medical veterinary importance for domestic species, *H. rubidus*.

***Morphology*.** (figure 16) The adults have a slender, equally calibrated and reddish body, the males measuring 4 to 7 mm in length and the females, 5 to 12 mm. At the anterior end, the mouth is delimited by a buccal collar and they have two cervical papillae. At the posterior end, the male has a bursa with well-developed lateral lobes and a small dorsal lobe; the spicules are equal and branched. The eggs are oval, with unequal poles (one less convex than the other), thin shell, measure 60-75/31-38 μm and they are in an early stage of evolution (so-called 'early tadpole') when laid.

***Life cycle*.** The adults of *H. rubidus* are localized in the stomach, along the lesser curvature in the fundic area, being fixed to the surface and gastric mucosal glands. They are haematophagous parasites; after copulation, the females lay eggs which are passed in feces. Under proper conditions of temperature, humidity and aeration, the eggs hatch in 2 days. After two consecutive moltings, $L_1$ will transform into $L_3$, infective larvae. The animals become infected through consumption of infective larvae. The larvae penetrate the gastric mucosa where they develop into $L_4$ after a new molting. Next, $L_4$ molt again becoming subadults and finally adults. The prepatent period is 3 to 4 weeks[523].

**Epidemiology**

***Geographical distribution*.** The disease has a worldwide distribution and different values of prevalence: 1.7% in Kenya[378], 11% in Burkina Faso[526], 28.5% in northern England[391] and 3.3% in a large reproduction herd of pigs from former Czechoslovakia[300].

***Sources of contamination*.** Sources of environmental contamination are the infected animals which eliminate eggs for a long period of time. The maximum incidence of egg-laying was registered for 10 to 12 months pi. The reservoirs of parasites are the sows that have a high risk of environmental pollution between 2 weeks before the pregnancy and 6 weeks postpartum. After weaning, egg-laying is reduced in intensity. The fecal egg counts vary between 100 and 1800 epg[526].

***Susceptibility*** is increased in youth and breeding sows and decreased in fattening pigs and adults. The last two categories can easily contaminate in food and zoohygiene deficient conditions.

***Route of contamination***: is accomplished by ingestion of infective larvae with feed and water or from the infested pastures by grazing.

***The resistance*** of the larvae on the pasture or in shelters and grassland pollution are low from January to July, reaching a maximum in October. The optimal temperature and humidity favorable for the exogenous development of eggs and larva survival is between 15 - 20°C and from 79.5 to 95.5%, respectively[190].

**Pathogenesis**. The adults act in a traumatic manner on the gastric mucosa; they penetrate deep into the mucosa and feed on the blood causing an anemia syndrome, hyperaemia and hemorrhagic gastritis. The parasites may cause ulcers in the fundic region, cellular infiltrations, proliferation of the epithelial lining of the cardia and pyloric orifice and granulomas in lamina propria. The subadults who have penetrated the gastric glands produce nodules that interfere with the stomach functions, resulting in diarrhea, dehydration and subsequent weakening. Reduced infestations often evolve subclinically, but those with a higher intensity of parasitism determine a rapid alteration of the general condition, apathy and stomach pain[456].

The inoculation action consists in superinfections and gastric abscess. The toxic action is expressed by eosinophilia and urticaria, and the spoliation by anemia.

Consecutive to the pathogenic effects exerted by the parasites on the gastric mucosa, a massive elimination of adult worms and L4 larval stages occurs[283].

**Clinical signs.**

The incubation period varies between 10 and 13 days. Further, the piglets present anemia, misconduct, poor appetite to anorexia, fever, vomiting and mostly diarrhea with fluid and blackish feces. Piglets lose their liveliness, present stagnating growth, messy and lackluster hair.

In sows, taste perversion, coprophagia, geophagy, low prolificacy, and sterility occur. Pregnant and lactating sows may have subclinical, asymptomatic forms, but may present pronounced weakness, which can end in exitus, due to perforated ulcers, bleeding and peritonitis.

**Pathology**. The development of worms inside the stomach is usually non-pathogenic. When a high number of worms are present, they may cause catharal gastritis, hyperenua and submucosal edema. Rarely, in severe infections, a yellow caseous and fibrinous pseudomembrane forms, which, if removed, leaves the mucosa with erosions and deep ulcers.

The **diagnosis** is suspected based on clinical signs and epidemiological data. It is based on a coproscopic exam using flotation methods, emphasizing strongyle egg type in live animals. The differentiation of *Hyostrongylus rubidus* eggs by *Oesophagostomum* spp and *Globocephalus* spp is difficult. The larvae may be recognized by coprocultures. The necropsy is based on highlighting the catarrhal, nodular, ulcerative or pseudomembranous gastritis, the presence of parasites in the gastric mucosa and it has a reliable value.

***Differential diagnosis*** is done for nonspecific anemia, salmonellosis, gastritis with another etiology, other nematodosis (ascariosis, strongyloidosis, spiruridosis, oesophagostomosis, and trichuriosis) and piglets coccidiosis.

**Treatment.** Basically, benzimidazole derivatives are useful in hyostrongylosis. The efficacy of the following has been demonstrated:

- fenbendazole at a dose of 5 mg/kg demonstrated a 100% efficacy in a 42-day-old artificial infection with *H. rubidus*[291];

- cambendazol, 10 to 15 mg/kg/day in food[522];
- levamisole HCl (8 mg/kg) showed an efficacy of 94.4% against *H. rubidus*[337];
- oxfendazole, at doses of 3, 4.5 and 6 mg/kg bw had an efficacy between 99.8 and 100% against *H. rubidus* infestation, at 20 - 51 days after contamination[287];
- flubendazole, 30 ppm in the feed for mass medication, for 10 consecutive days, was 100% effective against *Hyostrongylus rubidus*[559];
- doramectin, 0.3 mg/kg bw has a 99.4% efficacy against natural infections with *H. rubidus*[509];

**Control**. The practicing of the closed herd turnover system is one of the best methods to prevent helminthoses in pigs[299]. Regarding the chemoprophylaxis, emphasis is placed on treatment of sows at farrowing, or of piglets when they are transferred to the growing units. Two treatments at an interval of 14-21 days are indicated. Continuous administration in the food is a complementary solution[416].

## 3.4. Chabertiidae

The Chabertiidae family includes medium-sized round worms, parasites in even-toed ungulates, macropods marsupials, rodents and primates. The family is systematized in two subfamilies (Chabertiinae and Oesophagostominae) and 5 genera: *Castorstrongylus*, *Chabertia*, *Cyclodonto-stomum*, *Ternidens* and *Oesophagostomum*.

Morphologically, the Oesophagostominae subfamily is characterized by the presence at the anterior end of a rectangular buccal capsule devoid of leaf crowns at the entrance to the capsule. The outer cuticle shows a dilatation that surrounds the cervical region forming a cephalic vesicle. Posteriorly, it continues with two cervical alae. The Chabertiinae subfamily has a bell-shaped buccal capsule equipped with a reduced leaf crown.

The life cycle is monoxenous, with a typical "strongyl" evolution in the external environment. Contamination is oral and the endogenous evolution is a non-migratory phase, larval stages developing in the wall of intestines.

### 3.4.1. Oesophagostomosis - Nodular enteritis in ruminants and pigs

Nematodes of the genus *Oesophagostomum* are parasites in ruminants, pigs and primates, which also have a low zoonotic potential[229].

**Definition.** This is an intestinal helminthosis which affect pigs and large and small ruminant species, caused by nematodes of the *Oesophagostomum* genus, expressed by severe digestive disorders, weight loss and reduction in body development in young animals. The disease is widespread throughout the world with enzootic and severe evolution in young pigs.

**Etiology.** Parasites belong to the Nemathelminthes phylum, Chromadorea class, Rhabditida order, Chabertiidae family and *Oesophagostomum* genus. Members of this genus are popularly called "nodular worms" because the larvae cause nodules in the intestines of their hosts.

In cattle: *Oesophagostomum radiatum* is localized in the large intestine and the larvae ($L_3$ - $L_5$) develops in the mucosa of the jejunum, ileum, cecum and colon.

In sheep and goats can be found:

- *Oesophagostomum columbianum*, in the small and large intestine;
- *Oesophagostomum venulosum* - adults in the cecum and colon and larval forms in the submucosa of the small and large intestine;

In pigs parasitize:

- *Oesophagostomum dentatum* - adult worms are located in the cecum and colon, and larvae ($L_4$ and $L_5$) in the submucosa of the small and large intestine;
- *O. quadrispinulatum*, with a cosmopolitan distribution;

- *O. brevicaudum* spread in southeastern United States and other areas with a similar climate;
- *O. granatensis* and *O. georgianum* in Europe and southeastern United States, species considered morphological variants of *O. dentatum*[417,507,129];

***Morphology*.** Adults are small nematodes, measuring between 10 - 25 mm in length, with a whitish body. The size of females, males and eggs are shown in table 8. Despite the differences in length in *Oesophagostomum* spp., the shape of the esophagus and the length of the female tail are the criteria used in species differentiation. At the anterior end it has a cylindrical or large, sub-globular and relatively shallow buccal capsule. The mouth opening is situated at the terminal end of the oral capsule and is surrounded by a leaf-crown. This crown is composed of a variable number of elements which are divided into two components: internal and external. The majority of species have this leaf-crown, but in some of them it may be incompletely developed, lacking the internal or external component while in others it is completely missing. The cuticle undergoes a dilatation that surrounds the entire anterior end and is called the anterior vesicle. It has delimited several sections: the cephalic vesicle, cervical vesicle and cervical alae. The cephalic and cervical vesicles are ventrally delimited from the cervical alae by a cervical groove. Cervical papillae are present behind or before the esophagus level, depending on the species. At the posterior end, the males have a copulatory bursa with developed lateral lobes, sustained by bursal rays. The spicules are long, equally calibrated, tubular and slender. The eggs are of the strongyle type, ellipsoidal, with a smooth membrane and variable dimensions from species to species, with limits between 52 and 120 / 30 and 54 μm, and contain 8-16 blastomeres when laid (figure 17).

*The* ***life cycle*** is direct, monoxenous. The adults are localized in the large intestine where they feed with desquamated mucosa residues and intestinal contents. They copulate in the intestinal lumen and, consecutively, the females lay eggs.

The eggs are passed in the environment through feces and the exogenous phase begins. In favorable temperature (20 - 25 °C), humidity (80%), and aeration conditions, rhabditiform first-stage larvae ($L_1$) hatch within 6-7 days and follow two successive molts.

Thereby $L_3$ infective larvae develop and retain their molting cuticle. Infective $L_3$ larvae show positive hydro- and thermotropism and negative geo- and phototropism.

In warmer, more humid periods, they climb on the grass, whence they can be consumed by animals, which they thus contaminate. In lower thermal conditions, of 15 - 20 $^oC$, the exogenous phase lasts 40 to 50 days. The development ceases below 12 - 15 $^oC$.

The endogenous stage is a non-migratory phase. The $L_3$ penetrate the lamina propria of the small intestine and cause nodular or capsular formations. Encapsulated $L_3$ molt to the fourth stage ($L_4$) inside the nodules and then return to the lumen as $L_5$, young adults, who migrate to the large intestine, where they reach adulthood.

Basically, the life cycle is similar for all species, but there are some particularities. In *O. columbianum* infections, two histotropic phases are described[131]. The first phase consists in encystation of $L_3$ larvae in nodules, in the anterior segment of the gut. It is followed by a second phase in which a part of $L_4$ larvae released from the nodules return to the lumen and migrate to the large intestine. Here, these larvae are arrested at the $L_4$ larval stage while other $L_4$ larvae will develop to the adult stage. All other species perform only one histotropic migration in which the $L_3$ larvae invade the intestinal mucosa and form nodules inside of which they molt in $L_4$.

**Table 8.** *Oesophagostomum* spp. Morphometry of evolution stages

| Species | female (mm) | | male (mm) | | egg (µm) | | ext / int leaf crown |
|---|---|---|---|---|---|---|---|
| | length | width | length | width | length | width | |
| *O. radiatum* | 16 - 22 | 0.3 - 0.8 | 14 - 17 | 0.3 - 0.4 | 88 - 95 | 44 - 55 | - / + |
| *O. columbianum* | 15 - 22 | 0.3 - 0.5 | 12 - 17 | 0.2 - 0.3 | 80 - 90 | 50 - 60 | + / + |
| *O. venulosum* | 13 - 24 | 0.5 - 0.6 | 11 - 16 | 0.3 - 0.4 | 87 - 105 | 55 - 64 | + / + |
| *O. dentatum* | 11 - 14 | 0.5 | 8 - 10 | 0.3 | 66 - 80 | 40 - 54 | + / + |
| *O. quadrispinulatum* | similar with *O. dentatum* | | | | 60 - 70 | 30 - 40 | + / + |
| *O. brevicaudum* | 6.4 - 8.5 | 0.3 - 0.4 | 6.2 - 6.8 | 0.3 - 0.4 | 52 - 67 | 30 - 45 | + / + |
| *O. georgianum* | 10 - 11 | 0.38 | 5.8 - 7.6 | 0.3 - 0.4 | 55 - 75 | 35 - 45 | + / + |

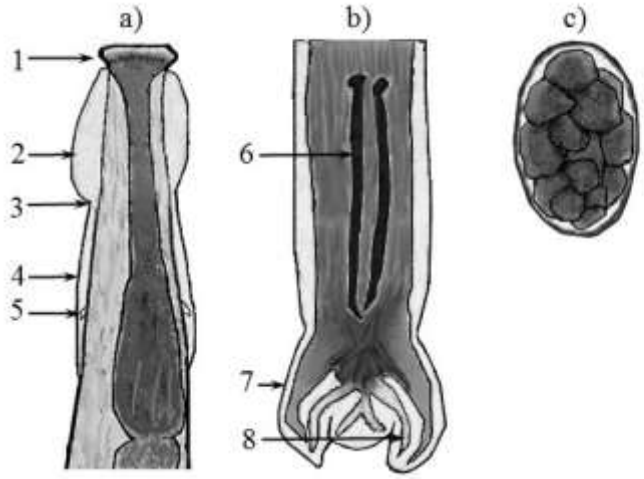


**Figure 17.** Morphology of *Oesophagostomum* spp.: a) anterior end; b) male, posterior end (copulatory bursa; c) egg; 1. cephalic vesicle; 2. cervical vesicle; 3. cervical groove; 4. cervical alae; 5. cervical papillae; 6. spicules; 7. lobes; 8. rays;

These larvae return into the lumen where, adults evolve after another intermediate molt. The prepatent period varies from 17 to 53 days, depending on the species and dose. A lower dose requires a reduced period compared with high doses, which need a long prepatent[106]. The lowest prepatent, meaning 17 days, is recorded for *O. dentatum*[525] while the longest, 53 days, was found with *O. quadrispinulatum*[503]. If the arrested phase sets in, the prepatent period will extend to up to 8-10 weeks or even seven months[270]. The lifespan of adults may reach up to 21 months in some species[10].

**Epidemiology**

***Geographical distribution.***

Oesophagostomosis has a worldwide distribution, being a common disease in temperate wet climates. There are also species that affect domestic animals, spread in tropical and subtropical regions (e.g. *O. columbianum*). The values of prevalence are variable from one region to another and from species to species.

In pigs, *Oesophagostomum* spp infestation was diagnosed in 27.5% of animals from 13 pig fattening farms located in northern Germany[271]. In northern England, 85% of

sows showed *O. dentatum* and *O quadrispinulatum* infestations over a period of two years of parasitological surveillance[391]. In central Romania, *O. dentatum* affected 4 – 16% of the weaned piglets and 2,5 – 20% of the fattening pigs[127].

In cattle, the disease affected 38.4% of animals originating in Kiambu District, Kenya[568]. In the State of Georgia (USA), the prevalence of *O. radiatum* was 61% between 1968 and 1973[109]. In goats, nodular oesophagostomosis recorded a prevalence of 62.8% in northern Benin[451]. The *O. venulosum* prevalence was 10% in sheep originating from the Burdur region, Turkey[547].

***Sources of contamination.*** Sources of environmental pollution are infected animals, with chronic disease and youth populations in the second year of grazing. The animals with an acute form caused by the larval stages do not pollute the environment because they are in the prepatent period. The risk of pollution and perennating of contaminated pasture depends on the incidence of infection in wild animals (ruminants and wild boar) which are susceptible to those parasites that also affect cattle, sheep, goats, and domestic swine.

Sources of animal contamination are represented by infective $L_3$ larvae spread on the pasture. Their dissemination on the pasture occurs through fertilization or irrigation with contaminated water.

***Susceptibility.*** Among farm species, cattle are more susceptible, followed by sheep and goats, while pigs are more resistant. Age seems to have a role in resistance to contamination. In cattle, the resistance to initial infection increases with age, the most susceptible being calves aged 8-24 months[79]. In small ruminants, the adult goats over one year of age and young sheep from three to 18 months tend to be more receptive[451]. The resistance of pigs can be explained by the minimum risk of contamination due to the breeding system.

***Route of contamination.*** The animal contamination is oral, by ingesting infective larvae with food and water, during grazing or at shelters. Percutaneous or intra-ocular contamination ways are demonstrated[209].

***The resistance.*** Temperature, humidity and direct sunlight are the factors that influence resistance of parasitic elements, eggs and larvae, on the pasture. The optimal temperature for the development and hatching of the eggs varies from species to species, but overall limits fit between 10 and 40°C, the optimal values being between 25 and 30°C. The optimal temperature for larval development from $L_1$ to $L_3$ ranges between 25 and 30°C. Drought conditions in the environment cause a rapid and marked mortality of eggs and preinfective larvae. The eggs cannot withstand negative temperatures during the winter and so are destroyed. The resistance of larvae in dryness and sunlight is reduced, but it is high in cold conditions. The survival of larvae on the pasture is possible in winter, and their survival period in summer is up to 2-3 months. The larvae of *O. dentatum* that developed during the autumn will remain viable until April next year (Hiepe, 1985; Rose and Small, 1980[10].

**Pathogenesis**. The complex pathogenic mechanisms depend on the affected species, the parasite location, their nutrition type and life cycle stage.

The inflammatory action of larvae in large and small ruminants, upon first contamination with *O. columbianum*, *O. radiatum*, and *O. venulosum*, is very low, the animals having a diminished reaction. In the case of re-infestation, the larvae penetrate the mucosa and the inflammatory response will be emphasized as a consequence of previous sensitization of animals. The larvae will cause nodules of different sizes and characters which will subsequently be caseated and/or calcified. After completion of the larval stage, the inflammatory action of adults is reflected on bowel mucosa causing typhlitis and colitis.

Some differences regarding the inflammatory pathogenicity between *Oesophagostomum* spp. in small ruminants have been recorded. The adults of *O. venulosum* cause small ulcers on the intestinal mucosa, whereas larvae of *O. columbianum* migrate deep into the mucosa and cause fibroblastic nodules, being more pathogenic. The larvae of *O. dentatum* from pigs have a moderate inflammatory effect, causing small nodules (1 mm diameter) and the adults cause catarrhal enteritis.

The nodule formation is also reflected by gut motility, which is disrupted, this being an expression of the mechanical action of the larvae.

The inoculation action is strong in the case of larvae that mobilize the intestinal flora (*E. coli*, *Salmonella* spp., etc.) and cause the nodule over-infection transforming them into micro-abscesses.

Spoliation is not very severe because the adults feed on intestinal content and only the larvae of some species are hematophagous, but their development inside the nodules limit this effect.

The toxic action is caused by toxins resulting from the death of the larvae in nodules and is expressed by edematous reactions of the affected mucosa, micro-haemorrhages and punctiform necroses.

One of the most important pathogenic factors in oesophagostomosis is anorexia. It was observed in ruminants and consists in a fast reduction in the average daily feed intake during the fourth post-infection week, followed by a slow return to the initial level of intake, about 14 weeks later. Anorexia may explain the metabolic disturbances recorded in oesophagostomosis: hypoproteinaemia, hypo-glycemia, the increase in activity of the glutamic-oxalic transaminase, lactic acid dehydrogenase acetate and glutamic acid pyruvate transaminase, a decrease in the alkaline phosphatase activity and a normochromic normocytic anemia[78,19].

**Immunity.** The immune protection in oesophagostomosis involves diverse action mechanisms and different statuses, which vary from one species to another, are known.

The haemagglutinin antibodies are involved in mediating the immune response in sheep[139]. This response is favored by the high protein diet that accentuates the immune competence of animals[140]. Reinfections emphasize the immune protection of animals which is expressed, in this case, by the development of a small number of worms compared to the first infection, and these worms are stunted[138].

In cattle is has been demonstrated that the newborn calf serum (BCS) totally inhibits the development of *O. radiatum* $L_4$ and the inhibition may be abolished by heat treatment[158]. Also, the polyparasitism does not cause cross immunity in cattle, between *Cooperia punctata* and *O. radiatum*.

The homologous reinfections induce a protective immune condition of low intensity in pigs. In the case of contamination with both species, no resistance to reinfection was recorded[524].

**Clinical signs**. Clinical signs and evolutive forms are extremely varied, ranging from asymptomatic to severe or subtle cases, with acute, chronic, and rarely other type of evolution. However, two major forms are differentiated: acute, caused by larval penetrations of the intestinal mucosa and chronic, due to repeated infections.

The acute form affects calves, lambs and piglets. It evolves during the summer, at 7-10 days pi, expressed by depression, hyperthermia, polydipsia, inappetence or anorexia, diarrhea with whitish feces that contain mucus, or black, fetid diarrhea. In the following days the diarrhea is profuse, animals are dehydrated, have colic, undergo a sudden weight loss and are anemic. Animals die in the 2-3 weeks or pass into the chronic form.

Chronic oesophagostomosis is most common in sheep and sows. In sheep, it is caused by

repeated infections, and in sows it evolves as "thin sow syndrome." Discontinuous diarrhea and reduced appetite are the typical symptoms in sheep. The sheep may become emaciated and anemic in a prolonged and severe chronic evolution. The "thin sow syndrome" is expressed by weight loss after farrowing and reduced milk production with side-effects on the growth of unweaned piglets.

**Pathology**. The lesions are associated with the two forms of clinical evolution: acute and chronic. Catarrhal enteritis with hemorrhagic nodules disseminated on the small intestine mucosa is the typical lesion in the acute form. Often, these nodules fill with pus, being transformed into small abscesses. The mucosa is infiltrated, congested and shows numerous petechiae caused by the penetration of $L_3$ larvae. Becoming chronic, the lesion will transform into nodular enteritis with fibrous nodules in the small intestine. Adult parasites in the large intestine cause hyperplastic typhlitis and colitis. The corpses are anemic, with muscle wasting, effusion fluids in the serosa and mesenteric lymph nodes are hypertrophied, edematous and infiltrated.

**Diagnosis.** Clinical exams and epidemiological data are valueless, directing the diagnosis to diseases caused by the bursate nematodes or strongyle-type nematodes (bunostomosis, globocephalosis, hyostrongylosis, trichostrongylidosis and others).

Identification of eggs in feces is of low value because they are similar to the eggs of all other strongyle-type species. Coprocultures and the study of larvae morphology are necessary for an accurate identification. Furthermore, the exam is valueless in the prepatent phase, caused by the larval stages $L_3$ and $L_4$ developed in nodules.

Necropsy is a diagnosis of certainty, lesions such as nodular enteritis, typhlitis or colitis being pathognomonic.

***Differential diagnosis*** - is required against: eimeriosis, trichostrongylidosis, acute fasciolosis and paramphistomosis in ruminants (of paratuberculosis in cattle); paratyphus, specific bacterial enteritis, nutritional diseases, ascariosis and balantidiosis in pigs.

**Treatment.** Specific treatment in ruminants is carried out using the same drugs as in trichostrongylidosis (chapter 2.3). Thiabendazole is highly effective and appears to be the most useful drug against *0. columbianum* larvae from nodules, at the minimum dose of 125 mg per kg bw[487].

In pigs, the following are used:

- dichlorvos at a dose of 17 mg/kg bw showed a 99.4% efficacy against *Oesophagostomum dentatum* and 99.9% against *O. quadrispinulatum*[337];
- levamisole HCl, 8 mg/kg bw has expressed an efficacy of 97.1% against *O. dentatum* and 99.7% against *O. quadrispinulatum*[337];
- pyrantel tartrate and citrate, at a dosage of 510 mg of free pyrantel base/kg of feed has expressed a 100% efficacy for each of the substances[408];
- cambendazole, at a dose of 1.5 g per 1 kg of liver weight, showed a 100% effectiveness in the control of *Oesophagostomum dentatum*[107];
- oxfendazole, at doses of 3, 4.5 and 6 mg/kg bw had an efficacy of 100% against *Oesophagostomum* sp. infestation, at 10 - 51 days after contamination[287];
- flubendazole at a dose of 30 ppm in the forage, for 10 consecutive days, was 100% effective against *O. dentatum*[559];
- fenbendazole, at 2.5, 1.0 and 0.25 mg/kg bw determined a high fecal egg count reduction (98%, 88%, and 91%, respectively)[407];
- ivermectin caused the decrease of the adult worm burden by 88.8, 96.2 and 99.6% at dose rates of 150, 300 and 600 micrograms kg-1 bw[397];
- moxidectin demonstrated 100% efficacy at 1.50 mg/kg(-1) body weight against *O. quadrispinulatum*[508];

- doramectin, 300 microg/kg live weight with 96.3% efficacy against *O. dentatum*[427];

**Control**. In ruminants, the measures described in trichostrongylidosis are applicable (chapter 2.3).

The opportunity of immunoprophylaxis is a particular element, available for oesophagostomosis. There are numerous experimental studies that demonstrate the development of immune protection in youth against contamination, following the administration of various antigens. Induction of partial immune protection in lambs was performed using the irradiated third stage larvae and somatic antigens in calves[469,200].

The control of the disease in pigs is based on chemoprophylaxis, but other methods may be applied at different levels: breeding system, type of floor in shelters, nutrition. Intensive pig farming has a major barrier effect because the contact between animals and parasites is almost completely avoided. The slatted floors, used for waste removal, also prevent contamination of pigs because exogenous stages of parasites cannot develop on such a floor. The type of feed and the method of feeding are also important in the prevention of pig contamination. The dry feed administered from troughs ensures the highest rate of protection while the moist feed allows contamination of the pigs at an almost double level[277]. Chemoprophylaxis is achievable using the same substances enunciated under treatment.

### 3.4.2. Chabertiosis in ruminants

**Definition.** Chabertiosis is an intestinal helminthosis with seasonal evolution, at pasture, affecting small ruminants, rarely cattle, wild bovids and cervids, and manifests itself through digestive disorders as a chronic colitis.

**Etiology.** The *Chabertia* genus includes only one species of veterinary importance, *C. ovina*, which affects goats and sheep, occasionally cattle.

***Morphology*.** (figure 18) The parasites have a cylindrical, equally calibrated and whitish body, slightly ventrally recurved at the anterior end. The size of adults varies between 12 and 14 mm in the case of males, and 17-22/0.4-0.5 mm in the case of females. At the anterior end, a well-developed, globular buccal capsule is present. It lacks teeth and is surounded by a double row of minute papillae at the edge of the capsule, which opens antero-ventrally. At the posterior end, the males have a trilobated copulatory bursa with an elongated dorsal lobe and two spicules, long and sharp. The body of the female ends with a sharp tail. The eggs are strongyle-type and measure 100/50 μm.

***Life cycle*.** The life cycle is direct, having an exogenous phase similar to the Trichostrongylidae. The adults are located in the large intestine, within the disk-like section of the colon[424] and they feed on mucosal tissues, sucking a plug of mucosa into the buccal capsule and subsequently digesting it. The females lay the eggs that pass through feces into the environment. The first larval stages hatch the eggs and molt twice, resulting in infective $L_3$ larvae. The animal is contaminated by eating infective $L_3$ with water and feed. After ingestion, $L_3$ exsheath in the small intestine, penetrate the mucosa and molt to $L_4$. Arrested development stage, or hypobiosis, may set in at this stage as a survival mechanism. During this phenomenon, $L_4$ penetrate deep into the mucosa of the small intestine or cecum and will survive the winter. These $L_4$ will return to the lumen, agglomerate in the cecum and molt to immature adults ($L_5$). The pre-adults pass on to the colon where they finalize the cycle becoming adults. The prepatent period is about 50 days.

**Epidemiology**

***Geographical distribution*.** The disease has a worldwide distribution, but is more common in temperate and cold areas.

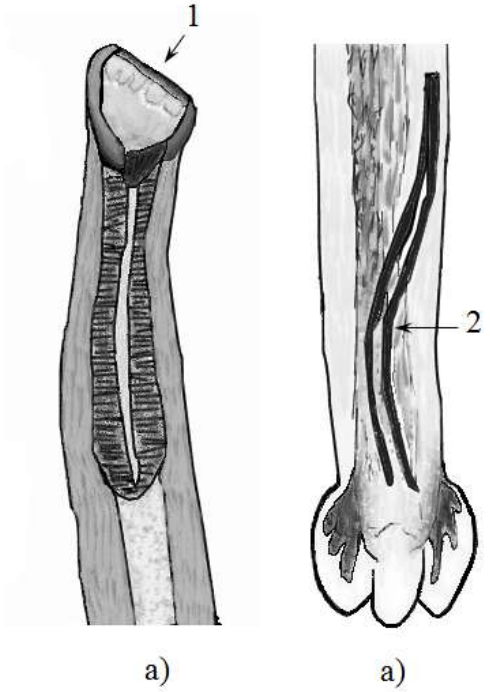


**Figure 18.** *Chabertia ovina* a) anterior end; b) posterior end; 1, buccal capsule; 2, spicules;

The prevalence varies from one region to another and from one species to another: 4.16% in cattle in central Afyonkarahisar, Turkey[466], up to 56% in sheep from Sweden where about 80% of the flocks are affected[318] and 3.1% in Argentina's Western Pampas[517]

***Sources of contamination*.** The pollution of pastures is accomplished by infected animals that eliminate eggs in feces. Fecal egg counts register a relative intensity of 350 epg and a maximum value of 4200 epg in sheep[318]. The animal contamination is performed by the $L_3$ infective larvae existing in the grassland.

***Susceptibility***. Sheep are the most susceptible, and, within the species, lambs have an increased sensitivity.

The ***Route of contamination*** is oral, the animal eating L3 larvae with the infested feed or water.

***Resistance*.** *Chabertia ovina* is considered a common species in temperate and cold regions, and so the eggs and larvae are characterized by an increased resistance to environmental conditions. The hatching is possible above 6°C and below 36°C, and both eggs and larvae can withstand freezing temperatures[439].

**Pathogenesis** is mainly conditioned by the adults'type of feeding in the intestines. Adults who are fixed to the intestinal wall and suck a plug of mucosa into their buccal capsule exert an irritative-inflammatory action. This is locally reflected by punctiform haemorrhages, ulcers, erosions, edema and generally consists in protein loss. The micro-ulcers created are inoculation sites for infectious pathogens.

**Clinical signs** are diarrhea; the feces contain blood and mucus, weight loss and anemia. In heavy infections, severe digestive and metabolic (hypoalbuminemia) disorders may appear during the prepatent period, when immature adults consume large quantities of tissue followed by the destruction of large areas of the intestinal mucosa.

**Pathology**. The parasites attached to the mucosa cause congestion, petechiae, edema, thickening of the lining of the large intestine, catarrhal colitis and haemorrhagic ulcers.

**Diagnosis.** Clinical examination is worthless due to the reduced intensity of the symptoms, many of them being common to several diseases. Parasitological examination has a group value showing strongyle-type eggs that cannot be differentiated from those of Trichostrongylidae, *Bunostomum* sp., etc. Necropsy reveals the lesions and adult parasites fixed to the mucosa.

***Differential diagnosis*** is done for other parasitic and bacterial diseases (eimeriosis, trichostrongylidosis, monieziosis, colibacillosis, etc.), viral diarrhea, and nutritional deficiencies with similar clinical signs.

**Treatment.** The active substances described in the therapy of trichostrongylidosis are useful also in chabertiosis (chapter 2.3). The particular efficacy against *Chabertia ovina* is demonstrated by:

- fenbendazole, 5 mg/kg bw of sheep proved 100% effectiveness[252];

- thiabendazole at 100 mg/kg bw is very effective against the arrested larvae of *Chabertia ovina* in lambs[117];
- oxfendazole doses at a rate of 5 mg/kg bw showed 100% efficacy for *Chabertia ovina* in lambs[146];
- albendazole at 3,8 mg/kg bw administered orally had a 100% efficacy againts *Chabertia ovina*[555];
- mebendazole at a dosage rate of 15 mg/kg bw administered intraruminally was excellent (100%) against all stages of *Chabertia ovina* in sheep[554];

**Control**. The usual procedures for pastures, sanitation, nutrition and chemoprophylaxis, described in trichostrongylidosis (chapter 2.3) apply.

## 3.5. Globocephalidae: Globocephalosis in pigs

The *Globocephalus* genus has undergone several systematic reorganizations. Due to the presence and structure of the buccal capsule, it was included in the Ancylostomidae family. Recently, the Globocephalidae family taxon was created and included in the Chromadorea class, Rhabditida order.

**Definition.** Globocephalosis is a digestive disease which affects domestic pigs and wild boars, with chronic and insidious evolution consisting in pasty feces or diarrhea, weight loss and sometimes death, especially in piglets.

**Etiology.**

The *Globocephalus* genus includes about 18 species, but their recognition is questionable, in some cases they are considered tobe synonyms or to belong to other genera. Typical hosts of these species are members of the Suidae family, but species that parasitize in monkeys, carnivores, rats, squirrels or marsupials have been described. The species have different geographical distributions, *G. urosubulatus* being the only one with a cosmopolitan spread (table 9).

***Morphology*.** Adult parasites (figure 19) have a small and equally calibrated cylindrical body coated with a thick cuticle with fine transverse striations, and the esophagus is elongated and posteriorly flattened. The female measures between 5 and 7 mm in length, and the vulvar opening is in the posterior half of the body. At the anterior end it has a sub-globular oral capsule without leaf-crowns or cutting-plates at the interior margin, equipped with two lancets at the base. The male varies between 4 to 5.5 mm in length and has a trilobated copulatory bursa at the posterior end. Spicules are slender, dorsally curved, long, thin and equally calibrated.

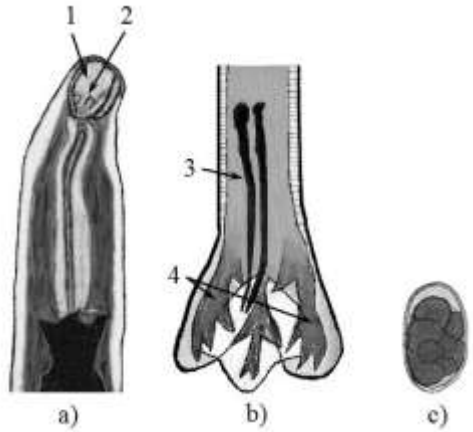


**Figure 19.** Morphology of *Globocephalus* spp.: a) anterior end; b) posterior end - male; c) egg; 1. buccal capsule; 2. lancets; 3. spicules; 4. rays;

Eggs are oval, thin skin, bilaminar. They are in the morula phase when laid, containing between 4 and 8 blastomeres, and measure 67-73/35-40 μm.

***Life cycle*.** It is monoxenous and direct. Adults parasitize the small intestine, mainly in wild boars, rarely in the domestic pig. They are hematophagous; the female is oviparous and the eggs laid with feces will evolve in the external environment. At 25 - 30°C, within 1 - 2 days, the $L_1$ larvae hatch, molt twice and in 1-16 days become $L_3$ infective larvae.

**Table 9.** Species of the genus *Globocephalus* and their hosts

| species | hosts | observations |
|---|---|---|
| *G. amucronatus* | Pig, wild boar | Japan (Shoho and Machida, 1979) |
| *G. asmilium* | Patas monkey (*Erythrocebus patas*)<br>Formosan macaque (*Macaca cyclopis*)<br>Southern pig-tailed macaque (*Macaca nemestrina*) | syn. *Characostomum asmilium* Morishita (1925)<br>Japan, French Guiana (Freitas Teixeira and Lent, 1936) |
| *G. callosciuri* | Squirrel (*Callosciurus caniceps*) | Cassone and Krishnasamy (1986) |
| *G. ciurcai* | Fish (Salmonidae) | Dinulescu (1942) |
| *G. connorfili* | Black rat (*Rattus rattus*)<br>Domestic pig | Type B specimens of *G. urosubulatus* Yadav and Tandon (1989)<br>Samoa, New Guinea, Bengala |
| *G. gigantospiculatus* | Hog badger (*Arctonyx collaris*) | Nguen (1978) |
| *G. longemucronatus* | Wild rat (*Diplothrix legata*)<br>European swine | Itagaki et al (1981)<br>identical with *G. urosubulatus* (Hartwich, 1986)<br>syn. *Crassisoma urosubulatum*<br>Europe, Japan |
| *G. lutrae* | *Lutra chinensis* | Wu and Hu (1938) |
| *G. macaci* | Monkeys | identical with *Ternidens deminutus* (Railliet et al., 1913) |
| *G. madgascariensis* | Crocodile | syn. *Hartwichia rousseloti* (Chabaud and Bain, 1966) |
| *G. maplestonei* | Bushpig | Maplestone's type A specimens of *G. urosubulatus* are considered a new sp., (Ortlepp 1964) |
| *G. marsupialis* | *Philander* (*Metachirops*) *opossum* (gray Four-eyed opposum) | Brasil (Freitas Teixeira and Lent, 1936) |
| *G. mexicanus* | *Pappogeomys tylorhinus* (Naked-nosed pocket gopher) | Gonzalez (1986) |
| *G. samoensis* | *Sus scrofa dom.*, *Sus leucomystax*, *Sika nippon nippon* (Japanese deer) | New Guinea, Samoa, Japan (Freitas Teixeira and Lent, 1936)<br>syn. *Crassisoma samoensis* |
| *G. sichuanensis* | Pig | Wu and Ma (1984), China |
| *G. simiae* | Small intestine of monkey (*Macaca fascicularis*) | Yamaguti (1954) |
| *G. urosubulatus* | Domestic pig and wild boar | cosmopolitan distribution |
| *G. versteri* | Red River Hog (*Potamochoerus porcus*) | Ortlepp (1964), South-Africa |

Contamination of pigs is oral by ingestion of water and food which contains $L_3$ larvae. These will migrate via the blood through the heart, lungs, where they will develop in 9-14 days. They undergo a molt, evolving into $L_4$ larvae, followed by swallowing and reaching the small intestine. In addition, some of the authors consider percutaneous contamination to be possible, but rare (Hiepe, 1985). The prepatent period is variable, between 12-56 days, depending on the route of contamination.

**Epidemiology**

***Geographical distribution.*** Infections with Globocephalus species are widely distributed, being diagnosed in almost all geoclimatic

regions on Earth. *G. urosubulatus*, the most common species of swine, is widespread in Europe, Africa, North and South America. The prevalence recorded in the world is variable: 5 - 75% in wild boar hunted in different areas from Corsica[187], 11.1% in Spain[182], 93.6% in Croatia[410], 40% in Romania (Gherman, personal observation), 21.35% in Bulgaria[373] and 74% in Iran[174].

***Sources of contamination*** are infected animals that pollute the environment disseminating eggs through feces. Pig contamination is achieved through consumption of $L_3$ larvae from the environment.

***Susceptibility***. The adult wild boar is the most receptive category. The domestic pig is rarely affected due to the breeding system in shelters. Adult age favors animal contamination due to their feeding behavior and various nutritional diets which predispose to consumption of infective $L_3$ larvae from the environment[186] (Gherman, unpublished data). Sex of animals does not influence their contamination, but Tamboura et al.[526] revealed a significantly higher prevalence in females (24%) than in males (19%).

***Route of contamination***: is oral via ingestion of $L_3$ infective larvae.

***The resistance*** of parasitic elements (eggs, larvae) in the environment is unknown, but is probably similar to that of species from the Ancylostomidae family in which the genus was included.

**Pathogenesis**. The pathogenesis is incompletely known because of the low pathological significance in the domestic pig. However, in massive infestations, especially in piglets, the spoliation due to hematophagous nutrition may become important, causing anemia. The attachment with the buccal capsule to the small intestine mucosa causes local irritation and creates inoculation sites for other pathogens.

**Clinical signs**. Generally, infestation evolves asymptomatically. The piglets may develop diarrhea, anemia and progressive weakening which may lead to emaciation.

**Pathology**. In acute forms, in piglets with clinical signs, parasites cause catarrhal or catarrhal-hemorrhage enteritis. In chronic forms, lesions will become hyperplastic.

**Diagnosis.** Subclinical, often inapparent evolution, with poorly expressed lesions, correlated with the small size of the parasites makes it difficult to diagnose the disease. Coprologic diagnosis using flotation methods reveals strongyle-type eggs with group value. The eggs are very similar to those of *Oesophagostomum* sp. and *Hyostrongylus* sp.

***Differential diagnosis*** should be performed in relation to other digestive diseases which affect piglets and youth in the traditional breeding system: ascariosis, oesophagostomosis, hyostrongylosis, eimeriosis and isosporosis, trichomonosis, bacterial or viral diseases, foodborne diseases.

**Treatment.** Basically, there is no special treatment described against *Globocephalus* spp. Modern benzimidazoles derivatives and avermectins are susceptible to be efficient.

Flubendazole, mebendazole, pyrantel tartrate and ivermectin have demonstrated good or acceptable efficacy in the therapy of polyspecific infestations in pigs and wild boars, in which *Globocephalus* spp. was also involved[603,75,182].

**Control**. The best method to control the evolution of globocephalosis is the semi-intensive or intensive pig husbandry system, avoiding the access to pasture. Artificial shelters with a floor made of concrete, woven wire mesh or other rough material do not allow the development of the exogenous phase of the biological cycle and thus prevent contamination of animals. Maintaining shelter hygiene with cleaning and washing of floor eliminates the parasitic elements and helps prevent contamination of pigs. Chemoprophylaxis is available, using benzimidazole derivatives in food.

## 3.6. Amidostomidae: Amidostomosis in aquatic birds

The members of this family are parasites of aquatic birds, localized in the gizzard and sometimes also into the proventriculus and esophagus of domestic and wild waterfowls (geese, ducks, swans, coots and charadriiformes). The family is divided into two subfamilies: the Amidostomatinae, which have a long, well-developed buccal cavity, and the Epomidiostomatinae, whose buccal cavity is significantly reduced.

The life cycle is direct, monoxenous, bird contamination being achieved through consumption of free-living third-stage infective larvae.

**Definition.** The amidostomosis is a geohelminthosis that affect birds included in the Anseriformes order, especially geese, expressed by digestive disorders and locomotory impairments. The disease is common across the globe and causes losses of livestock maintained on pasture.

**Etiology.** Three species included in the *Amidostomum* genus, with cosmopolitan distribution, are important:

- *A. anseris* (syn. *A. nodulosum*) is a parasite mainly of wild and domesticated geese and ducks, rarely of other birds.
- *A. acutum*, a common, cosmopolitan parasite of the gizzard, dominant in Anatinae (ducks). A systematic review was recently proposed, according to which the species must be regarded as a species complex. The three new separate species are *A. acutum*, *Amidostomoides monodon* and *Amidostomoides petrovi*[282].
- *A. fulicae* is a parasite of the common Eurasian coot (*Fulica atra*).

Other species widespread in Europe are *A. cygni* (swan), *A. henry* (considered as *species inquirendae* within the subgenus *Amidostomoides*)[399] and *A. spatulatum* (wild geese).

Of the *Epomidiostomum* genus, the *E. uncinatum* species (syn. *E. anatinum*) is important, which is cosmopolitan in the case of ducks and geese.

***Morphology*.** (figure 20)

*A. anseris* has a cylindrical, equally calibrated, slender and reddish body, the male measuring 10 - 17/0.25 - 0.35 mm and the female, 12 - 24/0.20 - 0.40 mm.. At the anterior end, the buccal capsule is short, wide, and armed with three conical pointed teeth at its base. At the posterior end, the male has a copulatory bursa with two large lateral lobes and two long, slender spicules, cleft near their middles. The vulva is placed in the posterior part of the body. The eggs are oval-shaped, thin shelled and measure 85 - 110/50 - 82 μm.

The length of *A. acutum* varies between 7.28 and 14 mm in the male and 8.8 to 19.1 mm in the female. The eggs are oval-shaped and measure 70 - 94/38 - 59 μm.

*A. fulicae* measures 8.40-8.60/0.16-0.20 mm (the male) and 5.34-9.30/0.15-0.23 mm (the female). At the anterior end, the buccal capsule is wider than it is deep. At the posterior end, the male has a copulatory bursa with two lateral lobes with their edges bent towards the ventral surface; the spicules are equally calibrated and measure 0.07-0.10 mm. In females, the vulvar opening is placed near the middle of the body. The egg is round to oval and measures 60-90/40-70 μm.

*Epomidiostomum uncinatum* has a filiform body; the male measures 6.5–7.3 mm long and 150 μm wide and the female is 10–11.5 mm long and 230–240 μm wide. At the anterior end it has a small pair of nodules and a buccal capsule surrounded by four papillae and a three-toothed fringe, formed by the posterior edge of cuticle, which bears two lateral epaulets. At the posterior end, the male has a trilobated copulatory bursa and two equal or nearly equal dark brown spicules. The distal end of each spicule is cleaved into three unequal branches. The female has a tail equipped with a conical appendage. The eggs are oval-shaped and measure about 80/50 μm.

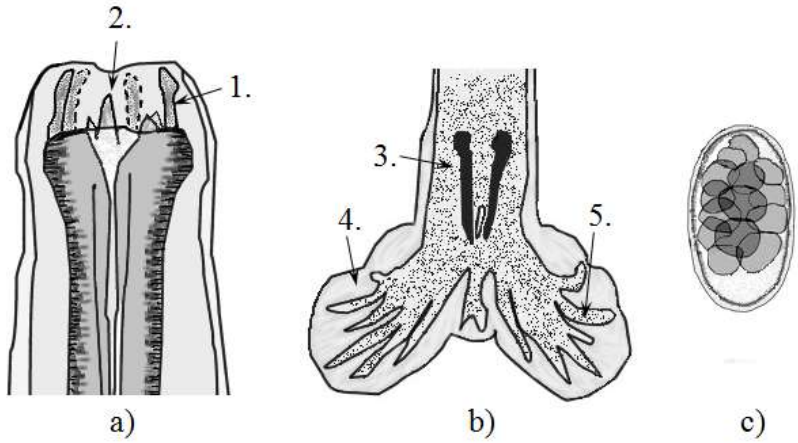


**Figure 20.** Morphology of *Amidostomum anseris*: a) anterior end; b) male, posterior end; c) egg; 1. buccal capsule; 2. teeth; 3. spicules; 4. caudal copulatory bursa (lateral lobes); 5. rays;

***Life cycle*.** The life cycle is direct, monoxenous. The adult parasites are localized in the gizzard where they penetrate beneath the stratum corneum. They may also be rarely foundin the mucosa and submucosa of the proventriculus and esophagus, in domestic and wild waterfowl. They are haematophagous parasites. The females lay eggs which are passed through feces in the environment in a partly developed stage. The first two larval stages, $L_1$ and $L_2$, develop inside the egg, through successive molts, keeping the molting cuticle. The $L_2$ larval stage hatch the eggs and become infective $L_3$. The eggs will fully develop to infective larval stage in 23 days at 20°C[163]. Contamination of birds is oral, by swallowing food or water, especially grass that contains $L_3$, giving the disease a summer grassland character.. Third-stage larvae may also infect through the skin of birds[166]. In oral contamination, the larvae penetrate the mucosa of affected digestive segments, molt twice and return to the lumen where they become adults. Larvae migrate hematogenously via the lungs in percutaneous infections and return to digestive tract as young adults and will transform into adults. The prepatent period is about 14–25 days.

**Epidemiology**

***Geographical distribution*.** It is a cosmopolitan disease that records high values of prevalence in waterfowl, for different species of *Amidostomum*, around the world: 94.2% in Romania in the case of *A. anseris*[375], 55% in AlDiwaniya and Diyala Provinces, Central Iraq[359], 92% for *A. acutum* and 56% for *E. uncinatum* in *Anas discors* in Kleberg and Kenedy counties, Texas[221], 9.4% for *A. acutum* and 12.5% for *Epomidiostomum crami* in *Anas platyrhynchos diazi*, in north central Mexico and southwestern United States[178], 51% for *A. acutum* and 9% for *A. anseris* of the green-winged teal, *Anas crecca* in southwest Texas[92].

***Sources of contamination*** consist of adult birds with subclinical evolution and diseased birds, both categories polluting the pastures. The second source is represented by the contaminated grassland on which the birds have acces.

***Susceptibility***. The following are susceptible: domestic and wild geese and ducks, swans, grebes (Podicipediformes order), pigeons, Rallidae and Recurvirostridae families. Within the species, the receptivity of goslings and ducklings is higher in the first months of life. The degree of susceptibility is accentuated by debilitating factors, stress, immuno-

suppressive states and intercurrent illness. The parasites are quite host-specific. Enigk and Dey-Hazra[167] failed to infect a variety of other wild and domestic hosts (chickens, turkeys).

***Route of contamination***. Contamination is performed orally by ingesting infective $L_3$ larvae by feed or water. Percutaneous infection is possible.

***Resistance*.** The eggs of *A. anseris* survive in freezing conditions, but infective $L_3$ larvae are destroyed. Both life stages are highly sensitive to desiccation being destroyed by the dryness. The presence of moisture is essential for their survival.

**Pathogenesis.** The larvae and adult parasites exert an irritating and inflammatory action on the gastric and esophageal mucosa and submucosa. The mucosa is necrotized, displays a dark discoloration, is loosened and often sloughing at the parasitic places. Adults are attached with the buccal capsule to the mucosa and cause microhaemorrhages, ulcers, tunneling of the stratum corneum and a diminishing of the motility of the gizzard. The spoliation is expressed by anemia, a decrease of 69.7% in hemoglobin, hematocrit 66.6%, serum iron and copper levels by 52.3% and 59.6% relative to the uninfected goslings[170].

**Clinical signs.** The clinical picture may be insidious, with symptoms common to other digestive helminthosis, without pronounced signs in adult birds, or may develop an acute form, with evident manifestations in goslings during summer.

Goslings suffer from weight and appetite loss, even anorexia, dysphagia, stagnating growth, anemia and sometimes diarrhea. They become dull, lethargic, weak, listless, and emaciated. They may also develop a staggering and difficult gait, ataxia, paresis and paralysis, prostration and agony. Mortality can reach 50%. In adult geese, the disease is subclinical, with weight loss and anemia.

**Pathology**. The parasites cause hemorrhagic and ulcerated ventriculitis with erosions and denudation of the gizzard mucosa. Large number of worms may be attached to the wall of the gizzard causing necrotic granulomas of the muscle. The gizzard wall may also contain many tunnels and galleries and the adult worms are embedded inside them. The following may appear: catharral and necrotic ingluvitis, duodenitis, ulcers and haemorrhages in the separation area between the gizzard and the glandular stomach.

**Diagnosis.** The clinical exam is worthless due to the evolutive similarity to many other diseases. Coprologic examination reveals strongyle-type eggs common to many species of nematode parasites in birds. The necropsy allows the identification of the adults in the gizzard, and the typical lesions have a value of certainty.

***Differential diagnosis*** is required in the case of: renal eimeriosis, histomonosis, spirochaetosis, drepanidotaeniosis, and different intoxications.

The **treatment** must be applied to the whole infected flock. The following can be used:

- mebendazole, at a dose of 10 mg/kg bw removed completely the *A. anseris* infection in naturally infected geese[169];
- flubendazole at a level of 30 ppm, for 7 consecutive days, caused a 100% worm elimination[557];
- cambendazole at a dose of 60 mg/kg bw is effective against adult and larval stages[162];
- ivermectin, 200 μg/kg bw was highly effective against *A. anseris* in geese[101];

Levamisole is contraindicated in the treatment of amidostomosis due to the intoxication phenomena induced in goslings and ducklings[604,231].

**Control**. Particularities of web-footed birds' growth, with access to the water surface, create the premises of contact between wild and domestic waterfowl. This complicates the application of a control program for amidostomosis. However, proper sanitation and good management of the farm can prevent future infections. To prevent cross contamination between wild and farmed

waterfowl on pastures, rotation of grasslands should be practiced. Chemoprophylaxis can also be practiced using different substances in food as mass treatments.

## 3.7. Dictyocaulidae: dictyocaulosis in animals

The Dictyocaulidae family is divided into two subfamilies: the Mertensinematinae, which comprises nematode parasites of amphibians and reptiles, and the Dictyocaulinae, localized in the respiratory system of wild and domestic Bovidae, Cervidae, Equidae and Suidae. The Dictyocaulinae subfamily contains two genera: *Bronchonema*, parasites of wild African ruminants, and *Dictyocaulus*, well-studied and important in ruminants and horses.

The Dictyocaulidae family is characterized by a lack of synlophe on the body, the absence of the buccal capsule, the absence of the caudal spine in females, a round copulatory bursa, and the absence of the cephalic vesicle. The Dictyocaulinae subfamily has as a characteristic the splitting of the dorsal rays at their base and the location of adult parasites in the respiratory tract of ungulates. The presence of a buccal ring and short and thick spicules, no longer than 1 mm, are typical for parasites included in the *Dictyocaulus* genus[11].

**Definition.** These nematodes cause dictyocaulosis, which is an endemic geohelminthosis, rarely epidemic, evolving chronically or acutely during the grazing season, expressed by respiratory signs in young animals. Calves, lambs, kids and foals are preponderently affected by an increased morbidity in late summer and autumn, rarely in winter. The youth during the first year of grazing is more seriously affected, in malnourished and poorly maintained conditions.

**Etiology.** Three species included in the *Dictyocaulus* genus, with a cosmopolitan distribution, are important from a medical veterinary point of view:

- *Dictyocaulus viviparus*, develops in the trachea and larger bronchi in domestic and wild bovines: cattle, buffalo, camels and deer.
- *Dictyocaulus filaria*, affects small ruminants in which it cause a chronic disease, sometimes with severe evolution in young sheep and goats. It is located in the large bronchi.
- *Dictyocaulus arnfieldi* affects equids (horses, donkeys, mules, hinnies, ponies, asses and zebras) and is localized in bronchi and bronchioles. It is a cosmopolitan species which causes clinical signs usually in horses, donkeys being asymptomatic carriers of infestations.

Other species with European distribution, especially in wild ruminants, are:

- *Dictyocaulus eckerti* found in the respiratory tracts of red deer (*Cervus elaphus*), reindeer (*Rangifer tarandus*), moose (*Alces alces*), fallow deer (*Dama dama*) and sika deer (*Cervus nippon*).
- *Dictyocaulus capreolus* in roe deer (*Capreolus capreolus*), chamois (*Rupicapra rupicapra*) and moose (*A. alces*).
- *Dictyocaulus noerneri*, a parasite of reindeer (*R. tarandus*), roe deer (*C. capreolus*) and red deer (*C. elaphus*).

***Morphology.*** (figure 21)

*D. viviparus* has a cylindrical body, thin, equally calibrated, threadlike, and whitish. The male measures 3.5 to 5.5 cm in length/ 0,3 - 0,5 mm in width, and the female is 6-8 cm long and 0.5 - 0.7 mm wide. At the anterior end it has a rudimentary buccal cavity with a terminal mouth opening. At the posterior end, the male has a caudal copulatory bursa, relatively underdeveloped, hoof-shaped. The dorsal ray has a characteristic aspect; it is forked at the base and each arm is also tri-branched at its terminal end. The spicules are relatively thick, short, brownish and the gubernaculum has a sponge structure. The tail of the female is simple, conical and the vulvar opening is placed in the middle of the body. The eggs of

*D. viviparus* are rarely seen in feces; they are larvated and measure 82-88/33-38 µm. The first larval stage ($L_1$) measure 390 - 450 µm in length and have a stout body with a tapered tail. The anterior and posterior thirds of the body are transparent and the median is granular, opaque. The larvae did not feed in the environment and contain nutrient granules which induce this aspect.

*D. filaria* has a threadlike, whitish body, the size of males ranging between 5 and 8 cm in length and 0.4 mm in width and that of females, between 6 to 10 cm in length and 0.5 mm in width. The caudal bursa is hoof-shaped and has two short spicules, brownish, equally and slightly recurved at the terminal end. The typical tri-branched aspect of the dorsal ray described in *D. viviparus* is also present in this species. The eggs are oval-shaped, measuring 116-138/68-90 µm. The $L_1$ larval stage is cylindrical, with a stout body and measure 500-580/25 µm. It presents a tapered short tail and a cephalic button. The body is opaque, gray-blackish and contains nutritional reserves which induce a granular aspect. Both extremities are transparent.

*D. arnfieldi* has a cylindrical, slender, slightly twisted, equally calibrated and pearly-colored body, the sizes reaching up to 36 mm for males and 60 mm for females. The anterior end is rounded and has a small buccal capsule. The caudal bursa is poorly developed; the upper ray is thick, forked and divided in two parts at terminal end of each arm. The spicules are thick, brownish and short. Eggs are larvated, oval and measure 80-100/50-60 µm. The first larval stage measures 400-500/10-20 µm. At both ends, the outer layer of the cuticle presents a slight detachment giving the aspect of small cephalic and caudal vesicles.

***Life cycle.*** Nematodes of the *Dictyocaulus* genus are geohelminthes with a direct life cycle in which the external phase from the environment and the internal parasitic phase succeede each other (figure 22). The adults live in the airways, in their specific habitats, and feed on mucus and exudate from the tracheal content. The females of all three important species are ovoviviparous and lay larvated eggs. These eggs may hatch while passing through the bronchial-tracheal tract, but are usually swallowed and will hatch when they pass through the digestive tract, as happens in *D. viviparus* and *D. filaria.*

In *D. arnfieldi* the eggs do not hatch while in the respiratory or digestive passage; they will be eliminated through feces as larvated eggs and will hatch in the environment. In the external environment the larvae do not feed and develop on the basis of contained nutritional reserves. Under proper conditions $L_1$ larvae enter into an inactive period when they molt in a few hours to the second larval stage, $L_2$. The second stage will molt again resulting in the third stage, which is an infective element. The third larval stages keep the molting cuticle of the anterior stages. The nutritious granules are present in the body of the first and second larval stages but disappear in the third stage. The sporangia of *Pilobolus* spp have an important role in the dispersal of *D. viviparus* and *D. arnfieldi* $L_3$ larvae in pasture[275,276]. It is demonstrated that between 10 and 25% of the *D. arnfieldi* and 3 to 23% of the *D. viviparus* $L_3$ larvae are dispersed on the pastures by *Pilobolus kleinii* and *P. crystallinus*[495,275]. The dispersal mechanism consists in the climbing of the infective 3rd-stage larvae of *Dictyocaulus* spp. on sporangiophores of the fungus. The larvae will invade the sporangia and will be dispersed in the environment when the sporangia are explosively discharged. The dispersion of *D. viviparus* is also favored by earthworms, in which the larvae survive for a period of time[383].

Animal contamination is achieved by ingestion of third larval stages with infested food and water.

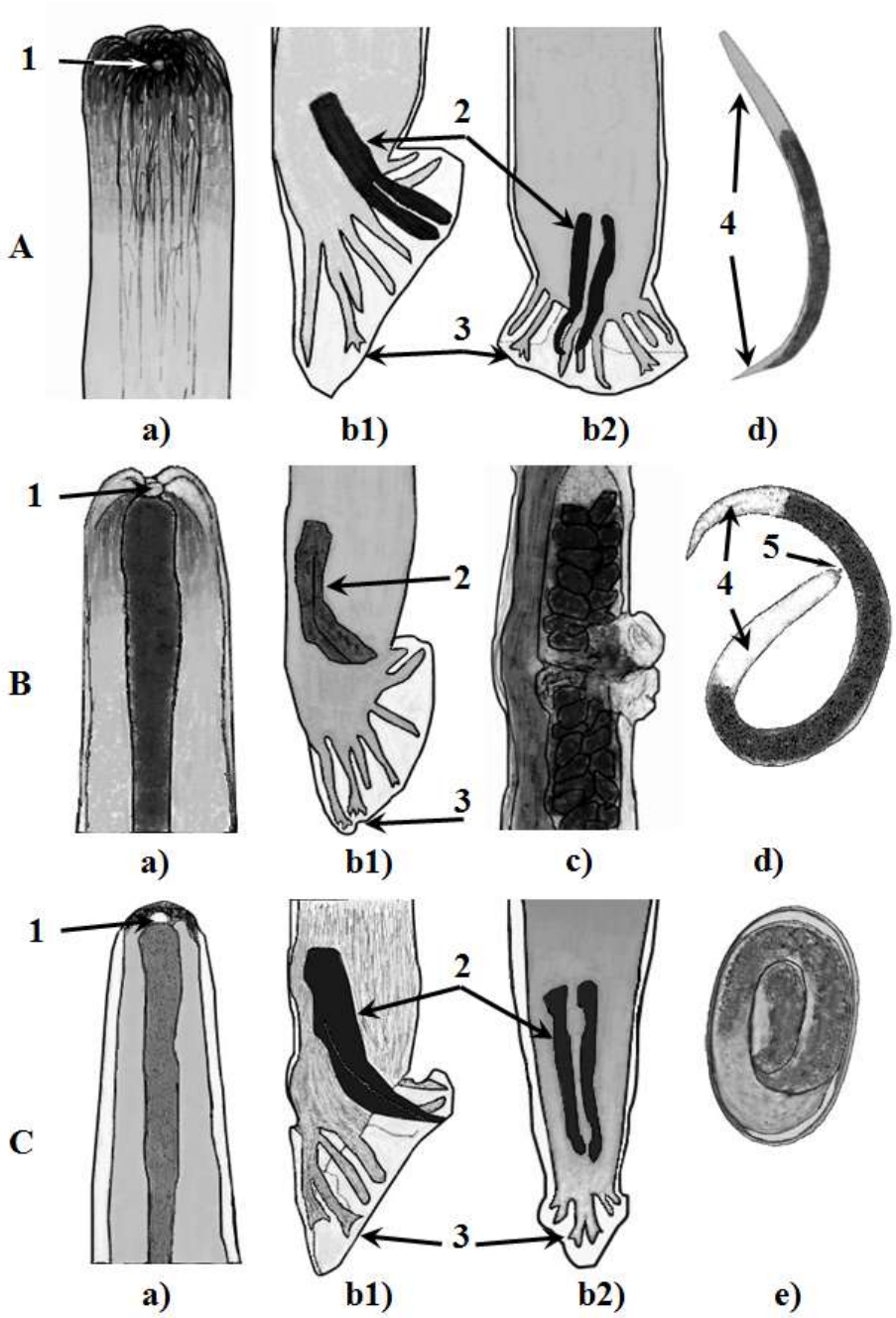


**Figure 21.** A. *Dictyocaulus viviparus*; B. *Dictyocaulus filaria*; C. *Dictyocaulus arnfieldi*; a) anterior end; b1) male, posterior end - lateral view; b2) male, posterior end - dorsal view; c) female - vulvar opening; d) first larval stage ($L_1$); e) egg - *D. arnfieldi*; 1 - mouth opening; 2 - spicules; 3 - dorsal ray; 4 - transparent extremities of $L_1$; 5 - protuding protoplasmic knob

After contamination, the $L_3$ larvae penetrate the wall of the small intestine and enter into the lymphatic capillaries. They travel to the mesenteric lymph nodes where they molt in $L_4$ larval stage. A new molt follows, resulting in $L_5$, which will continue to travel to the lung through the thoracic duct, anterior vena cava, heart and pulmonary arteries. Inside the lung, $L_5$ larvae leave the circulatory system and come out in the aerophore tract where they move to the characteristic biotope and mature into adults.

The prepatent period varies between 28 and 57 days in the case of *D. filaria*, depending on the species affected (sheep or goat) and 21 to 30 days in the case of *D. viviparus*[409,217]. The patent period varies between 27 and 72 days in both species but may extend to up to 150 days when arrested larvae are present in the lungs[442,530].

**Epidemiology**

***Geographical distribution*.** Dictyocauloses of herbivorous animals are cosmopolitan diseases with endemic or epidemic evolution and a seasonal character during the warm and rainy seasons. *D. viviparus* is common in cattle in northwest Europe; *D. filaria* is less pathogenic, but causes diseases in Mediterranean countries, Australia, Europe, and North America; *D. arnfieldi* is spread worldwide and causes severe symptoms in horses but not in donkeys. Their prevalence registers different values from one species to another, in the world.

In sheep from northeastern Iran the overall prevalence of *D. filaria* infection was 3.7% and 0.5% in goats, being highest in winter (7.8%) and reduced during the dry summer (0.8%)[67]. In northeastern Ethiopia, *D. filaria* infection was diagnosed in 3.1% of sheep and was not identified in goats between November 2008 and March 2009[418]. In the Kirikkale region of Turkey, 23.5% of sheep were infected with *D. filaria* between October 2002 and September 2003[600]. In Germany, between 1998 and 2002 *D. filaria* was detected in 0.2% of sheep feces samples and was not identified in goats, while *D. viviparus* in 0.7% of cattle samples[171]. In Argentina's western Pampas, *D. filaria* infection was observed in 4.2% of the Corriedale sheep flock[517]. The seasonal character of *D. filaria* infection in sheep was demonstrated in north-east England, where the prevalence in lambs was low in spring and summer and increased in late autumn or winter[198]. In cattle from peninsular Malaysia, about 5% of fecal samples and 1% of the examined lungs were positive *D. viviparus*[312].

In culled cows from Ireland, the prevalence of *D. viviparus* was 14% during the autumn of 2002 and the summer of 2003, based on larval identification in fecal samples[372]. In an organic dairy herd from Sweden, the seroprevalence of *D. viviparus* infection during 2001 was 2.3% and 5.6% in May and September, respectively[253]. In adult dairy cows in Belgium, the seroprevalence of *D. viviparus* was 7% from November 1997 to October 1998[3]. In the Netherlands, the prevalence of *D. viviparus* determined by feces examination in 125 dairy cows was .6% during the period November 1997-October 1998[65].

Infection with *D. arnfieldi* in horses was diagnosed in the Sudano-Guinean climatic zone of Cameroon, registering a5.22% prevalence[316]. In working donkeys of Ethiopia, the prevalence was 14.2%[211]. In other African countries, the infection recorded high values of prevalence in donkeys: 70.5% in Khartoum State, Sudan[465], 48% in Morocco[388] and 83% in Ethiopia[185]. In Upper Bavaria *D. arnfieldi* infection was diagnosed in 16.2% of the donkeys[38]. The prevalence of *D. arnfieldi* reached 0.04% in horses and 17.4% in donkeys in Germany, between 1984 and 1991[172]. In Denmark, 87.5% of the donkeys, 10.4% of the horses from donkey herds and 8.8% of the hospitalized horses excreted *D. arnfieldi* larvae between January to May 1981[9].

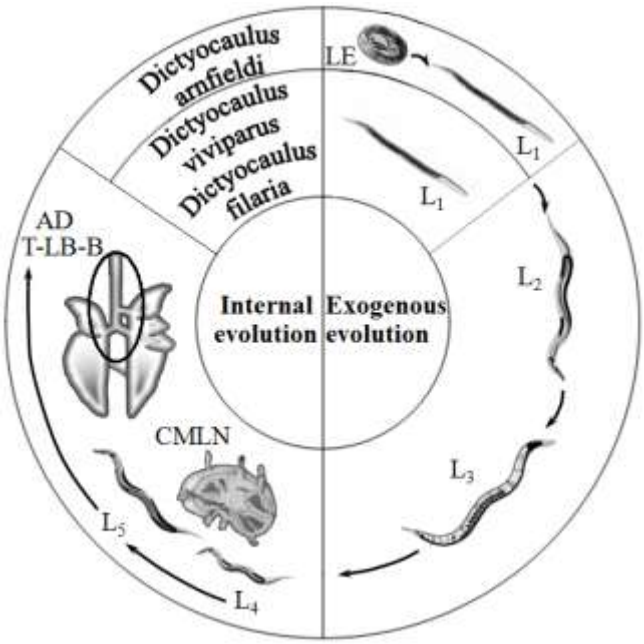


**Figure 22.** LE - larvated eggs; $L_1 \ldots L_5$ - the larval stages; CMLN - colic mesenteric lymph nodes; AD - adults; T-LB-B - trachea, large bronchi, bronchioles;

***Sources of contamination*.** Several major sources of pastures pollution can be distinguished: diseased young domestic animals, infected adults with asymptomatic or unapparent chronic forms, wildlife and manure used as natural fertilizer.

Concerning *D. viviparus*, the light pasture contamination realized by adult dairy cows, which are the predominant carrier animals, and subsequent auto-infections are the most important sources of pasture pollution and disease in animals. The heavy contamination of pastures caused by calves and yearlings followed, as importance and overwintering capacity of larvae seem to play a minor role[446]. Regarding the carriers of *D. filaria*, the ewes carry a moderate number of parasites during the stabling period[18]. The role of the carrier for *D. arnfieldi* in equines is assigned to donkeys which acquire asymptomatic infections.

For the actual contamination of animals, the disseminated infective $L_3$ larvae on the pastures are the main source of infection. Contamination in the stable is not very important, but may sometimesoccur.

***Susceptibility***. The sensitivity is high in small ruminants, especially sheep, followed by cattle, horses and donkeys. Within the species, the youth is the most sensitive, acquiring severe forms of the disease. In ovines, the lambs and young animals up to 1 year of age are very vulnerable and adult sheep are more resistant, but pure breeds (Merinos, Karakul) are more severely affected. Goats are more resistant to infection because of the feeding behavior. They mainly feed on buds, leaves, and underbrush, where infective larvae are not found. In cattle, the calves aged 6 to 24 months are the most sensitive to infestation and the morbidity is lower under this age and over 2 years. In horses, foals and donkeys are most receptive. The receptiveness of animals is accentuated by several factors, of which the important ones are poor nutrition, immunodeficiency states, evolution of other intercurrent diseases and overcrowding. In horses, the age of animals and body condition

are the most important risk factors. The highest prevalence was recorded in old (22.95%) and young (18%) animals, probably related to decreased immunity. The infection rates of 50 %, 16.3% and 5.2% were found in poor, medium and good body condition scores[492].

The ***route of contamination*** is oral by ingesting $L_3$ larvae along with infested feed or water.

***Resistance.*** Generally, the larvae of *Dictyocaulus* spp. are more resistant to low rather than high temperatures and are not significantly resistant to desiccation, but tolerate freezing temperatures. *Dictyocaulus* larvae survive on the pastures over the winter, until April when temperature and moisture fluctuations increase the sensitivity causing their death[296]. *D. filaria* survived for 23 weeks during winter and spring (January to June) and only 7 weeks in summer conditions in the UK, from June to August[435]. The larvae of *D. viviparus* resisted for 4 weeks on pasture in May and persisted for 13 weeks in the cold season, from October to January in a temperate oceanic climate[352]. Influence of environmental factors on *D. filaria* larval development is felt also in the time needed for the exogenous phases of the life cycle from one season to another. The development of the first-stage larva to the third stage required 4-9 days in late spring and summer, one week and half to 4 weeks in autumn, and five weeks and half to 7 weeks during winter[197]. Despite the long period needed during winter, the larvae overwinter and easily withstand low temperatures.

**Pathogenesis.** The severity of pathogenic actions exercised by the parasites depends on their evolutionary stage, the intensity of parasitism induced in turn by the infective dose, the affected segment of the respiratory tract and the immune status of animals, conditioned in turn by the general condition, intercurrent diseases, age and diet.

The larvae exert, during migration, a traumatic action that consists, at the beginning of the process, of micro-lesions of the intestinal wall and lymph node parenchyma. The larvae will cause traumatic tracks in the parenchyma after reaching the lung tissue, lesions of the alveoli walls and micro-hemorrhages. Affected tissues will respond with inflammation which consists in broncho-pneumonia and eosinophilic infiltrates. The infiltrate blocks the lumen of the bronchioles, resulting in the obstruction of the airways and the collapse of alveoli distal to the block. The larvae may bring bacteria from the gut at the beginning of the migration process, exerting such an inoculation action.

Adults localized in the lumen of the trachea and bronchi exert, basically, the same traumatic-obstructive and inflammatory actions as the larvae, but more intense. They form movable balls in the lumen, that move actively, synchronized with respiratory movements. These movements irritate the tracheobronchial mucosa causing inflammation associated with frothy mucus and cough. The adult balls act mechanically, being able to obstruct the bronchial lumen. Consequently, atelectasis, interstitial vicarious emphysema and pulmonary edema may develop. The movements of parasite balls and the micro-lesions caused create infection sites for aerial secondary bacterial infections. Metabolic products and antigenic aggregates resulted from the death of adults act toxically on vascular permeability and cytotoxically, emphasizing bronchopneumonia, pulmonary edema, or triggering allergic pneumopathies. The exchange of oxygen and carbon dioxide is low and bronchiectasis limits or even cancels the functional capacity of the affected lobes. Adults located in the tracheo-bronchial lumen feed on mucus and exudates exerting a spoliation action that is expressed by a persisting normochromic normocytic anemia[51].

During the patent period, the eggs and $L_1$ larvae laid and aspirated into the alveoli cause a foreign body reaction consisting in eosinophilic, granulomatous and non-suppurative pneumonia. Eosinophils, macrophages and giant cells are accumulated and necrosis processes with purulent mass appear. The caudal lobes are usually affected.

The pathogenic effects were described especially for *D. viviparus* infection and are, generally, the same in all *Dictyocaulus* species, with reduced particularities. In *D. filaria* infections, interstitial emphysema is not common, and in *D. arnfieldi*, bronchial lesions predominate. Allergic syndromes with asthmatiform manifestations appear in reinfections with either of the *Dictyocaulus* species.

**Immunity.** An acquired non-sterile (premunition) active immunity appears post-infection in dictyocaulosis. It acts against the larvae before they reach the lungs or against the juvenile and adults in the lungs. The difference between these two expressions of immunity is the absence or presence of an "immune memory" toward the migratory larvae, or juveniles and adult worms, respectively. Anyway, in the post-patent stage, immune protection against the adult parasites gradually disappears and, in the absence of reinfection, after 6-12 months, the cattle will be completely susceptible to a new infection. The acquired immunity against the maturation of juvenile larvae in the lungs does not seem to decrease in intensity[402].

In cattle, a sterile or non-sterile immunity is provided by immunization using irradiated or live-attenuated larval vaccines[73]. In Western Europe, an attenuated larval vaccine for the prevention of dictyocaulosis was used for over 30 years. This vaccine has several disadvantages: a short shelf life, the need for annual production, requirement to stimulate immunity through natural infection to maintain the protective level of immunity, the decrease in sales of irradiated biological products, the risk of preventive anthelmintic programs not providing sufficient exposure to natural sources of *Dictyocaulus* spp. to stimulate protective immunity. In this context, recent studies have accentuated the necessity of obtaining a vaccine capable to stimulate a prolonged immunity. The modern strategy focuses on enzymatic components which assist the worms in their invasion, feeding, replication or evasion, as target of the immune response of the host. Acetylcholinesterases, superoxide dismutases and proteinases (serine-, cysteine- and metalloproteinases) are the most important enzymatic complexes targeted in obtaining vaccines with prolonged protection[346].

The immune defense processes are cellular and humoral mediated. In the first case, migratory larvae are destroyed in the main barriers: the intestinal mucosa, the mesenteric lymph nodes and lymph vessels or lung alveoli, by the intervention of giant cells and eosinophilic granulomas. The humoral mechanism is based on the induction of precipitating, complement-fixing and/or larval growth inhibitory antibodies that appear at 2-3 weeks pi and persist for several months.

Immune processes in small ruminants and equines are similar to those of cattle dictyocaulosis.

**Clinical signs.** The disease evolves acutely or chronically in cattle as two distinct entities: the primary infection and reinfection syndrome. The primary infection evolves usually in calves; the acute form is recorded in high infective doses while the chronic form may be a consequence of the acute form, it may evolve from the beginning, due to the low infectious doses or it may affect the youth, a less sensitive age group.

In the course of the heavy ***primary infection***, with an *acute evolution*, Ploeger[402] distinguishes four phases:

1. Penetration phase (day 1-7 pi) when the larvae penetrate the body and migrate to the lungs;

2. Prepatent phase (day 7-25 pi) consisting in the development of the larvae in the lungs;
3. Patent phase (day 25-55 pi) characterized by production of eggs by mature worms;
4. Postpatent phase (day 55-90 pi) when occasional flare-up of severe respiratory signs may occur at the end of the disease.

The first transient signs that appear in the acute form and massive infection, during the penetration phase, are diarrhea with brown watery feces, diminished appetite and moderate polydipsia. After completion of larval migration, during the prepatent and patent phases, appear the first respiratory signs as a consequence of the blockage of the small bronchi and bronchioles by eosinophilic exudates. These are: a deep and harsh cough, tachypnea, dyspnea, orthopneic position of the head and neck, abdominal breathing, salivation and anorexia. On lung auscultation, bronchial fremitus (or rhonchal fremitus), sibilant and subcrepitant rales, bronchial breathing (harsh breath sounds), and hypersonority can be heard under auscultatory percussion. The symptoms are caused by the adults located in the trachea and bronchi and aspirated eggs and larvae. Microbial superinfection may complicate the symptoms, and fever and purulent nasal discharge occur. Acute forms could be endedeither by death within 10 - 15 days, by long-term convalescence or they can pass into the chronic form.

In the *chronic form*, after 14-21 days of incubation, in the early stage, capricious appetite occurs, followed by anorexia, weight loss, difficult movements, preferred decubitus, enophtalmia, painful shallow breathing, dehydration and horripilation. An intermittent cough, more pronounced on exercise, dry, becoming productive (when sputum is coughed up) and frequent after a few days is recorded. Respiratory rate and lung auscultation are often normal, sometimes squeaks can be heard. The disease has a sluggish evolution, for several weeks, the end being lethal due to the state of cachexia.

The ***reinfection syndrome*** is caused by massive reinfection doses that contaminate previously immunized cattle by prior infections or vaccines. These larvae may reach the lung before being destroyed by the immune defense of the organism. It seems to be the most common form of dictyocaulosis evolution in adult cattle. It is expressed by coughing, continous, frothy and abundant nasal discharge, frightened facies, tachypnea, anorexia, decreased weight gain, dyspnea, suffocation attacks, pyrexia following bacterial infections and an orthopneic position with a stretched neck and tongue sticking out signifying "air-hunger". Harsh sounds, rhonchi and various degrees of emphysematous crackling are present on lung auscultation. Evolution may be deadly within hours.

The disease usually evolves chronically in sheep and goats, with outbreaks in June-July in youths and in autumn in adults. It is expressed by dry cough that becomes productive, with attacks during the morning when flocks are moved. Dyspnea, bilaterally and abundant nasal discharge, crackles, decreased appetite, weight loss, anemia, loss of wool, hyperthermia consecutive to bacterial overinfections, and an impaired general condition are the typical symptoms. This form evolves for weeks or months, with a fatal outcome due to the cachexia.

The acute evolution occurs in massive infestations of the lambs. The onset of the disease is associated with feverishness, anorexia, severe dyspnea and death after 10-15 days of evolution.

The reinfection syndrome is much rarer than in cattle.

In equines, the clinical signs are similar to those of calves. Chronic cough in donkeys and dyspnoea and moist cough in horses always accompany the disease.

**Pathology**. The lesional pattern in *cattle* may be acute or chronic. Heavy infections produced by migratory larvae in youth evolve acutely and are characterized, during penetration and prepatent phases, by hypertrophic lymphadenitis with infiltrated lymph nodes and micro-hemorrhages in the tissue sections. In the lung parenchyma, these larvae cause pneumonia or bronchopneumonia in the diaphragmatic lobes and perifocal lobular emphysema or subpleural lymphoid nodules. The lumen of the bronchioles is blocked with exudate or mucus and alveoli collapse. In the patent phase, the adults cause the damage of the tracheal and bronchial epithelium, resulting in exudative tracheitis and bronchitis and the blockage of air passages. The eggs and $L_1$ larvae aspirated into the bronchioles and alveoli determine the consolidation of lobules (the loss of air space and its replacement with fluid). In the post-patent phase, the number of parasites in the trachea and bronchi decreases, but the chronic lesions may become more severe, developing pulmonary edema, interstitial emphysema and alveolar epithelial hyperplasia.

Histopathology consists in the loss of ciliated epithelial cells in the bronchi, or just of vibratile cilia and bronchial epithelial metaplasia. The walls of the alveoli are thickened, hyaline membrane, abundant infiltration with eosinophils, macrophages and giant cells are present and hyperplasia of alveolar type II cells[461].

In *small ruminants*, general lesions consist of anemic mucous membranes and full-body wasting. Local lesions are: catarrhal enteritis with disseminated micro-hemorrhages and/or gray miliary nodules and mesenteric lymphadenopathy with scattered nodules in the cortex and medulla. The acute form is characterized by pulmonary hemorrhages, catarrhal-exudative tracheitis, abundant mucus that contains streaks of blood and numerous adult parasites as mobile balls or clews. These block the lumen of the trachea and major bronchi causing atelectasis, pneumonia foci, more frequently in diaphragmatic lobes, abscessed areas and compensatory pulmonary emphysema[69]. Histopathological aspects are similar to those of cattle dictyocaulosis.

In *equines*, the lesions are similar to those of cattle. The infected bronchi exhibited a marked eosinophilic bronchitis with hyperplasia of the goblet cell and an abundant lymphoid inflammatory infiltrate. These areas also showed a localised bronchiolitis and overinflated alveolar tissue that surrounds affected bronchi, lacking a true emphysema[326,379].

**Diagnosis.** Epidemiological aspects such as the occurrence of diseases in youth, during the summer and autumn, in animals kept on pastures or in shelters, but fed on contaminated green mass have a guidance value. The clinical picture dominated by respiratory symptoms is worthless, being common to many diseases. The parasitological exam emphasizes, intra vitam, the first larval stages ($L_1$) in feces using the Baermann technique. It has no diagnostic value in the penetration and prepatent phases when larvae are not eliminated through feces. To emphasize *D. filaria* larvae, the Vajda method may be practiced due to the particular round shape of feces in small ruminants. The observation of *D. arnfieldi* eggs in horse feces requires a flotation method, such as Willis. Necropsy has a value of certainty, allowing the observation of lesions and adult parasites in tracheal and bronchial lumen. Immunodiagnosis is based on the use of the following tests: indirect hem-agglutination, indirect immune-fluorescence, complement fixation and ELISA and others, but they are not practiced routinely.

***Differential diagnosis*** will be performed in cattle and horses, for other pulmonary diseases, ascarids larval migration through the lung and pulmonary evolution of strongyloidosis or other nematodosis with respiratory signs. In small ruminants, from

protostrongylosis and muelleriosis, pulmonary hydatidosis and viral or bacterial bronchopneumonia are favored by the cold.

**Treatment.** The therapy is based on the use of anthelmintics associated with symptomatic treatment, improvement of quality and quantity of food and stopping the contamination of animals. The entire population that finds itself under the same risk conditions must be treated. Specific treatment with good or very good efficacy is based on benzimidazole or thiazole derivatives and avermectins. Active substances used in dictyocaulosis therapy of large or small ruminants and equines are shown in table 10.

Symptomatic treatment is based on the application of sulphonamides and antibiotics, expectorant, anti-allergic (corticosteroids), cardiotonic drugs, and vitamin therapy (A, C). The diet during convalescence will be dietetics, rich in vitamin and minerals.

**Control**. The complex of control measures aims several specific objectives:

- general hygiene measures of the shelter and food to prevent ingestion of infective larvae;
- control of parasitic elements in the environment by biological or chemical methods;
- specific prevention: chemoprophylaxis or the use of natural dewormers and immunoprophylaxis;
- technological measures targeting the grazing system and pastures: application of a pasture rotation system, use of cultivated pastures, setting aside isolated pastures for young animals, avoiding pasture pollution by biothermal sterilization of manure, destruction of temporary biotopes on the pasture, favorable to larval evolution;

General hygiene measures applicable in shelters and food (daily removal of feces, washing the floor, clean and dry litter, clean and dry fodder storage) are meant to improve the feeding and maintenance of animals. Consequently, the nonspecific immune resistance of animals will increase.

The inactivation of larvae from the environment can be accomplished by chemical or biological methods. Chemical control involves the application of substances that have a larvicidal effect on the pasture. Calcium cyanamide is one of these substances which prevent contamination of grazing animals by destroying the eggs and larvae of numerous pasture nematodes, including *Dictyocaulus* spp. The dose rate is around 300 kg/ha and the first fertilizer application is at the beginning of the spring, when the vegetation starts. Another condition that must be respected refers to humidity. The soil should be wet, but the turf dry. The grazing can restart when calcium cyanamide has dispersed, the grass becoming green again about 2-3 weeks after fertilization. The second application can be performed any time, but under the same conditions of humidity. Copper sulphate, 23 kg/ha, mixed with 90 kg/ha of sand is also effective against the *Dictyocaulus* lungworm on the pastures[328].

Biological inactivation involves the use of natural pests that consume or destroy *Dictyocaulus* spp. larvae from the environment. Nematode-trapping fungus *Duddingtonia flagrans* caused the reduction of larval release from feces by 86%[237]. The dose-level required for a significant reduction of infective *D. viviparus* larvae in cultures ranged between 6250 and 12500 chlamydospores/g of feces[181]. *Aphodius* spp. beetles (Scarabaeidae) determined a significant decrease (to a level of 5 %) in the median number of *D. viviparus* larvae after 90 hours, at a density of one beetle per gram of feces[219]. One or two beetles/g feces reduced the number of 1st larval stage and adult of *D. hadweni* from elk by 77-92% within 4-36 h[49].

Chemoprophylaxis involves the use of the same substance stated under treatment, but as drug formulations that provide a prolonged protection of animals.

**Table 10.** Active substances used in the therapy of dyctiocaulosis

| active substance | species | dose (mg/kg bw) | efficacy (%) | stage | author |
|---|---|---|---|---|---|
| levamisole | cattle | 8.0 | 84-100 | adult | Curr, 1977 |
| | | 5.0 sc; 10.0 po | 98 / 99 | adult | Vanparijs and Quick, 1991 |
| febantel | cattle | 5.0 | 90.6-97.1 | adult, $L_4$ | Williams et al., 1988 |
| thiabendazole | cattle | 110 | 100 | adult | Williams and Broussard, 1995 |
| | sheep | 100 | 100 | $L_4$ | Gibbs and Pullin, 1963 |
| | horse | 440, 2 days | 100 | adult | George et al., 1981 |
| albendazole | cattle | 7.68 - 8.18 | > 99 | adult | Wescott et al., 1979 |
| | | 7.5 | 96.4 | adult | Benz and Ernst, 1978 |
| | sheep | 2.5 / 3.8 | 99.0 / 89.3 | adult / $L_5$ | van Schalkwyk et al., 1979 |
| | | 10.0 | 100 | adult | Theodorides et al., 1976 |
| | ponies, horse | 25 twice/day, 5 days | 100 | adult | Reitsma, 1983 |
| fenbendazole | cattle | 5.0 | 99.7-100 | adult | Saad and Rubin, 1977 |
| | | 5.0 | > 99 | adult | Crowley et al., 1977 |
| | sheep | 5.0 | 100; > 80 | adult, $L_4$, $L_3$ | Ross, 1975; Malan and Roper, 1983; |
| oxfendazole | cattle | 4.5 | 89.1-100 | adult, $L_5$, $L_4$, $L_3$ | Berger and Tema, 1982 |
| | | 4.5 - 6.75 | > 94.6 | adult | Miller et al., 1988 |
| | sheep | 5.0 | 99.8; 92.0; 37.5 | adult and $L_5$, $L_4$, $L_3$ | Berger, 1980 |
| mebendazole | sheep | 15.0 | 97.3 - 99.9 | adult, $L_5$, $L_4$ | Westhuizen van der et al., 1984 |
| | donkey | 15.2 - 20.0/day, 5 days | 75 - 100 | adult | Clayton and Neave, 1979 |
| luxabendazole | sheep | 7.5 - 12.5 | 100 | adult | Kassai et al., 1988 |
| abamectin | cattle | 0.20 | > 99 | adult, $L_4$ | Heinze-Mutz et al., 1993 |
| ivermectin | cattle | 0.05, 0.10, 0.20 | 88.2, 98.0, 99.8 | $L_4$ | Benz and Ernst, 1981 |
| | | 0.20 | 100.0 | adult, $L_4$ | Benz et al., 1984 |
| | sheep | 0.20 | 99.4; > 96 | adult | Yazwinski et al., 1983; Wescott and LeaMaster, 1982 |
| | ponies | 0.20 | 100 | adult, $L_5$, $L_4$ | Britt and Preston, 1985 |
| moxidectin | cattle | 0.20 | 100.0 | adult, $L_5$ | Williams et al., 1992 |
| | | 0.5 pour-on | 100.0 | adult, $L_5$, $L_4$ | Eysker and Boersema, 1992 |
| | sheep | 0.20 | 100.0 | adult | Hidalgo-Argüello et al., 2002 |
| doramectin | cattle | 0.20 | 99.6-100 | adult | Weatherley et al., 1993; Eddi et al., 1993; Jones et al., 1993 |
| eprinomectin | cattle | 0.50 | 100 | adult | Yazwinski et al., 1997a |
| | | 0.20 - 0.50 | 98-99 | adult | Shoop et al., 1996 |
| | sheep | 0.50 | 100 | adult | Kircali Sevimli et al., 2011 |
| | donkey | 0.50 po | 100 | adult | Veneziano et al., 2011 |

Certain methods of substance administration are differentiated: periodic deworming, inclusion of active substances in extended-release excipients and their inoculation in various ways (injectable or oral) and the use of slow-release boluses. Classical periodic deworming consisted of two treatments per year; the first during spring at 14 days before grazing and the second in autumn, at 14 days after entry into stabulation. A much better protection is ensured by a deworming program that stipulates 4 anthelmintic treatments per year, quarterly.

A prolonged efficacy is demonstrated for many active substances, especially avermectins, in the case of extended-release formulations. Eprinomectin, in an extended-release injection (ERI) formulation, demonstrated a ≥98% efficacy against fourth-stage larvae and adults of *D. viviparus*[420]. The protection period was up to 150 days in experimental infection[491] or 120 days in grazing cattle[305,421]. Pour-on formulation elicits a moderate protection. Doramectin provided ≥ 91.9% efficacy against a challenge with *D. viviparus* for only 35 days post-treatment[360]; administered pour-on on days 0 and 56 pi has protected for a period of 112 days[561]. The controlled-release capsule is another way to administer the active substances; ivermectin administered in this form at a rate of 1.6 mg per day for 100 days was highly effective (≥ 99%) against *D. filaria*[422]. Moxidectin, topically administered, at a dose rate of 0.5 mg/kg bw, showed an excellent activity (> 99%) against *D. viviparus* for up to 5 weeks[254]. Abamectin at 0.2 mg/kg prevented against *D. viviparus* for at least 70 days when administered at the turnout and again six weeks later[265].

Use of the slow or pulse-release boluses is highly prevalent in dictyocaulosis control. There is an accentuated variety of commercial or experimental products that have proven their variable efficacy. Although these boluses are advantageous because they provide a long lasting, higher-level protection, they have a major disadvantage, namely, it does not allow the development of post-infection immunity, these animals being susceptible to infection just as if previously untreated. However, it is estimated that pasture larval infections are enough to allow the development of immunity[176]. Good results were obtained with Ivomec SR Bolus (ivermectin), which proved to be highly effective against *D. viviparus*[425]. An ivermectin bolus offered protection for 154 grazing days providing a season-long protection against *D. viviparus*[460]. In contrast, the Protect Flex bolus (morantel tartrate) provides insufficient protection against this infection[243]. The oxfendazole pulse release bolus (OPRB) provided good results in the prophylaxis of dictyocaulosis, the late administration having the additional advantage of covering the period of higher infection risk[242].

Comparing the results obtained by using 4 boluses, a morantel sustained-release bolus, a levamisole sustained-release bolus, an oxfendazole interval bolus, and an Albendazole interval bolus, all boluses prevented severe clinical signs. Even if all allow a buildup of solid immunity, none of them completely prevented excretion of larvae[66].

Immunoprophylaxis - dictyocaulosis is one of the very few parasitoses in which immunoprophylaxis is an applicable method, with good results in the prevention of diseases in animals. Comparing the control systems based on anthelmintic treatments (which are unpredictable) with immunization, it is concluded that vaccination is the only effective method of prophylaxis[551]. In addition to the protection offered, vaccination has two other major advantages[236]. First of all, animals with developed immunity can withstand new infection without obvious symptoms. On the other hand, these animals may develop subclinical infection with the onset of premunition and elimination of a small

number of worms, this being a strong and lasting protection. Basically, a vaccination program which addresses dictyocaulosis requires certain minimum criteria: a minimum age of eight weeks, a four-week interval between doses and a further interval of not less than two weeks before turnout[146]. Different antigens were used to induce immune protection over time. The whole worm vaccine[266], excretory-secretory antigens of adults enriched for acetylcholinesterases[347], gamma-attenuated infective larvae[467], crude adult worm antigen[459] or a homoeopathic oral vaccine[531] have been used. The results obtained following applied vaccinations were more or less satisfactory, comparable or not with chemoprevention. However, a 25-year-old field experience has allowed the conclusion that the parameters were similar to those for non-parasitic vaccines, although the fact that these vaccines against lungworms do not provide a parasitologically sterile immunity to challenge and requires special consideration[550].

Technological measures that targeted the grazing system and the pasture are more or less efficient in the control of dictyocaulosis, although they are credited with a high degree of confidence[175].

## 3.8. Protostrongylidae

The Protostrongylidae family consists of 13 genera systematized in four certain subfamilies: Elaphostrongylinae, Muellerinae, Protostrongylinae, Varestrongylinae and a group that contains unclassified Protostrongylidae. The members of the Cervidae family are considered primary hosts for protostrongylids; species of Bovidae, the Giraffidae or Antilocapridae families and from the Leporidae family included in the Lagomorpha order were subsequently colonized[97].

Most species of Protostrongylidae are localized in different segments of the respiratory tree, from the bronchi up to the alveoli or lung tissue. Some species have veins distant from the lungs as characteristic location (e.g. *Elaphostrongylus*, *Parelaphostrongylus*).

The typical morphological element of the family refers to the first-larval stage tail, which is elongated, tapered, slightly wavy or with a sub-terminal dorsal spine, ending in a sharp point. In addition, all $L_1$ larvae in the family seem to have well-developed lateral alae.

In terms of life cycle, the family members are bio-helminths that require intermediate hosts to complete their development. These are represented by terrestrial gastropods.

Family members cause diseases in domestic and wild animals, protostrongylosis and muelleriosis which affect sheep and goats being the most important ones.

### 3.8.1. Protostrongylidosis in small ruminants

**Definition.** Muelleriosis and protostrongilosis are bio-helminthoses which affect small ruminants caused by nematodes from the Protostrongylidae family. They evolve as parasitic bronchitis and pneumonia primarily affecting young animals. They are important diseases in countries where sheep and goats intensively graze in environmental conditions involving warmth and moisture.

**Etiology.** In domestic goats and ovines from Europe, there are 3 main species:

*Muellerius capillaris* (syn. *Synthetocaulus capillaris*) included in the *Muellerius* genus, is a cosmopolitan nematode of sheep and goats localized in the alveoli, bronchioles, bronchi and subpleural tissue.

*Protostrongylus rufescens*, from the *Protostrongylus* genus, occurs in the smaller bronchi of domestic and small wild ruminants.

*Cystocaulus ocreatus* occurs together with *M. capillaris* in the alveoli, bronchioles and bronchi of sheep and goats in Europe, Africa and Asia.

***Morphology*.** All species have a thin and slender body, whitish or reddish, equally calibrated, of variable sizes. The morphology of $L_1$ larvae, eliminated in the external environment through feces is important for microscopic diagnosis.

*M. capillaris* is called the hair lungworm because of its thread-like aspect. The male measures 12 to 23 mm in length per 0,1 mm wide; the female is longer, measuring 18 30/0.15 mm. At the anterior end, it shows a simple mouth opening. At the posterior end, the male has a spiral, coiled tail and a rudimentary caudal bursa with two spicules of variable length, between 127.82 and 170.01 µm.

The first larval stage ($L_1$) measures 240-340 µm in length per 12-15 in width; it has a transparent body, a rounded anterior end, an undulating and sharply pointed posterior end with a subterminal spine, thorn-like and dorsally oriented (figure 23A).

*P. rufescens*, or the red lungworms, are slender and reddish. The sizes of males vary between 22 and 45 mm in length per 0,15 mm in width and 30-60/0.17 mm in the case of females. The caudal bursa is small, undeveloped and displays 13 ribs, the dorsal one being ball-shaped. The two spicules are thin, equal and vary between 253.44 and 295.68 µm. The vulvar opening is subterminal.

The $L_1$ larvae are cylindrical and measure 320-400 µm in length. The posterior half of their transparent body may be curled and they have a pointed and undulated tail (figure 23B).

*C. ocreatus* - the male measures 18-45 mm in length and the female 50-95 mm. The caudal bursa is small, and the two spiculi are distally branched into two parts. The $L_1$ length varies between 340 and 480 µm and they are transparent, with a slightly curved terminal end; besides the dorsally curved spine, similar to that of *M. capillaris*, additional dorsal and ventral spines are present on the middle part of the tail (figure 23C).

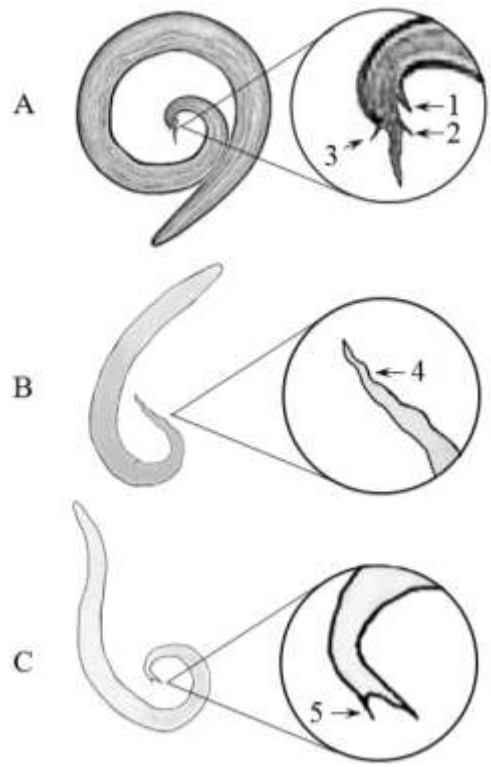


**Figure 23**. Posterior end of protostrongylids larvae: A. *C. ocreatus*; B. *P. rufescens*; *M. capillaris*. 1, 2, 3, 5 spines; 4. curled tail;

***Life cycle*.** (figure 24) All species included in the Protostrongylidae family are bio-helminths with a dixenous development involving a definitive host (ruminants) and an intermediate host (terrestrial and aquatic gastropods). The adults live in their specific biotope and feed on detritus or blood. The females deposit unembryonated eggs, which develop in the lungs of the host. The eggs embrionate and rhabditoid larvae hatch inside the bronchus or tracheal lumen. They will be swallowed and eliminated in the external environment through feces. Some reports had considered that the first-larval stage ($L_1$) molts inside the airways and the second stage ($L_2$) is eliminated through feces. Today it is generally

accepted that $L_1$ is the stage that is shed in the environment by feces[246].

The mobility of $L_1$ larvae, namely their movements on the pasture from a mass of feces to the ground and on/in the soil, in order to seek their IH, is conditioned mainly by the ambient temperature and humidity. Migration of *Muellerius capillaris* and *Cystocaulus* spp. $L_1$ from feces to substrate soils at 100% R.H. and 26°C differs in dry, wet and flooded soils. The highest migration rates (90%) in both species occurred on flooded soils. The next highest migration rates were on the wet soils and no migration occurred on dry soil or dry-substrate papers. Migration of $L_1$ from feces to soil can be achieved only during rainy periods when the land snail activity reaches a peak in any type of terrestrial habitat[493]. The age, density of larvae and cold weather negatively influence the motility of larvae; the increase of temperature and optimal concentrations of magnesium, calcium and sodium salts influence their motility in a positive manner[89].

After the larvae find their IH, they will invade the foot of terrestrial or aquatic gastropods and develop in their body to infective $L_3$ larvae. The invasion consists in penetration to the body by the epithelium of its foot, and localization in muscular tissue. At this level, the larvae molt twice and retain the cuticles of both molting processes but will lose them when larvae are released from the tissues of snails. The larval stage lasts about 15 to 90 days in the snails' bodies in optimal thermal conditions of 20 - 26°C, depending on the species. When the ambient temperature decreases, the larvae do not develop but will resume their development in favorable thermal conditions.

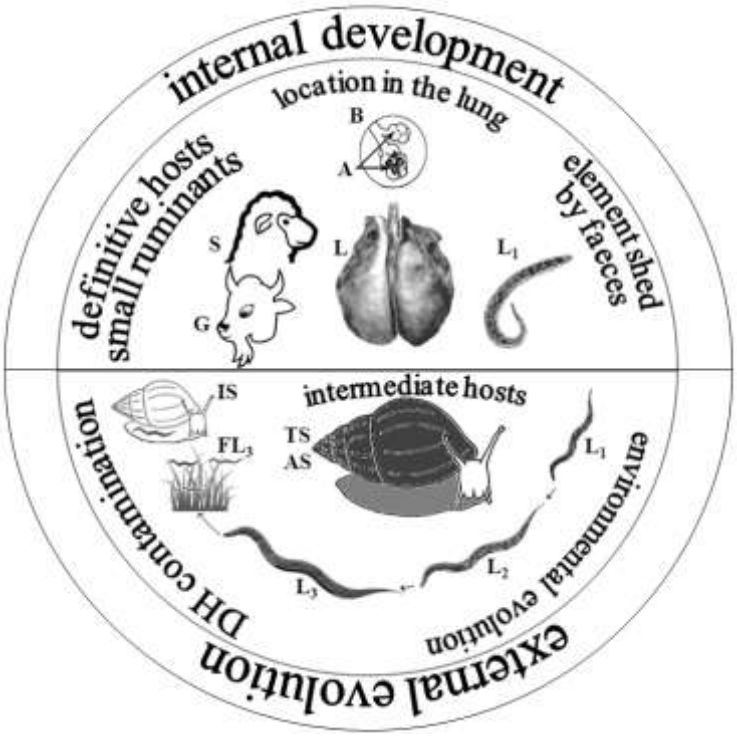


**Figure 24.** Life cycle of protostrongylids: G, goat; S, sheep; L, lung; A, lung alveoli; B, bronchioles; TS, AS terrestrial and aquatic snails; $FL_3$, free third-stage larvae; IS, infected snail; $L_1$, $L_2$, $L_3$, larval stages

The larvae are able to survive for up to 2 years in the body of IH, withstanding the conditions over the winter. Some common dormancy state of snails, such as aestivation, delay the endogenous cycle of the lungworm and the larval development stagnates in the periods in question, usually in the $L_2$ stage[494]. Old reports considered that infective $L_3$ larvae may leave the IH body and small ruminants will acquire the infection by ingesting larvae on vegetation[133]. Today this feature is questionable; it is generally accepted that DH contamination is achieved by eating infested IH.

The specificity of larval stages to the intermediary hosts in which they can develop experimentally and under field conditions is reduced. It is demonstrated that more than 90 species of land and freshwater snails included in about 65 genera and 28 families respectively, are suitable intermediate hosts (table 11).

Contamination of animals occurs commonly to pasture consuming snails infested with $L_3$ or free larvae with grass. Transplacental contamination and contamination via the colostrum are demonstrated in the case of some species of the three genera[244,443,292]. Ingested snails will release infective larvae in the small and large intestine of the DH. Further, the larvae penetrate the intestinal wall and migrate to the mesenteric lymph nodes. From here, they move through the hepatic portal system and heart to the lung. The larvae arrived in the lung will molt twice, resulting in the $L_5$ young adult stage. They leave the circulatory system settling in the alveoli and bronchioles. The prepatent period varies between 38 and 48 days.

**Epidemiology**

***Geographical distribution*.** The diseases have a cosmopolitan distribution, in the lowlands, hills or mountain areas, influenced by multiple factors, being directly related to the presence and activity of terrestrial gastropods. Their prevalence is variable. In the Italian region Emilia-Romagna, *M. capillaris* reached a 50% prevalence in sheep, *C. ocreatus* 26.86% and *Protostrongylus* spp. 12.35%[403]. In a sheep flock in Maryland, infection with *P. rufescens* registered a19.1% prevalence[333]. In the Rabat and Middle Atlas areas in Morocco, the lungworm prevalence has varied between 69 and 78% in *M. capillaris*, 16 to 25% in *Protostrongylus* spp. and 5 to 6% for *Cystocaulus ocreatus*[50].

In 59 slaughtered sheep from the Swabian Alb, Germany the prevalence or lungworms were: *C. ocreatus* (74.6%), *M. capillaris* (72.9%), followed by *P. brevispiculum* (37.3%) and *Protostrongylus rufescens* (28.8%)[423].

In farm-bred sheep from North Bohemia (Czech Republic), *M. capillaris* was the most prevalent species (8.75% in ewes and 39% in rams), followed by *P. rufescens*, which had a sporadical evolution (6.67%), while *C. ocreatus* was not found[303].

In Bovidae species from Uzbekistan (*Ovis aries*, *Capra hircus*, *C. falconeri*, *C. sibirica*, *Ovis ammon* and *O. vigneis*) the general prevalence of lungworms was: *Protostrongylus* spp. 42.6%, *C. ocreatus*, 29.8%, and *M. capillaris* – 15.8%[302].

The presence and evolution of disease outbreaks has a pronounced seasonality being influenced by temperature, relative humidity and rainfall. In an intermediate sub-humid Mediterranean/Atlantic/European Atlantic climate the prevalence and intensity of infection with *M. capillaris* and *C. ocreatus* larvae decrease when the temperature increases and increase when the R.H. and rainfall increases.

***Sources of contamination*.** The sources of parasites are domestic ruminants, sheep and goats, but wild ruminants are also important in spreading the disease. Season and age are important risk factors involved in larval output. Pregnant ewes in lambing period and in autumn/winter increase the degree of pasture pollution[91].

**Table 11**. The lungworm species and their mollusk intermediate hosts[10,57,332]

| type of snail | family | genera |
|---|---|---|
| land snails and slugs | Agriolimacidae | *Deroceras* |
| | Arionidae | *Arion* |
| | Ariophantidae | *Macrochlamys* |
| | Bradybaenidae | *Fruticicola (syn. Eutola), Pseudiberus (syn. Cathaica), Bradybaena* |
| | Chondrinidae | *Abida, Solatopupa* |
| | Cochlicellidae | *Cochlicella* |
| | Cochlicopidae | *Cochlicopa* |
| | Discidae | *Anguispira* |
| | Enidae (syn. Buliminidae) | *Chondrula, Ena, Jaminia, Parachondrula, Zebrina, Pseudonapaeus* |
| | Euconulidae | *Euconulus* |
| | Endodontidae | *Goniodiscus* |
| | Gastrodontidae | *Zonitoides* |
| | Helicidae | *Arianta, Cepaea, Chilostoma* (syn. *Cingulifera*), *Eobania, Helicigona, Helix* (syn. *Euparypha*), *Levantina, Otala, Theba* |
| | Hygromiidae | *Angiomphalia, Candidula, Cernuella, Euomphalia, Helicella, Leucozonella, Monacha, Monachoides, Perforatella, Pseudotrichia, Trochoidea, Trochulus, Zenobiella, Xeropicta* |
| | Limacidae | *Agriolimax, Limax* |
| | Milacidae | *Tandonia (syn. Milax)* |
| | ? | *Praticollella* |
| | Parmacellidae | *Candaharia* |
| | Pristilomatidae | *Hyalina* |
| | Pupillidae | *Pupilla* (syn. *Gibbulinopsis*) |
| | Succineidae | *Succinea, Oxyloma* |
| | Urocyclidae | *Atoxon* |
| | Valloniidae | *Vallonia* |
| | Vitrinidae | *Vitrina (syn. Helicolimax)* |
| | Zonitidae | *Retinella* |
| freshwater snails | Lymnaeidae | *Lymnaea, Galba. Radix, Omphiscola* |
| | Planorbidae | *Anisus, Gyraulus, Planorbis, Segmentina* |
| | Physidae | *Physa* |

Gastropods, as intermediate hosts, intervene in parasite dissemination and, consecutively, in pasture pollution, thus ensuring the perenniality of outbreaks in pastures. The increased longevity of terrestrial gastropods, 2-3 years in the wild, their high density in some pastures, between 15 and 20, even 50-60 individuals per square meter, increased

prevalence of infections with larval stages, between 22-60% and, sometimes, high intensity, between 1.5 ± 0.8 up to 39.3 ± 14.1 individuals/snail, are factors that accentuate their role in pasture contamination and maintenance of the diseases in an area[302].

***Susceptibility***. The data obtained worldwide suggest that sheep and goats are the species most infested by Protostrongylidae. It seems that goats are more susceptible, the output of $L_1$ of lungworms being higher in goats than sheep[50]. The goats' food habits, which consist in searching for and eating young sprigs, climbing on green hedgerows (favorable biotope of snails) are responsible for this fact because they favor the contact of goats with snails. Inside the species, some breeds may be more sensitive, as demonstrated in sheep[228]. Supra- and re-infestations associated with increased opportunity for adult animals to consume snails lead to a high prevalence of diseases in adults (rams, pregnant ewes) compared to lambs and kids[303].

Also, the gastropods show differences in susceptibility to infection that depend on age; young snails are most vulnerable in comparison with adults during the reproductive period, when the resistance to infection is expressed[88].

***Route of contamination*.** Contamination is performed orally, by consumption of infected snails with $L_3$ larvae; it is also possible to be achieved by consumption of infective $L_3$ larvae that left the snail's body and are free on the pasture.

***The resistance*.** The resistance of IH and larval populations to the interaction of environmental factors determines seasonal and regional features of outbreaks, temperature and humidity being the major environmental factors that condition the resistance. The $L_1$ larval stage, free on the pasture, of all three nematode species enunciated in the etiology, have a high survival rate (> 99% overall) when directly exposed to 0% R.H. at 23°C. The results demonstrate the ability of $L_1$ to survive extreme desiccation through anhydrobiosis[493]. *M. capillaris* is the most tolerant of these factors, but it better survives at 4°C[90].

**Pathogenesis**. It is considered that protostrongylids act in a way similar to *Dyctiocaulus* spp., but the general effects are less intense, except in cases of massive infestation, when the obstructive action of the bronchioles and alveoli is severe. The adult worms live in the alveoli, pulmonary parenchyma and small bronchioles where they exert an irritative effect followed by the development of a local inflammation. The resulting exudate will fill the alveolar and bronchiolar lumen, causing desquamation of the epithelium. An infiltration with leukocytes and proliferation of connective tissue will occur. Therefore, foci of pneumonia, nodules that will necrose or calcify, and inflammation of the pleura may develop, sometimes as an expression of the inoculation action of the larvae that engage bacteria in their migration (possible with *Pasteurella multocida*, *Corynebacterium pseudotuberculosis*)[602].

**Clinical signs** of infection, which ranged from mild to severe, included diarrhea, weight loss, and respiratory distress[333]. Usually, the evolution is chronic, asymptomatic in moderate infestation, or evidenced by a dry, then productive, cough, dyspnoea and nasal discharge. Animals weaken and lose their wool. On auscultation crackles, crepitation and hypersonority are perceived. The symptoms are obvious in sheep and goats during autumn and winter.

**Pathology**. The lesions in the lungworm infections are preferentially localized in diaphragmatic lobes. *M. capillaris* cause nodular pneumonia with firm, gray nodules, seen as small, grayish areas on the dorsal surface of the lobes, in goats. Gray and congested areas situated close to the lung pleura are sometimes observed. The lesions may be more severe, unorganized as nodules, but as firm, grey to black areas affecting a

large part of the lung surfaces in sheep. Diffuse congestion of the tissue appears on a section of the organ. Adults of *C. ocreatus* cause nodules with another structure: they are well differentiated from the surrounding tissue, slightly prominent above the serous surface of the visceral pleura, but not very dense and of normal or soft consistency. They contain internal cavities filled with a caseous substance[387]. Adults of *Protostrongylus* spp. do not cause nodules; the lesions have the aspect of polygonal plaques, more than 1 cm in diameter, glassy aspect, dark-red to grey or gray with a whitish or greenish hue. In the early stage, a hemorrhagic zone is observed in the peripheral area. The consistency of plaques is tough. Agglomeration of adults and eggs and the presence of a cell infiltrate cause occlusion, atelectasis and emphysema[342].

Histological, desquamated epithelial cells are in the bronchi, bronchioles and alveoli associated with alveolar macrophages, neutrophils, and parasite forms in different stages, sometimes surrounded by lymphoid hyperplasia. Additionally, the thickening of the alveolar septa, parasite granulomas, calcification, peripheral lymphoid hyperplasia, serous alveolitis, giant cell and macrophage are present in sheep. In some animals, sclerosis of the parenchyma with a lymphocyte infiltration of the sclerotic areas may appear[387].

**Diagnosis.** The clinical picture associated with the seasonal evolution, during winter, are indicative. The larvoscopic examination of feces based on the Baermann or Vajda methods allow a sure intra-vitam diagnosis. The exam allows highlighting of the $L_1$ larvae, which can be differentiated by their morphology and the aspect of the posterior extremity. The deep location first-stage larvae of Protostrongylidae in the core of pellet feces impose the crushing of semi-dried pellets. As a consequence, the number of collected larvae will increase 7 times[188]. A high efficiency can be obtained when fecal pellets are baermannized for 24 hr compared to 8 hours and when feces are crushed; small glass funnels determine the recovery of more larvae per gram of feces than larger plastic funnels; cheesecloth and/pr cellulose filters do not influence the effectiveness of the method[34]. Necropsy is a diagnosis of certainty, emphasizing the injuries and adult parasites. It is not always successful because of the microscopic width of adult parasites (100 - 200 μm), when a magnifying glass exam is necessary.

***Differential diagnosis*** must be performed for the same diseases as in dictyocaulosis: strongyloidosis, pulmonary hydatidosis and viral or bacterial bronchopneumonia.

**Treatment.** Generally, the same active substances as in dictyocaulosis can be used. Several substances are tested against the two pulmonary nematodosis, in particular:

- luxabendazole at 7.5, 10.0, and 12.5 mg/kg reduced the fecal excretion of larvae of protostrongylid species (*P. rufescens*, *C. ocreatus* and *M. capillaris*) by 97.8%-99.6%[281];
- albendazole at dosages of 1.25, 2.5 or 5 mg/kg bw in the food for 1 or 2 weeks was highly effective against *Muellerius capillaris* infection in goats[234];
- oxfendazole, a single dose of 5 or 10 mg/kg bw or with a dose of 5 mg/kg bw given three times at 48 hour intervals has reduced the larval counts in the feces by 95.7, 89.9, and 99.6%, respectively, in goats infested with *M. capillaris*[122];
- fenbendazole, 10 mg/kg bw, per os for three days at 48 hour intervals is 100% efficient against *M. capillaris*[343];
- flubendazole at a dose of 3 x 15 mg/kg bw is highly effective, the drug quickly stopping *M. capillaris* excretion in the mouflon droppings[310];
- derquantel-abamectin formulation at 2mg/kg derquantel and 0.2mg/kg abamectin has demonstrated an efficacy of more than

98.9% against *Protostrongylus rufescens* adults[319];

- moxidectin at a dose rate of 0.2 mg/kg bw has shown a 100% efficacy against small lungworm infestation (*Cystocaulus ocreatus*, *Muellerius capillaris* and *Protostronglylus rufescens*) in sheep[389];
- eprinomectin, 0.5 mg/kg topical pour-on, caused a 100% reduction of *Muellerius capillaris* infection in dairy goats, being a practical alternative to benzimidazole treatment of lungworms[212];

**Control**. The complex of measures targets the same actions as in sheep dictyocaulosis. It is difficult to combat the gastropods. Cultivated pastures are probably less contaminated by them. Low and moist pastures should not be used and lambs should be separated from older stock. Chemoprophylaxis during the grazing period using different drug formulations may be a viable method of protection. Several products are tested:

- Ivermectin controlled-release capsule (CRC), which delivers 1.6 mg ivermectin per day intraruminally ensures a 100% protection for 100 days against *P. rufescens*, *P. brevispiculum*, *C. ocreatus* and 96.2% to *M. capillaris*[419];
- Fenbendazole medicated salt (0.5%) for four consecutive winters, with apple pulp as an attractant, determined the decline of *Protostrongylus* spp. fecal prevalence from pretreatment winters to treatment winters and maintenance of animal protection during the following chemo-prevented winters[273];

### 3.8.2. Protostrongylosis in rabbit

**Definition.** This is a bio-helminthosis caused by several species of the genus *Protostrongylus*, affecting different species of the order Lagomorpha. It is widespread and expressed by respiratory disorders mainly in adult rabbits.

**Etiology.** Several species are involved:

- *Protostrongylus boughtoni* (syn. *Synthetocaulus leporis*) reported in the bronchi of *Lepus americanus* - snowshoe hare and *Sylvilagus floridanus* - eastern cottontail rabbit in North America;
- *P. pulmonalis* (syn. *P. terminalis*, *P. commutatus*) localized in the bronchioles of *Lepus timidus* - mountain hare and *Lepus europaeus* - brown hare in Europe;
- *P. sylvilagi* in cottontail rabbits (*Sylvilagus* spp.) and jackrabbits (*Lepus* spp.) in USA;
- *P. oryctolagi* in rabbits in Hungary;
- *P. tauricus* in *Lepus europaeus* - brown hare in the former USSR, central and eastern Europe and the Iberian peninsula and in *Oryctolagus cuniculus domesticus* - domestic rabbit as experimental infection;
- *P. cuniculorum* is considered a variety of *P. rufescens* found in rabbits and hares that do not infect small ruminants;

***Morphology.***

*Protostrongylus boughtoni* has a slender and whitish, cylindrical, and equally calibrated body, measuring 13 - 26 mm long by 160 - 320 µm wide (the male) and 21 - 36 mm long by 160 - 250 µm wide (the female). The anterior end is simple and the mouth opening is bounded by six small lips. At the posterior end, the male has a copulatory bursa and two relatively long spicules. The first larval stage measures 320 - 360/14 - 16 µm and has a relatively long and straight caudal appendage.

The ***life cycle*** is similar to that described in small ruminants. Adults live in bronchi and bronchioles and oviparous females lay embrionated eggs. The first larval stage, hatched in the airways, will be swallowed and subsequently shed in the environment through feces. In the outdoor environment, they actively penetrate the muscular foot of snails, their intermediate hosts. Species of *Vallonia*, *Helicella*, *Pupilla*, *Succinea* and *Vertigo* genera are involved worldwide. In their body $L_3$ infective larvae develop. Contamination of animals is accomplished by consumption of infected snails. The larvae penetrate the intestinal wall and migrate to the lung through

lymph vessels. En route, they molt twice and finally generate adults in the bronchi. The prepatent period varies between 19 and 54 days depending on the parasite species and the development particularities of snails[297].

**Epidemiology**

***Geographical distribution.*** Generally, *Protostrongylys* spp. infections of hare and rabbit are recorded worldwide. Particularly, in Europe, *P. pulmonalis* was recorded in the eastern region of Dresden in hare[380] and in *Lepus timidus* and *L. europaeus* from Finland, with a 86.9% prevalence[499].

***Sources of contamination.*** Diseased rabbits and hares, those contaminated with subclinical, inapparent forms and IH snails are the sources of environmental contamination of healthy animals.

***Susceptibility*** - wild adult hares and rabbits are more susceptible to infection compared with domestic and/or young animals.

***Route of contamination*** - orally, by ingesting infested snails.

***The resistance*** is similar to that of the species described in small ruminants, and is conditioned by ambient temperature, humidity and rainfall.

**Pathogenesis**. The parasites act in a traumatic (i.e., irritative-inflammatory) manner on tracts of the larval migration or bronchial epithelium; they cause the destruction of tissue and proliferative reactions with the formation of nodules and peri-lesional compensatory reactions. They can take and inoculate infectious agents from the intestinal lumen.

**Clinical signs**. Symptoms are not well known, but are the expression of parasitic bronchitis and peribronchitis caused; cough and nasal discharge are associated with weight loss and general bad condition.

**Pathology**. The gross lesions consist of bronchitis and peribronchitis with small, discrete, firm, yellowish gray, granular areas having a tendency toward necrosis. These lesions may occur throughout the entire lung parenchyma, but are usually grouped in small foci rather than in a single one. The foci contain a gelatinous exudate; pleural adherence, enlargement of the spleen, abscesses or cysts in the liver may occur. Lesions are reported to be more severe in rabbits than in hares[216].

Histologically, bronchiolitis, alveolitis, interstitial pneumonia, and intra-alveolar collections of larvae and eggs are visible during microscopic examination.

**Diagnosis**. Epidemiological data and symptoms are indicative; the necropsy and parasitological examination using Baermann technique clarify the presumptive diagnosis.

***Differential diagnosis*** should be done for other diseases with respiratory symptoms in lagomorphs: pasteurellosis, *Pneumocystis* sp. infection, bacterial pneumonia (*Bordetella bronchiseptica*).

**Treatment.** Although reference data is scarce, it is certain that benzimidazole derivatives and/or avermectines are highly effective against lung nematodes in hares and rabbits. Ivermectin at a dose rate of 0.4 mg/kg bw reduced by approximately 80% two wk after treatment with a single dose the prevalence of *Protostrongylus boughtoni* in snowshoe hares (*Lepus americanus*) in Canada[498].

**Control**. Husbandry technologies prevent exposure of lagomorphs to infected intermediate hosts.

## 3.9. Metastrongylidae: metastrongylosis of pigs

The Metastrongylidae family includes nematodes of wild and domesticated swine localized in the bronchi and bronchioles. The family is restricted to a single genus, *Metastrongylus*, because of its unique morphological and biological features.

From a morphological point of view, the parasites are characterized by the presence of two lateral trilobed lips that surround the mouth opening, a copulatory bursa with two broad lateral lobes and two very long and

threadlike spicules and the presence of a provagina. The eggs are embryonated, containing larvae, and the shell is thick and sculptured.

The members of the family are bio-helminths, the earthworms being intermediate hosts.

**Definition.** Metastrongylosis is a bio-helminthosis of the respiratory system that affects young swine kept on pastures or in small households. It evolves chronically, with respiratory disorders. The incidence is correlated with the presence of earthworms (IH), and it increases during summer. The disease is not reported in the intensive piggery system.

**Etiology.** The *Metastrongylus* genus includes 5 species: *M. elongatus* (syn. *M. apri*), *M. pudentodectus*, *M. salmi*, *M. confusus*, and *M. asymmetricus.*

***Morphology*.** (figure 25) The morphology of all species is similar, but they have different sizes. Their body is slender, threadlike and creamy-white. At the anterior end, the mouth opening is small, simple, bounded by two trilobed lips. At the posterior end, the males show a small copulatory bursa with obvious and developed lateral lobes, supported by short rays and two long, slender and equally calibrated spicules. At the posterior end, the females present a vulvar opening near the anus and a developed provagina. The morphological differences among species are confined to the posterior end of females and the length of the spicules. Thus, females of *M. salmi* and *M. confusus* do not have a provagina, while those of *M. elongatus*, *M. asymmetricus*, and *M. pudendodectus* have a well-developed provagina. The eggs are ellipsoidal, with a thick shell and slightly wrinkled surface, brown-grayish, containing $L_1$ when laid. The morphometry of all stages is shown in table 12.

***Life cycle*.** Adults live in the bronchi and bronchioles and feed on bronchial content represented by exudates, desquamated epithelial cells and mucus. Ovoviviparous females lay embryonated eggs which are removed by coughing and secretions in the pharynx, where they are swallowed and eliminated in the environment through feces. In the external environment, the eggs are consumed by members of the Annelida phylum, the so-called earthworms, which are intermediate hosts. Species of the *Lumbricus*, *Eisenia*, *Holodrilus*, *Aporrectodea*, *Dendrobaena*, *Allolobophora*, *Bumastus* and other genera are involved.

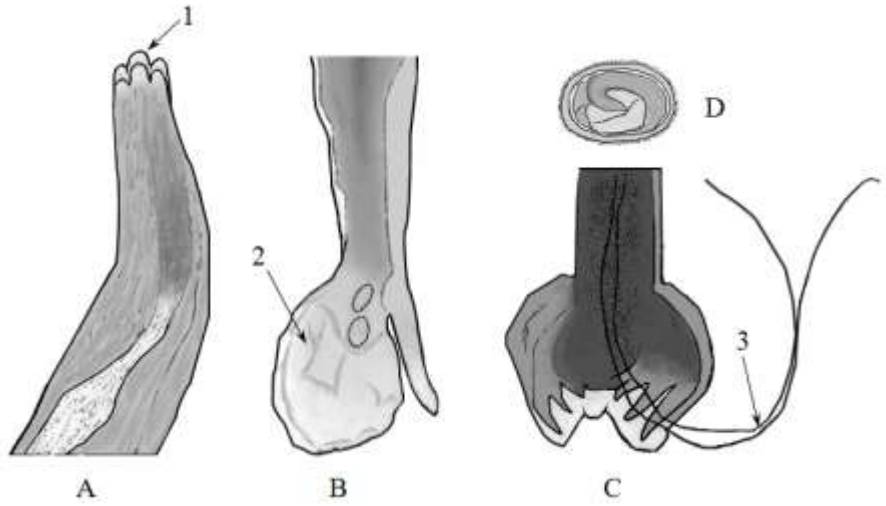


**Figure 25.** Morphology of *Metastrongylus elongatus*: A, anterior end; B, posterior end (female); C, posterior end (male); D, egg; 1. trilobed lips; 2. provagina; 3. spicules

**Table 12.** Morphometric features of *Metastrongylus* species[382].

| Characteristic | *M. pudendodectus* | *M. elongatus* | *M. salmi* | *M. confusus* | *M. asymmetricus* |
|---|---|---|---|---|---|
| **dimensions of females** | | | | | |
| body length (mm) | 23.4 - 35.8 | 34.2 - 50.5 | 27.7 - 41.0 | 25.3 - 44.1 | 21.0 - 28.4 |
| length of tail (μm) | 126.1 - 171.7 | 72.0 - 106.0 | 60.6 - 100.1 | 68.9 - 94.4 | 147.8 - 219.8 |
| **dimensions of males** | | | | | |
| body length (mm) | 14.6 - 19.5 | 13.8 - 19.4 | 12.5 - 18.5 | 14.6 - 17.9 | 14.3 - 20.1 |
| length of spicules (mm) | 1.36 - 1.50 | 3.71 - 4.73 | 1.71 - 2.76 | 2.01 - 2.91 | 0.52 - 0.68 |
| **dimensions of eggs** | | | | | |
| length (μm) | 56.3 - 61.1 | 41.8 - 54.7 | 45.1 - 53.8 | 41.9 - 58.9 | 49.2 - 55.9 |
| width (μm) | 38.2 - 43.3 | 31.2 - 41.8 | 32.3 - 41.6 | 26.0 - 41.0 | 34.4 - 41.4 |

The enzymes in the earthworms' digestive tract stimulate the secretion of fluids that break down the egg shells in the esophagus and pharynx. The liberated larvae penetrate the wall of the crop and invade the calciferous glands of the annelid. At these levels, the larvae molt twice, becoming infective $L_3$ larvae. Subsequently, they are spread to the heart, dorsal vessel, the anterior part of the crop, and the anterior esophagus. In general, the larvae have a preference for circulatory vessels so that the majority of annelids inhabit the vascular system and blood sinuses of the earthworms' organs[304]. Sometimes, infective $L_3$ larvae leave the body of their IH, actively or passively, when the anelids die. The $L_3$ larvae survive in the environment for long time, depending on the variation of the environmental factors.

The contamination of animals is achieved by consumption of infected earthworms. In the intestine, the liberated larvae from digested anelids penetrate the intestinal mucosa and migrate to the mesenteric lymph nodes. Here, the third molt occurs, resulting in the $L_4$ larval stage. They continue their migration through the venous portal system or thoracic duct to the heart and pulmonary arteries, reaching the lungs. The gradual reduction of the diameter of the lung capillaries stops the movement of the larvae and their exit from the circulation into the lumen of the alveoli. Now, $L_4$ molt again resulting in $L_5$ larvae, which move to the bronchioles and bronchi, where they reach maturity. The prepatent period is about 3-6 weeks and the lifespan of the worms varies between 8 and 12 months.

**Epidemiology**

***Geographical distribution*.** The disease is widespread, recording different values of prevalence in the domestic pig and wild boar, which are the main affected species. It is diagnosed in Busia District, Kenya in 18.5% of the examined farms, with a prevalence of 9.8% in pigs[278]. In Japan, at a slaughterhouse in Osaka, *Metastrongylus* spp. infection recorded a 2.3% prevalence in pigs[340]. But there are also geographic regions free from *Metastrongylus* spp infection in pigs, as is the situation of the Danish organic swine herds[98]. The prevalence of *Metastrongylus* spp. infection in the Dongting Lake Region (Hunan Province) of China, based on the fecal egg count analysis, was 25.8%. The species identified by necropsy were *M. apri* and *M. pudendotectus*[56]. In crossbred pig farms in the

Upper East region of Ghana, *Metastrongylus salmi* infection registered a 19.3% prevalence[393]. In the Ituri pig farms (Upper-Zaire), the infections with *M. salmi* and *M. pudendoctus* recorded a high prevalence, between 64 and 86%[104]. In pigs of the Plateau and Rivers States, Nigeria the incidence of *Metastrongylus salmi* was 3.7%[452]. In Korea, 20.3% of the examined pigs were infected with *Metastrongylus apri*[355]. In a large-scale pig reproduction farmin the Czech Republic, *Metastrongylus* sp. infection recorded a 0.3% prevalence[300]. The prevalence of *M. apri* infection in pigs slaughtered at the Pretoria Municipal Abattoir, South Africa was 26.9%[251]. Mixed infections, comprising *M. pudendodectis* (69 %), *M. apri* (18 %) and *M. salmi* (13 %), were diagnosed in pigs of Papua New Guinea[118].

In feral swine, *Metastrongylus* spp. infections are more prevalent because of their more frequent contact with earthworms. In southern Florida, *M. apri*, *M. salmi*, and *M. pudendotectus* were found in 94%, 76%, and 64% of 90 feral animals, respectively[189].

Most recorded data regarding the geographic distribution of metastrongylosis in the world, involves the wild boar:

- 41.1% in southwestern and 85% in eastern Spain, the species involved in the first region being *M. apri* (71.4%), *M. pudendotectus* (28.0%), and *M. salmi* (0.6%)[199,370];
- 60 % in the state of Rio Grande do Sul, Brazil, with the occurrence of the species *M. apri*, *M. salmi*, and *M. pudendotectus*[477];
- *M. apri* (59%), *M. salmi* (52%) and *M. pudendotectus* (52%) in the Bursa province of Turkey[464];
- *M. elongatus* in two young female wild hogs from the Demilitarized Zone, Korea[601];
- 82% in Estonia (*M. pudendotectus* - 78%, *M. salmi* - 77% and *M. elongatus* - 41%)[267];
- 100% in the Western Region of Tokyo, Japan, the species identified being *M. elongatus*, *M. salmi*, *M. asymmetricus*, and *M. pudendodectus*[365];
- *M. apri* (16%), *M. pudendodectus* (14%), and *M. salmi* (14%) in protected regions located in north, northeast, and southwest Iran[174]; in the Luristan province of the same country, *M. apri* (41.6%), *M. pudendotectus* (16.6%), and *M. salmi* (8.3%) were found[490];
- *M. salmi* (91.9%), *M. apri* (88.7%) and *M. pudendotectus* (87.1%) in southern Germany[31];
- in several regions in France, the general prevalence was 92%, the species identified being *M. asymmetricus*, *M. confusus*, *M. elongatus*, *M. pudendotectus*, and *M. salmi*[256];
- in Romania, *Metastrongylus* spp. prevalence was found to be 89.47% in mountain populations and 77.58% in those from the hills[376];
- general prevalence of infection was 80.0%, in southern Poland. Five species were distinguished: *M. pudendotectus* and *M. confusus* (76.0%), *M. salmi* (72.0%), *M. elongatus* (64.0%) and *M. asymmetricus* (40.0%)[382].

Translocation of animals is one of the important mechanisms that contribute to the spread of parasites[183]. The house fly (*Musca domestica*) is also a potential vector host that participates in the dissemination of *Metastrongylus* spp. Eggs and/or larvae of *Metastrongylus* spp. were found on the flies' skeletons and in their intestines[194].

***Sources of contamination.*** Subclinically infected or diseased animals and earthworms are the sources of contamination. Diseased animals pollute the environment. The high longevity of the larvae in the body of earthworms perpetuates the infestation.

Prevalence of infection of lung nematode larvae in earthworms is variable according to the type of ecosystem. Usually, the forests are not common areas for infected earthworms, while feeding centers landscaped for wild boars in the hunting areas are favorable zones for contaminated annelids. The density of

larvae in earthworms is also important and can reach dozens or hundreds (between 1 and 600 larvae/earthworm) of larvae per earthworm[256,255].

***Susceptibility*** of animals is correlated with age. The most vulnerable are the piglets up to the age of 6 months, after which the sensitivity attenuates[298]. Antagonistic interaction between nematodes of pigs may influence the susceptibility of animals to infections. Mixed infections with *A. suum* and *M. apri* are expressed by the decrease of mean burdens of immature *A. suum* and immature and adult *M. apri*[195].

***Route of contamination*.** Contamination occurs orally, by ingestion of infested worms or infective larvae reached on the pasture, in water.

***Resistance***. The eggs resist in biotopes with a moist substrate between 3 and 18 months and in manure for 6 to 8 months, which indicates that they can remain viable on pasture from autumn to the next spring[552]. The survival of larvae is in fact interconnected with the lifespan of earthworms, intermediate hosts which can reach ages of 8 to 9 years in an optimum environment[371]. Liberated infective larvae on the soil survive for several months, less than one year, depending on climatic variations.

**Pathogenesis**. Pathogenic actions exerted are similar to those of dictyocaulosis and depend on the intensity of parasitism and age of the pigs. The traumatic action of both stages is very important. The larvae destroy the tissues during their migrations and adults obstruct bronchial lumen causing compensatory emphysema. The irritative-inflammatory action of the larvae consists in nodular inflammations disseminated in the lung parenchyma from diaphragmatic and sub-pleural lobes. Adults cause bronchiolitis and bronchitis with epithelial descuamations, exudate and mucus in the bronchial lumen.

Inoculation action - the exercising of an inoculation action by the mobile evolutionary stages of *Metastrongylus* spp was enounced by Shope[474,475] who surmised from his researches on swine influenza that the virus may survive in the mature and immature lungworms in a kind of "masked" form. Other viral diseases, such as swine flu, Teschen disease and hog cholera may be conveyed and inoculated by lungworms[156,327].

**Clinical signs**. The disease usually evolves chronically in young animals, rarely acutely, with a persistent cough, which is initially a dry cough, as “thumps,” and subsequently a productive cough, muco-purulent nasal discharge, dyspnea and sometimes tachypnea. Rhonchal fremitus and sibilant rales are present on auscultation. The appetite diminishes, animals lose their condition, the movements are slowed, growth retardation and occasionally, in bacterial over-infections, feverish conditions set in. Morbidity may reach 20% and the mortality rate less than 2%[411].

**Pathology**. The diaphragmatic lobes are affected. Micro-hemorrhages in lung and subpleural parenchyma, miliary nodules, with a diameter of about 1 mm, whitish-gray, formed by the destruction of larvae, are found in the early stages of the disease. Chronically, parasites cause bronchopneumonia, atelectasis, and bronchial lumen obstruction by the crowded parasites and abundant mucus. Compensatory emphysematous areas surround the lesions.

Histopathology is characterized by bronchial and peri-bronchiole infiltrations by eosinophils, hyperplasia which affects the bronchial epithelium and subjacent muscle tissue, cell metaplasia resulting in the replacement of the various cell types of the bronchial epithelium by the goblet cells. Emphysematous areas are observed, characterized by an enlargement of the alveoli associated with the atrophy of the inter-alveolar septa and dense nodules consisting of inflammatory cells surrounding an egg or delimitating dead larvae or adult parasites[255].

Inside the IH body granulomas that include the larvae are formed. Initially, capsules around the larvae occur in the interlamellar spaces of calciferous glands, after the larvae leave the narrow blood sinuses of these glands. Subsequently, reactions of fibrous, peripheral connective or muscular tissues will transform the capsule into a granuloma[255].

**Diagnosis**. The occurrence of the disease in young animals that have access to the pasture is an indicator of lungworms. Flotation tests reveal the eggs in feces; these must be differentiated from the Ascaris suum eggs, which embryonate in the older fecal mass. Necropsy is amethod of certainty. It reveals the lesions and adult parasites in the bronchi. For an easier highlighting, bronchial exudate is sampled and examined.

***Differential diagnosis*** is required for pulmonary forms of ascariosis, strongyloidosis or specific pneumopathies favored by the cold.

**Treatment.** Curative treatment may be used with good results in metastrongylosis and other nematodosis, involving the following active substances:

- levamisole, 8 mg/kg bw in the feed is 99.6% efficacious against *Metastrongylus* spp.; in drinking water its effectiveness is slightly reduced, to 99.5%[180];
- albendazole at at 30 ppm for 5 consecutive days, has a 100% efficacy[179];
- fenbendazole, at 3 and 5 mg/kg bw was 97% and 99.9% efficacious against *Metastrongylus* spp.[511];
- oxfendazole at a rate of 3.0 mg/kg bw administered once in the feed, has a degree of efficacy as high as and similar to larger dosages or multiple doses[120];
- flubendazole, 1.5 mg/kg bw mixed in feed, for 5 consecutive days, demonstrated 100% efficacy against mature *Metastrongylus apri*[75]; at a dose rate of 30 ppm for 10 consecutive days, in the feed, it showed the same efficacy[559];
- ivermectin at 100, or 500 microgram/kg bw had a 99.4% to 99.9% efficacy against *Metastrongylus* spp.[512]; administered in feed at concentrations of 100 or 200 micrograms/kg bw/d for 7 days, it had an efficacy of 97.8% or 100% for *Metastrongylus* spp.[7];
- moxidectin, 0.5% pour-on, at dose rates of 0.75 mg/kg bw was 100% effective against *Metastrongylus* spp.[508];
- doramectin, at 300 micrograms/kg bw by intramuscular injection ranged from 98 to 100% against *Metastrongylus* spp.[320]; at the same dose, it proved 100% effective in the removal of *Metastrongylus salmi*, *M. elongatus*, *M. pudendotectus*[597];

**Control**. The implementation of principles and technological measures associated with chemoprophylaxis has a protective value. Intensive piggeries, using stables with concrete or slatted, cleaned floors reduce or eliminate sources of earthworms, intermediate hosts. Extensive and semi-intensive systems rearing the pigs in a sty, pig-shed, ark or curtain-barn stables favor the interaction between animals and intermediate hosts. In these situations it is very important to ensure hygienic conditions in shelters, paddocks and proper nutrition, especially of the youth. To destroy the eggs of metastrongyles, the manure will be collected and stored in a bio-thermo-sterilization platform. On rainy days, when earthworms are numerous on the ground surface, the movement of pigs in shelters and around them will be forbidden.

Chemoprophylaxis consists in administering anthelmintic products such as those enunciated at Treatment, but drug formulations should be introduced into the feed for a longer period of time.

## 3.10. Syngamidae: syngamidosis

The Syngamidae family includes parasites of the respiratory system of birds or mammals, of the urinary system of swine or of the intestine of *Hirax*. They are, morphologically,

easily recognizable by their dorsal gutter and the absence of their perioral groove, a reduced copulatory bursa with short and thick spicules and a vulva located at midbody, except the *Stephanurus* genus[11].

The family is divided in three subfamilies: Stephanurinae, Syngaminae and Archeostrongylinae. The first contains the monotypic genus *Stephanurus* represented by one species, *Stephanurus dentatus*, in the kidney of the pig. The Syngaminae subfamily includes 5 genera: *Mammomonogamus*, parasites of mammals (ruminants, carnivores, primates, elephants) from the tropics, *Rodentogamus*, parasites of rodents in the Paleartic region, *Syngamus* in birds (especially fowl and passerines), and *Cyathostoma* in waterfowl, both distributed worldwide, and *Boydinema*, also in birds. The latter contains one genus, *Archeostrongylus*, common in the intestine of *Histrix*[11].

The life cycle shows large variations and can be monoxenous, without the intervention of intermediate hosts, or heteroxenous with one or two intermediate or paratenic hosts.

Important diseases from a medical and veterinary point of view are syngamosis in poultry, cyathostomosis in waterfowl, and stephanurosis in pig.

### 3.10.1. Syngamosis in poultry

**Definition.** This ss a nematodosis of the trachea, caused by the cosmopolitan nematode *Syngamus trachea*, manifested by respiratory and general disorders, more severe in young birds. The disease affects chickens, turkeys, pheasants, partridges and many other wild and game birds. It is a disease with a high significance in the breeding of pheasants, species in whose case the inflicted mortality can reach 40, even 80% in the afflicted flocks[589].

**Etiology.** The agent is *Syngamus trachea*, included in the *Syngamus* genus. Several popular names are assigned to it: ***gapeworm*** or ***gapes*** because they block the airways causing gapes (open-mouth breathing), ***Y-shaped*** or ***forked*** worm (because of the permanent procreative conjunction of males and females, and due to the reduced length of the male, the couple looks likre the letter "Y"), and ***red worm,*** because of the color of their body, caused by hematophagous nutrition.

Other known species that affect, generally, wild birds are *S. merulae*, *S. arcticus*, *S. alcyone*, *S. gibbocephalus*, *S. microspiculum*, *S. palustris*, and *S. taiga*. It is possible that some of them to be synonymous with *S. trachea* (e.g. *S. merulae*).

***Morphology.*** Several important morphological features are common in *S. trachea*[595]:

- permanent joining of males and females aiming continuous copulation, induce the “Y” shape;
- the presence of an accentuated sexual dimorphism, the females being 3 to 4 times longer than males. The sizes range from 2 to 6 mm long by 200 μm wide (males), and 5-20 mm/350 μm (females);
- the presence of a well-developed, cup-shaped oral capsule. At the anterior end, it has an orbicular mouth surrounded by a hemispherical chitinous capsule, armed with eight sharp teeth at the base. A chitinous plate with an incised outer edge forming six opposite festoons surrounds the mouth;
- a cylindrical, stout and brighty red body. At the posterior end, the male has a well-developed, obliquely truncated copulatory bursa, with asymmetrical rays and equal, slender and short spicules measuring 57-64 μm in length. The female has a conical posterior end; the vulva is located at the limit between the first and second quarters of the body, from the anterior to the posterior end of the body;
- the eggs are elliptical, operculated at both poles, in the morulation phase, with 8-16 blastomeres when laid, and measure 85–90/50 μm;

The ***life cycle*** is monoxenous, optionally heteroxenous when paratenic hosts are involved. Adults are located in the trachea or bronchi of a large number of bird species, and feed on blood. Oviparous females lay eggs which are swallowed and passed through feces in the environment. In optimal conditions of temperatures (15-29$^{o}$C), humidity (85-90%), and oxygenation of the environment, evolution to the infective stage ($L_3$) takes place in 8-15 days. Below 10$^{o}$C, embryogenesis stagnates. All non-parasitic larval stages ($L_1$, $L_2$ and $L_3$) develop inside the egg.

Further, the cycle can be carried out directly or indirectly. The direct cycle involves the birds' contamination by ingestion of embryonated eggs or infective $L_3$ larvae that leave the eggs, being free in the external environment. The indirect cycle means the intervention of various paratenic hosts which serve as transport hosts: earthworms (*Eisenia*, *Helodrilus*, *Lumbricus* and *Allolobophora* genera), terrestrial snails (*Cepaea* spp., *Helicella* spp.) and slugs (*Agriolimax* spp.), freshwater snails (*Lymnaea* spp.) and insects (*Tipula* spp., *Lucilia* spp., *Musca domestica*). These hosts become contaminated through consumption of eggs that contain any of the larval stages $L_1$, $L_2$ or $L_3$ or by ingestion of $L_3$ larvae that hatch from the eggs. The larvae have various localizations in the paratenic host's body and do not change their morphology, but may become encapsulated.

Contamination of birds can be achieved in four ways: eating embryonated eggs containing infective $L_3$ or with free $L_3$ from the environment or by paratenic hosts that contain embryonated eggs or hatched $L_3$.

After contamination, the larvae approach multiple migratory pathways to the trachea. The majority penetrates the duodenal mucosa and migrates through the liver, the portal bloodstream to the lungs. A smaller percentage penetrates the wall of the crop and esophagus and migrates directly to the lungs. Other larvae penetrate directly into the peritoneal cavity and migrate to the lungs. When they reach the lungs, the larvae molt twice and the adults are developed. The prepatent period varies between 12 and 17 days[572] and the lifespan between 98 days in the guinea fowl and 224 days in turkeys[573].

**Epidemiology**

***Geographical distribution*.** Syngamosis has a cosmopolitan distribution, being diagnosed in all geographic regions: Eurasia, North America[42], South America, Australia and New Zealand[571], and Africa. The spread of the disease is influenced by certain risk factors, the most important being the season and climate, housing and husbandry variables, and the age of birds, respectively. In rural scavenging poultry in Tanzania, the prevalence of the disease was 0.7% during the wet season and 2% in the dry season[394]. In the same country, the prevalence was significantly higher in growers (14%) than in adults (3%)[330]. In Wales and England, the higher prevalence was established among free-range flocks of laying hens[472].

Translocation is another factor that contributes to the spread of pathogens over long distances. The reintroduction of Eurasian cranes (*Grus grus*) to England resulted in the spread of *S. trachea*, considered a medium risk hazard, to new territories[450]. Pheasants translocated from Romania and Poland to Italy for repopulation purposes were infected with *S. trachea* at a rate of 9.80%, which demonstrates that the release of game birds from foreign countries is a risk factor for native animals[527].

Interactions between domestic and wild birds may also contribute to the spread of the disease. Syngamus-infected pheasant roosters have induced an occasional incidence of syngamosis in the chickens and turkeys from small stocks of fowl kept in gardens close to the fields visited regularly by roosters[40].

The prevalence of infection in chickens in Dschang, western Cameroon, was 13.7%; the

infection rate was not influenced by the sex of the host, but younger chickens showed an increased sensitivity to *S. trachea*[369]. The infection rate of *S. trachea* in the indigenous poultry from various towns in Kenya was 0.40%[263]. The prevalence of *S. trachea* in the Samsun region, northern Turkey, between July 1999 and June 2000, was 2%[306]. In 51.5% of pheasants originating from two pheasantries in Germany, *S. trachea* was present[201]. In the same country, members of the Syngamidae family (*Hovorkonema variegatum*, *Syngamus trachea* and *Cyathostoma trifurcatum*) were indentified in wild bird species from Ciconiformes, Falconiformes and Gruiformes orders[301].

The ***sources of contamination*** are represented by the infected poultry, with or without symptoms, which pollute the environment. Wild birds also represent a significant source of pollution for ecosystems. Alterations of natural biotopes in order to transform them into agricultural land caused a change in the importance of certain species of birds in the case of environmental pollution by *S. trachea* eggs. The transformation of natural biotopes covered with trees and shrubs into arable land has determined the replacement of partridges by pheasants as the dominant species in these areas[40]. The second source of contamination is represented by the paratenic hosts, earthworms being considered the most important of the categories listed above.

***Susceptibility***. According to Yamaguti[592], a great variety of bird species belonging to the following orders are affected: Galliformes, Passeriformes, Anseriformes rarely "Ardeiformes" now Ciconiiformes, Pelecaniformes, Piciformes, Otidiformes. *Syngamus* spp infestations of birds belonging to other orders, such as Gaviiformes[516] and Charadriiformes[444], are cited. The disease is important and may cause significant economic losses especially in wild and domesticated Galliformes (chicken, turkey, guinea fowl, pheasant, peacock, partridges, quail, and willow grouse).

Receptivity varies depending on species, age, and other factors. In general, in all species the youth is more sensitive than the adult birds. Turkey poults, baby chicks, and pheasant chicks at 2 - 3 weeks of age are very receptive and become more resistant after 3 months. Turkey is receptive at any age. Stressors, intercurrent illness, hypovitaminosis and immunosuppressive states increase the responsiveness of birds.

***Route of contamination***: contamination occurs orally, by ingesting embryonated eggs, infective $L_3$ larvae or paratenic hosts that contain embryonated eggs or $L_3$.

***Resistance*.** Free infective larvae $L_3$ do not survive over the winter, but embryonated eggs resist for 8 to 9 months. The character of the natural outbreak is due to earthworm populations and embryonated eggs which ensure the perenniality of outbreaks[164]. Gapeworm larvae in the earthworm remain infective to young chickens for as long as 4 years[595].

**Pathogenesis**. The actions of parasites may be separated according to the evolutionary stage involved. The migratory larvae exert a traumatic action that consists in the destruction of tissue on their migration tracts. Inoculation action is less important, but the larvae may take bacteria from the intestine, complicating the lesions. The adults exert mechanical, inflammatory and spoliation actions. Mechanical action consists in their obstructing trachea and bronchial lumen due to their size and the mucus resulting as a consequence of the local inflammation. On the other hand, the inflammatory action consists in the catarrhal inflammation of the affected mucosa and development of nodules at the attachment sites. Spoliation action is due to the hematophagous nutrition of parasites and is reflected in several hematological changes: heterophilia, monocytosis, eosinophilia,

lymphocytopenia, and a decrease in the packed cell volume[258].

**Immunity**. Cell-mediated immune reactions (CMI), intensified following successive infections, develop into *S. trachea* infections. In turkeys, CMI that involve macrophage develops starting on the fourth day after infection, peaking at day 15 and then slowly decreasing, only to disappear in the 13th week. Re-infestation induces significantly greater CMI. In chickens, the reactions are similar, but develop faster[396].

**Clinical signs**. The disease may develop acutely or chronically. An acute evolution is recorded in chickens, pheasant and turkey chicks and goslings after 14-21 days' incubation. It is expressed by respiratory disorders such as asphyxia, dyspnea, orthopneic position (open mouth with head extension - "gape"), wheezing, convulsive head-shaking, cough, repeated swallowing, progressive weight loss and death, resulting from attacks of suffocation or progressive emaciation. Orthopnea position and repeated swallowing are common in goslings[562]. The chronic form develops in youth and is expressed by anemia, weight loss, slowed growth, capricious appetite and repeated swallowing. It evolves for 3-4 weeks, the mortality being sporadical, consecutive to cachexia.

**Pathology**. The lesions are correlated with the clinical form. Catarrhal and pseudo-membranous duodenitis followed by pulmonary congestion and hemorrhage, lobar pneumonia and adjacent emphysema are found initially, in the acute form, caused by the migration of the larvae[515]. Catarrhal-exudative or hemorrhagic tracheitis and bronchitis are identified in the chronic form; necrotic nodules and circular ulcers are dispersed in the mucosa and submucosa of the trachea and bronchi. Nodules are caused mainly by the permanent attachment of the males, while females detach and reattach. The nodules may develop into abscesses successive to bacterial over-infections. Adult parasites cause tracheal obstruction with bloody mucus.

**Diagnosis.** Clinical examination reveals an orthopneic position and suffocation, which are indicative. Identification of the eggs in feces by flotation tests is a method of certainty. Necropsy allows the identification of the lesions and couples of parasites fixed on the tracheal mucosa.

*A **differential diagnosis*** will be conducted, in comparison to mycoplasmosis, laryngo-tracheitis and infectious bronchitis, coryza and aspergillosis.

**Treatment** is based on some anthelmintic substances with good efficacy. The following are used:

- levamisole at a dose rate of 2 mg/100g body weight, administered subcutaneously, has been effective in the treatment of pheasants[386];
- fenbendazole, 100 ppm, for 4 consecutive days, reduced infection with *S. trachea* by more than 90%[290]; at 20 mg/kg bw, it showed a 100% efficacy against *S. trachea*[505];
- mebendazole in a dose of 120 mg/kg of feed, for 7 to 13 days, is suitable to treat syngamosis in pheasants[358];
- flubendazole, for 7 consecutive days, at a level of 30 ppm, food medication in naturally infected geese, showed a 100% efficacy in worm elimination[557];
- cambendazole administered for three consecutive days, 3-4, 6-7, and 16-17 days post-infection, has revealed a 94.9% efficacy in chickens and 99.1% in turkeys against *S. trachea*[165];
- thiabendazole administered for 9–20 days in 4-week-old turkey poults removed 98% of the gapeworms[574];
- ivermectin administered perorally in dosage schemes 1 x 0.8 mg/kg of body weight (bw), 1 x 1.6 mg/kg h.w., 3 x 0.8 mg/kg bw, and 3 x 1.6 mg/kg bw to pheasants has demonstrated a helminthostatic and partially

helminthocide effect against adults of *S. trachea*[309];

**Control**. Proper sanitation and chemo-prophylaxis can control the infection. General hygiene measures consist in removing feces to control the earthworm populations, avoiding backyards and other natural places with moist soil that contains nutrients, suitable for earthworms, avoiding mixing different species of bird chicks, keeping the birds on dry and clean ground, and avoidance of contact between wild and domestic birds.

Some issues related to the breeding technology are important in the control of the disease. The breeding of avian youth in large farms represents a technological method for the prevention of the disease. In a semi-intensive system, the youth will be isolated from the adult birds in previously unused spaces. In contaminated units, chemoprophylaxis with thiabendazole is recommended, at a dose of 0.05 - 0.5% in food, for 14 days, during risk periods, with good efficiency[515].

### 3.10.2. Cyathostomatosis in waterfowl

**Definition.** This is a nematodosis caused by *Cyathostoma bronchialis* which affects web-footed birds, evolving endemically, and which manifests itself by a severe respiratory syndrome in waterfowl buds.

**Etiology.** The *Cyathostoma* genus belongs to the Syngamidae family and is characterized by the absence of a collar at the oral opening. Based on the aspect and sizes of the rays and spicules, the species were assigned to one or two genera: *Cyathostoma* or *Hovorkonema*, also considered to be subgenera[64].

The genus contains multiple species, the most common being *Cyathostoma bronchialis*, parasitizing in the larynx, trachea and bronchi of their hosts. Other species are: *C. americanum* and *C. brodskii* in the air sacs of raptors[313], *C. microspiculum* in the great cormorant[279], *C. phenisci* in penguins[280], *C. cacatua* in cockatoo[71] and *C. lari* in the orbital and nasal cavities of gulls, crows and birds of prey[480].

***Morphology.*** *C. bronchialis* has a reddish cylindrical body, very similar to *S. trachea*, only larger, adult males measuring 8 to 12 mm long by 200 to 600 μm wide and adult females 16 to 30 mm long by 750 to 1500 μm wide. The sexes are not firmly and permanently united in copulation. At the anterior end, the buccal capsule is cup-shaped, armed with six or seven triangular teeth at its base. At the posterior end, the males have a copulatory bursa with long, slender and threadlike spicules, measuring 540 μm to 870 μm in length. The spicules have tips that are slightly curved inwardly. The vulva is situated in the terminal portion of the anterior third of the body and has fairly prominent lips. The eggs are oval-shaped, 68 to 90 μm in length by 43 to 60 μm wide, in the morulation phase, when laid, with slight opercula[595,364].

***Life cycle.*** Adult parasites live in different segments of the respiratory system, being hematophagous. They attach themselves to the affected mucosa by vacuuming a piece of mucosa into their buccal capsule, thus creating a hole at the attachment site[537]. The life cycle may be direct or indirect. The direct cycle involves the contamination of birds by consumption of infective third-stage larvae. The indirect cycle consists in the contamination of birds by consumption of earthworms, paratenic hosts (*Allolobophora*, *Bimastus*, *Lumbricus*, *Octolasium* genera).

The $L_3$ larvae released in the intestines migrate to the lungs through the coelomic cavity and air sacs, with no migration through the bloodstream or liver port system. Chronologically, the larvae reach the abdominal sacks in 1-2 hours post-infection and, after 4 hours, reach the lungs, where they develop between 2 and 5 days pi. At this level, the larvae are, initially, localized in the parabronchi, then in the secondary bronchi, and 5 days pi, especially in the primary bronchi. They reach the trachea in 6 days pi.

Migratory larvae molt twice, but only in the lung[184]. The prepatent period is 13 days.

**Epidemiology**

***Geographical distribution.*** *Cyathostoma bronchialis* has a worldwide distribution but records low or moderate values of prevalence. In southwest Germany, between 2007 and 2008, a very low level was recorded, of 0.04%, in feral greylag geese (*Anser anser*)[590].

***Sources of contamination.*** Contaminated birds intervene in environmental pollution and earthworms are the source of infection for birds.

***Susceptibility.*** Goslings, ducklings and young animals of all affected bird species are more susceptible to infection.

***Route of contamination*:** oral, by ingestion of infective $L_3$ larvae or earthworms.

***The resistance*** is similar to that recorded in *S. trachea*.

**Pathogenesis.** The larvae act traumatically and inflammatorily, causing bronchitis of the primary, secondary, and tertiary bronchi and hyperplasia of the epithelium. The adults exert mechanical action with the obstruction of the bronchi and trachea. Inflammation caused by the adults consists in laryngotracheitis. The aspirated eggs have an allergic effect, causing generalized pneumonitis.

**Clinical signs.** Morbidity may reach 80% and mortality 20%[364]. Affected birds may display difficult breathing, gaping, dyspnea, growth retardation or weakness and death.

**Pathology.** The lesions recorded during the evolution of cyathostomatosis are: exudative laryngotracheitis, bronchitis, which may become purulent, hyperplasia of the bronchial epithelium, pneumonitis, airsacculitis, pulmonary emphysema, and presence of adult worms. Kidney edema, anemia and emaciation of muscle masses may also occur[532].

**Diagnosis.** Combining the identification of eggs in the feces by flotation tests with recovery of the adults in the trachea following the necropsy and clinical signs will beget a diagnosis of certainty.

***Differential diagnosis*** is required for parrot fever (psittacosis), geese influenza, aspergillosis and nonspecific pneumonia.

**Treatment** and **control** is similar with syngamosis. Thiabendazole and fenbendazole are effective.

### 3.10.3. Stephanurosis in pigs

**Definition.** It is a common disease in tropical and subtropical areas caused by the kidney worm *Stephanurus dentatus, and is* characterized by progressive weight loss up to emaciation, hind limb paralysis and stiffness.

**Etiology.** *Stephanurus dentatus* is included in the *Stephanurus* genus, member of the Stephanurinae subfamily from the Syngamidae family.

***Morphology.*** The adults have a stout body, with a mottled appearance due to the transparency of the cuticle that allows the emphasis of internal organs (reproductive and intestinal tracts) and alternaton of the colors black and white. Adult males measure between 2 and 3 cm in length, females are 3-4.5 cm, and both sexes are about 2 mm in diameter. At the anterior end they have a thick-walled, prominent buccal capsule, armed with teeth, surrounded by a discrete leaf crown at the entrance to the mouth. At the posterior end, the male has a small, square-shaped copulatory bursa. The eggs are ellipsoidal, measure 120/70 μm, with a thin wall and morulated when removed.

***Life cycle.*** Adult parasites are localized in the perirenal fat and kidney where they develop into cysts that communicate with the ureters through the fistulas. The pancreas, lumbar muscles, spinal cord, and lungs are other uncommon locations[506]. Eggs are eliminated in the environment through the urine, the greatest number being recorded in the first matutinal urination. Eggs hatch and the first-larval stage molts twice resulting in infective $L_3$ stage in 4-6 days, in proper temperature

conditions (26°C). The infective larvae are able to survive for several months in moist, warm and shaded conditions. Earthworms may intervene as paratenic hosts and larvae will survive in their body. Animal contamination occurs by ingestion of infective $L_3$ larvae or infected earthworms, paratenic hosts, skin penetration by infective larvae, and transplacentally[33]. The ingested larvae migrate to the mesenteric lymph nodes where they molt once, resulting in the $L_4$ larval stage. This stage moves to the liver and, thereafter, molts again to $L_5$, the young adult stage. Other $L_4$ larvae will disseminate into almost any part of the body: bronchiole, lymph nodes, lungs, pancreas, spleen and fetus body, transplacentally. The $L_5$ larvae pass from the liver into the peritoneal cavity and migrate through the body cavity to the perirenal and mesenteric fat. At this level, cysts will result and the parasites will be localized in these cysts. They perforate the walls of the ureters and become adults.

When contamination is performed transcutaneously, $L_3$ larvae migrate to the lungs, go out in the respiratory tree and ascend the trachea, the pharynx, and will finally be swallowed only to reach the intestine. From the intestine they will follow the same route as in the case of ingested larvae. The prepatent period is at least 9 months and egg-shedding extends over a period of 3 years pi[33].

**Epidemiology**

***Geographical distribution.*** *Stephanurus dentatus* occurs throughout the world, but the disease is common in tropical and subtropical areas, with warm and moist climates. It is responsible for the significant economic losses caused by condemnation of organs or carcasses which are unfit for human consumption due to the cachexia (at least 95% of liver in the southeastern United States according to Batte et al.[32]). The prevalence is higher in those regions. The infection rate following three years of investigations in the Ghanaian dwarf pig was 33%[455]. The prevalence of *S. dentatus* infection in pigs in Belize was 42%[214]. In the Rohilkhand division of Uttar Pradesh (India), 40.5% of examined pigs harbored *S. dentatus*[481]. In another sub-tropical and high-rainfall area of the same country, the prevalence was much lower, of 9.75%[591]. In pigs slaughtered at Deonar abattoir, Mumbai (India), *S. dentatus* recorded a 0.39% prevalence[202]. In pigs from Ibadan, southwest Nigeria, *S. dentatus* recorded a low prevalence of 1.1%[500]. In south China, the infection rate was 62.5%[566].

***Sources of contamination.*** Two categories of sources are differentiated: contaminated birds that pollute the environment by removing eggs and, implicitly, infective $L_3$ larvae which, together with the paratenic hosts, infect the birds.

***Susceptibility.*** All age categories, including fetuses, are susceptible to infection. Several climatic risk factors such as moisture and shady pastures favor the evolution of the disease.

***Route of contamination*:** peroral, by ingestion of infective $L_3$ or earthworms, paratenic host, percutaneously or prenatally.

***Resistance.*** The eggs and all external larval stages are sensitive to temperature and dessication. Negative temperatures rapidly destroy the eggs; below 10°C, they are unable to hatch; between 10 and 15°C and at 35°C, the second larval stage never develops. The eggs can hatch and the external larval evolution may be achieved at 25 cm below the surface of water. Infective larvae may live in moist surroundings for 5 months. High temperatures, above 35°C, associated with desiccation, exert a marked ovicidal activity[105,569].

**Pathogenesis.** The larval migration and the adults' development are accompanied by the exercise of traumatic, inflammatory, and inoculation pathogenic actions, respectively. The inflammatory action causes multiple traumatic pathways wherever they migrate, including on the skin. Together with the

inoculation action, they are responsible for abscesses and adhesions on the migratory route and pus in urine. Traumatic and inflammatory actions consist in the destruction of tissue and formation of nodules in the mesenteric lymph nodes, liver, spinal cord, pancreas, heart, lungs, spleen and skeletal muscles.

**Clinical signs.** The disease is characterized by nonspecific symptoms correlated with larval migration and the pathogenic actions performed. The following occurs: depressed growth rate, loss of appetite, emaciation, stiffness and posterior paralysis, hematuria and eosinophilia.

**Pathology:** destruction of liver tissue, thrombosis of hepatic vessels, hepatic abscess, "milk spots" on the liver, liver fibrosis, cirrhosis, peritonitis, cystitis, congestion of the lung, mesenteric lymph nodes edema, necrotic spots on the kidney surface, fistulized nodules in perirenal fat and ureters.

**Diagnosis.** The clinical exam is valueless because of the nonspecific symptoms. Intra-vitam diagnosis is made by urine sediment examination, which reveals characteristic eggs. Necropsy allows highlighting of lesions and adults in and around the perirenal tissues.

***Differential diagnosis*** is required against *Dioctophyme renale*, leptospirosis and other kidney disorders in pigs.

**Treatment.** The following substances have demonstrated a good efficacy:

- doramectin, at the rate of 0.3 mg/kg bw, showed a 100% efficacy[510];
- ivermectin (300 micrograms/kg bw) demonstrated a 100% efficacy at 14 to 21 days after treatment[35].
- fenbendazole, mixed in feed at the rate of 3 mg/kg bw for 3 days, caused the disappearance of worms at 3 weeks post-treatment[36];
- levamisole at 10 mg/kg and flubendazole at 50 mg/kg in feed are effective against prepatent stephanurosis[257];

**Control.** Control of the disease is based on general sanitation measures and the management system. The hygiene measures target the shelters and their floors, watering and feed. The management system refers to gilt-only breeding system. It consists in the separate breeding of boars from the gilts that shall be kept for a single breeding cycle. After weaning of the piglets, sows will be removed from the premises. The prepatent period of S. dentatus ranges between 9 and 16 months, the interval in which a female will wean their piglets and will be removed from the stock before development of adult parasites, eliminators of eggs. Thus, after 3-4 seasons of farrowing, the disease will be eradicated, even in traditional extensive free range pig farms.

## 3.11. Crenosomatidae: crenosomosis in carnivores

The Crenosomatidae family includes five genera that contain parasites localized in the bronchi, frontal sinuses and veins of a large variety of mammals from the Carnivora or Insectivora orders and, rarely, marsupials. Family members are recognizable by the presence of a highly developed caudal bursa and vulva location in the median mid-region of the body. They are bio-helmints with gastropods as intermediate hosts and cause crenosomosis.

**Definition.** This is a nematodosis which manifests itself clinically through chronic tracheobronchitis. It is a cosmopolitan disease with local incidence, related to gastropods, IH.

**Etiology.** The *Crenosoma* genus contains several nematode species that inhabit the trachea, bronchi and bronchioles of their hosts, and which have a worldwide distribution or are limited to specific geographic regions:

- *Crenosoma vulpis* (syn. *C. decoratum*, *C. semiarmatum*) inhabit the bronchi and bronchioli of dogs (*Canis familiaris*) and wild carnivores: fox (*Vulpes vulpes*), gray fox (*Urocyon cinereoargentus*) and arctic fox

(*Alopex lagopus*), wolf (*Canis lupus*), coyote (*Canis latrans*), raccoon dog (*Nyctereutes procyonoides*), bears (*Ursus americanus*, *Ursus arctos*) and some mustelid species: Eurasian badger (*Meles meles*), Eurasian otter (*Lutra lutra*) and martens (*Martes martes*, *M. foina*, *M. zibellina*), worldwide;

- *C. goblei*, which parasitize the respiratory system of the raccoon (*Procyon lotor*);
- *C. melesi, in* the respiratory system of European badger, least weasel (*Mustela nivalis*), European polecat (*Mustela putorius*) and, possibly, other mustelid species;
- *C. schulzi*, found in the Eurasian badger;
- *C. petrowi* in the respiratory system of the marten (*Marten americana*), fisher (*Martes pennanti*), American badger (*Taxidea taxus*), and black bear (*U. americanus*);
- *C. potos*, in the black bear and kinkajou or "honey bear" (*Potos flavus*);
- *C. taiga* (syn. *C. mustelae*) in the European polecat, American mink (*Mustela vison*), wolverine (*Gulo gulo*), stoat (*Mustela erminea*), Siberian weasel (*Mustela sibirica*), beech marten (*Martes foina*), sable (*Martes zibellina*), least weasel, and European badger;
- *C. coloradoensis* from *Martes americana origenes* and *Martes caurina origenes*;
- *C. brasiliense*, parasite of the lesser grison, *Galictis cuja*, a mustelid from South America;
- *C. hermani* (syn. *C. schachnatovae*), from the American mink and stoat;
- *C. schulzi*, found in the Eurasian badger;
- *C. mephitidis* (syn. *C. canadensis*, *C. zederi* and *C. microbursa*) in different species or subspecies of the *Mephitis* genus, "skunks", (*M. mephitis*, *Mephitis m. nigra* and *Mephitis m. hudsonica*) in the New World;
- *C. striatum* in several species of hedgehogs: the European hedgehog (*Erinaceus europaeus*), the northern white-breasted hedgehog (*E. roumanicus*) and the southern white-breasted hedgehog (*E. concolor*);
- *C. lophocara* (syn. *C. caucasicum*), in the European hedgehog and northern white-breasted hedgehog;
- *C. skrjabini* in the Eurasian water shrew (*Neomys fodiens*) and shrew-mouse (*Sorex araneus*);

***Morphology*.** The morphology of the *C. vulpis* species is described, common in domestic and wild carnivores, worldwide. It has a small, slender, cylindrical body, equally calibrated and whitish, tapered at both ends. The cuticle is transversely striated giving the appearance of being encircled by horizontal lines or segmented to the anterior end[345]. Adult males measure 3.5 to 8 mm in length and 0.28 to 0.32 mm wide and females are 2 - 16/0.300 - 0.480 mm. At the posterior end, the male presents a well-developed and relatively wide copulatory bursa sustained by three groups of rays and two relatively long and thick spicules (0.35 - 0.40 mm). In females, the vulva is located near the middle of the body and its opening is surounded by two cuticular plates that form a wall.

Females are ovoviviparous, laying embryonated eggs, but in the respiratory tree or digestive tract tree they will hatch, so the first-larval stage will be directly removed in the environment through feces. The first-larval stage is a small larva with a cylindrical body, measuring 243 to 281/16 - 22 microns[344]. The anterior end is blunt and rounded; the tail is tapered, straight, pointed and is slightly deflected just before the tip[471].

***Life cycle*.** The life cycle is indirect, heteroxenous, requiring an intermediate host. Adult parasites are in the bronchi and bronchioles of carnivores and feed on local content, desquamated cells and exudates. The females lay embryonated eggs that hatch in the respiratory or digestive passage, the first-larval stage being removed through the feces. In the environment, $L_1$ search for an intermediate host, represented by a terrestrial gastropod (snail or slug). A wide variety of species belonging to a great number of genera

are suitable to be intermediate hosts for *Crenosoma* spp.: *Agriolimax*, *Arianta*, *Arion*, *Cepaea*, *Fruiticicola*, *Helix*, *Mesodon*, *Succinea*, *Triodopsis*, and *Zonitoides*. The $L_1$ larvae penetrate the muscular foot of a gastropod, molt twice and develop into infective $L_3$. The definitive host contamination is achieved by eating snails or slugs. Infective $L_3$ larvae penetrate the wall of the intestine and initially migrate through the lymphatic system. They reach the lymphatic vessels, mesenteric lymph nodes and thoracic duct. Now, they pass into the blood circulation, continuing through the vena cava to the right ventricle of the heart and finally to the lungs via the pulmonary artery. Migration through the hepatic portal system is possible. In the lung, $L_3$ stage moults twice resulting in $L_5$ subadults, which move up to the bronchi, where they turn into adults. The prepatent period ranges from 18 to 21 days. The life span of the parasite is 8 - 10 months.

Several paratenic hosts may intervene in the life cycle of *C. vulpis*, in a manner similar to *C. mephitidis*, in which the Pacific garter snake, *Thamnophis sirtalis infernalis*, preys on its intermediate hosts[248]. In their body, the $L_3$ larvae survive and remain infective. Similarities between *C. vulpis* and *C. mephitidis* allow the hypothesis that *C. vulpis* larvae may be able to infect similar poikilothermous paratenic hosts.

**Epidemiology**

***Geographical distribution*.** Crenosomosis is a cosmopolitan disease, its prevalence being correlated with the presence of definitive hosts, domestic or, especially, wild carnivores in the respective area and their interaction with the intermediate hosts. Dog and fox are the most important species involved in the parasite flow in nature. Different values of prevalence are recorded worldwide in these species.

In dogs, *C. vulpis* was detected in 27.3% by an antemortem survey and 3.2% by a postmortem exam during 1995 - 1996 on Prince Edward island[52]. In Germany, the prevalence was 0.36% in Bavaria[462], 0.9% from 1999 to 2002[30], 0.4% in the whole country between 2003 and 2010[28] or 7.4 % from September 2007 to March 2009[29] while other national studies reveal a value of 2.4%[528]. In Denmark 1.4% of dogs were found positive for *C. vulpis*[528]. In Italy, the first case of spontaneous *C. vulpis* infection in a dog was identified in 2007[432]. In Atlantic Canada (New Brunswick, Newfoundland, Nova Scotia and Prince Edward Island), crenosomosis was diagnosed in 20.7% of dogs[114].

The disease is considered endemic in the red fox, the prevalence determined in various studies being: 53.8% in Lithuania[82], 14.7% in Tuscany (central Italy)[329], 0.02% in Great Britain[361], 17.4% or 28.2%, respectively, in Denmark[448,588], 58% in Norway[132], 78.4% in Prince Edward Island[377], 50% in Romania[213], 24% in Hungary[504], 3.46% in Spain[8], 4.5% in the Netherlands[61] and 54.1% in New Brunswick and Nova Scotia, Canada[486]. Other species of carnivores in which infection was diagnosed are: the Eurasian badger (*Meles meles*) in Poland[405], raccoon dogs (*N. procyonoides*) in Lithuania (15.1%) and Germany[82], the coyote (*Canis latrans*) in Canada (19%)[80], the wolf, *C. lupus* in Latvia (9.1%)[20] and the arctic fox, *Alopex lagopus* on St. Lawrence Island, Alaska (4%)[414].

***Sources of contamination*** are the carnivores (foxes, especially) and terrestrial snails.

***Susceptibility*.** The foxes are the most susceptible, and within the species it is the youth between 6 and 12 months that is the most susceptible.

***Route of contamination*:** contamination is achieved orally by consumption of snails infected with the third-larval stage.

***Resistance*.** The $L_1$ larvae of the *Crenosoma* spp that are free in the external environment are considered highly resistant to the aggression of environmental abiotic factors, especially temperature. Larvae of *C. goblei*

found in raccoons can survive for up to 14 months at temperatures of -25°C[488].

**Pathogenesis.** The larvae, throughout their migration, exert a traumatic action causing tissue destruction on their route. It is associated with an inoculation effect taking pathogens from the gut. The inflammation action of the larvae consists in neutrophilic inflammatory lesions. Combined with the transport of bacterial pathogens from the intestine, it is responsible for developing pyogranulomas.

Adults in the lung exert a mechanical action, which consists in the obstruction of the bronchial lumen, and an inflammatory action, associated with bronchitis and bronchiolitis.

**Clinical signs.** Respiratory disorders such as moist productive cough, deep rasping accompanied by mucoid or mucopurulent nasal discharge, possible hemoptysis, wheezing, bronchial rales on auscultation and exercise intolerance, are common. The cough can be elicited by tracheal palpation. Bacterial superinfection may cause a complicated and severe evolution with the appearance of dyspnea and fever. The digestive symptoms as reduced appetite, retching and progressive weight loss, may appear. Hematological parameters may be normal, although mild eosinophilia, basophilia and mild monocytosis are common. A mild to moderate bronchial patterns that may have a diffuse interstitial component most evident in the diaphragmatic lobes may be observed on radiographs. The disease progresses chronic, without mortality in dogs[541], but it can be severe in foxes, with cough, anemia, emaciation, decreased fur quality and significant mortality.

**Pathology.** Migratory larvae cause small, white or yellow foci, necrotic areas and granulomas in liver, interstitial pneumonia, eosinophilic infiltration around bronchioles and occlusion of the bronchioles because of accumulation of moulting cuticle and infiltrated cells. Ecchymoses and gray nodules are visible on lung surfaces and interstitial pneumonia in the lung parenchyma. The adults cause erythematous bronchitis, marked bronchitis with accumulation of large amounts of mucus, irregular nodular mucosal surface, accumulation of pus and bronchial hemorrhage[548].

**Diagnosis.** Clinical and radiographic exam and transtracheal wash fluid examination are guidance methods. Examination of fecal samples with the Baermann technique allows the highlighting of $L_1$ larvae in feces, being the most effective method used in diagnosis of lungworm parasitic diseases. Necropsy is, also, an effective method allowing to see the lesions and adult parasites but it is a postmortem method.

***Differential diagnosis*** will be done for respiratory capillariosis, angiostrongylosis and filaroidosis.

**Treatment.** Broad-spectrum anthelmintics are used:

- fenbendazole at a dose rate of 50 mg/kg bw, daily, for 3 days exhibit a maximum efficacy[398];
- levamisole, 8 mg/kg bw eliminate 100% of the *C. vulpis*[513];
- levamisole and ivermectin have determined the disappearance of clinical signs in two, respectively other two dogs, within two weeks post-treatment[249];
- imidacloprid, 10 mg/kg bw combined with moxidectin at a dose rate of 2.5 mg/kg (Advantage Multi®/Advocate®) in a single topical treatment has shown an 100% efficacy against *C. vulpis*[115];
- milbemycin oxime at a dose rate of 0.5 mg/kg bw, four weekly oral doses, has healed 15 of 16 natural infected dogs[114];

**Control.** Preventive measures are applicable in silver fox farms and concern: sanitation conditions in shelters, cleaning and storage of manure for bio-thermal sterilization, quarantine of the newly introduced foxes with their parasitological control. Intensive farming of foxes in cages raised above the ground to prevent ingestion of snails and slugs is a

technological measure with high efficiency. Fighting against gastropods is more difficult, but it can be done with molluscicides preparations, on a certain area around the shelters. The removing of bushes, decayed wood, logs and dry leaves from farm grounds causes the disappearance of specific biotopes of intermediate hosts and contribute to gastropods elimination. Chemicals and snails traps may be additionally used to repel IH. Periodically chemoprophylaxis, quarterly realized, will protect dogs and foxes against natural infections.

## 3.12. Filaroididae: filaroidosis in dogs

Filaroides family includes abursate worms and seems to be related with the Angiostrongylidae family, which has several genera characterized by the presence of a small and atypical caudal bursa. Morphologically, it is characterized by the absence of the caudal bursa, small spicules, a terminally or sub-terminally placed vulva, and from a biological point of view it is an unusually varied family, the parasites being heteroxenous or monoxenous without IH. The systematics of the family has been extensively analyzed and reorganized over time. Seneviratna[463] has defined and reclassified this family into five subfamilies: Filaroidinae, Angiostrongylinae, Vogeloidinae, Oslerinae and Marsupostrongylinae. According to Anderson et al.[11], the family contains the following genera:

- *Filariopsis*, parasites of primates;
- *Oslerus*, parasites of canids and felids;
- *Oslerus* (*Oslerus*), new subgenus (n. subg.);
- *Oslerus* (*Anafilaroides*), n. subg.;
- *Filaroides*, parasites of terrestrial and aquatic carnivores, rarely primates;
- *Filaroides* (*Filaroides*), n. subg. (= *Pseudostrongylus*);
- *Filaroides* (*Parafilaroides*), n. subg.;

**Definition.** The disease caused by the members of the *Filaroides* genus is named filaroidosis. It is a bronchopulmonary nematodosis in domestic and wild carnivores that has a sporadic, benign, sometimes inapparent evolution, which is, however, severe in immunosuppressed young animals.

**Etiology.** The most important species are:

- *Filaroides hirthi*, found in the lung parenchyma of dogs, being potentially fatal in immunosuppressed animals;
- *Filaroides* (syn. *Oslerus*) *osleri*, causes nodules in the trachea and bronchi of canids (dogs, foxes, wolves, coyotes);
- *Filaroides* (syn. *Andersonstrongylus*) *milksi*, occur in nests in the bronchioles, bronchi and pulmonary parenchyma of dogs, hog-nosed skunks (*Conepatus leuconotus*);

Other species with particular hosts or geographical distribution are:

- *F. martis* (syn. *F. bronchialis*), parasite in the lungs and blood vessels of mustelids (*Mustela vison*, *M. lutreola*, *M. putorius*, *M. erminea*, *M. americana*), in which it is localized in theperibronchial nodules, at the pulmonary hilum;
- *F. canadensis* in otters (*Lutra canadensis*);
- *F. mephitidis* in skunks;
- *F. cebus*, *F. gordius*, found in the lungs of capuchin and squirrel monkeys;
- *F. pilbarensis*, found in Australian marsupials;
- *O.* (syn. *Filaroides*, syn. *Anafilaroides*) *rostratus*, may cause tracheobronchitis in felines (domestic cats, bobcats - *Felis rufus*);
- *O.* (syn. *Filaroides*) *pararostratus* causes nodules in the trachea of dogs;

***Morphology***.

*Filaroides hirthi* males measure 2.3 to 3.2 mm in length and females, 6.6 to 13.0 mm. The cuticle is inflated, forming a voluminous "teguminal sheath" (the outer cortical layer of the nematode's cuticle, according to Stockdale et al.[514]). At the anterior end, the oral opening is small, centrally placed and surrounded by 4

mound-like excrescences. At the posterior end, the male has two short and stout spicules and the caudal copulatory bursa is inapparent; the vulva, in females, is opened near the anus. The first larval stage removed through feces in the environment, measures 250 to 280 μm long and has a slight indentation and a very straight tail to its end[344].

*Filaroides osleri*: the male reaches 8 mm in length by 0.2 mm wide and females are 15 mm long. The caudal bursa is atrophied and the spicules are short and slightly unequally calibrated. The female is ovoviviparous. Eggs measure 80/50 μm, being embryonated and oval-shaped when are laid. The first-larval stage is cylindrical, 230-250 μm in length, and has a rhabditiform esophagus. The tail has a prominent constriction and is distinctly wavy after this point[344].

*Filaroides milksi* is very similar to *F. hirthi* but can be distinguished by its larger size and its shorter and more robust spicules, with developed knobs for the attachment of the retractor muscles.

***Life cycle.*** Adult parasites are localized in different segments of the respiratory tree: *F. hirthi* inhabits the lung parenchyma of canid species; *F. osleri* is localized in the trachea and major bronchi, in nodules situated at the tracheal bifurcation; *F. milksi* develops in the bronchioles and lung parenchyma of the diaphragmatic lobes. Parasites in these habitats feed on local content. The females are ovoviviparous and lay embryonated eggs that contain the first-stage larvae. Along the respiratory tree or digestive tract, after swallowing, the eggs hatch and $L_1$ larvae are shed in feces.

The infective stage of all three species morphologically described is the first stage larvae, and their life cycles are monoxenous. Contamination of the animals is different from one species to another. *F. hirthi* and *F. milksi* are transmitted through feces contaminated with the first larval stage while *F. osleri* contaminates the pups during the regurgitative feeding of the adults. Contamination with *F. osleri* is possible even with the first stage larvae obtained from nodules in the trachea and bronchi, "some hatched, others unhatched"[206]. Licking and cleaning of the pups imediately after birth is another way of contamination with *F. osleri*[145].

Autogenous re-infection with *F. hirthi* is possible. It consists in the re-invasion of the host realized by the first-larval stage, which moves from the lungs to the anus to be eliminated in the environment[208].

The first larval stage in the intestine penetrates the wall and migrates to the mesenteric lymph nodes and molts several times, generating the second, third and fourth larval stages ($L_2$, $L_3$ and $L_4$). Further, all larvae stages may migrate through the lymph nodes and liver to the lung, where $L_4$ completes the final molt, becoming $L_5$, young adults and, finally, the mature adults.

The chronobiology of the evolutionary stage of *F. hirthi* is characterized by the presence of $L_1$ larvae in the mesenteric lymph-nodes at 2, 4, 6, 8 and 24 h after infection, in the liver after 2 hours and, at 6 hours postinfection they already occur in the lung where they begin to molt after 24 hours. $L_3$ and $L_4$ larvae are present in the lymph nodes at 6 days postinfection[207]. The prepatent period varies around 5 weeks.

Other *Filaroides* species, such as *F. martis* or *F. rostratus*, require intermediate hosts in order to complete their life cycle. These IH are represented by snails (*Agriolimax*, *Arion*, *Succinea*, *Zonitoides*, *Monacha*, *Theba*), which consume the first-larval stage, and the infective $L_3$ stage develops in their body[10].

**Epidemiology**

***Geographical distribution.*** *Filaroides* spp. infections are widely distributed throughout the globe, different domestic and wild animal species being affected. The prevalence is variable from species to species and from one geographic region to another.

In dogs, the disease is diagnosed in a Beagle colony in Germany, where a prevalence of 98% was recorded[21], and in Italy, in the same breed (4.2%)[123]. Other affected species are: West Highland white terrier from Ireland[539], Scottish terrier in Spain[95], Pomeranian breed dog in Japan[295], and Miniature Schnauzer dog in USA[85]. The disease is registered in many other countries: Canada, Great Britain or the Netherlands[112,502,536].

In wild species, the disease was evidenced in coyotes (*Canis latrans*) in USA, where a prevalence of 17% was recorded in the Great Plains (eight central states: Oklahoma, Colorado, Wyoming, Iowa, South Dakota, Nebraska, Texas, and Kansas)[367], 18% in central Utah[116] and 22% in the southwestern USA[366]. In Canada, the prevalence varied from 15% in Alberta to 100% in Saskatchewan between 1975 and 1985[250,404,593].

In wolves, *F. osleri* is spread throughout North America: Minnesota (4%), Alberta (15%), Manitoba (8%)[87,250,453]. In Romania, the prevalence was 3.3% in both *F. osleri* and *F. hirthi* infections (personal unpublished data).

***Sources of contamination*.** In monoxenous species, the source is represented by diseased animals that pollute the environment with $L_1$ shed through feces. In heteroxenous species, terrestrial gastropods, IH, intervene as secondary sources. In the case of autogenous re-infection, the animal is its own source of contamination.

***Susceptibility*.** Responsiveness is influenced by multiple risk factors. Canids are the most susceptible followed by mustelids, felines being more resistant. Within the species, the breed seems to have a differential receptivity. The most responsive is the Beagle, followed by other small breeds such as Foxhound and Cocker Spaniel[593].

The immunosuppression condition with different causality is often involved. The evolution of the disease was recorded in association with canine distemper[96], adrenal cortical carcinoma[553], corticosteroid regimen imposed by other causes[204] or chronic stress caused by surgical interventions[17].

The ***route of contamination*** is oral, by ingestion of the first larval stage by coprophagy. The route in autogenous infections is not known.

***The resistance*** of the larval stages to the action of various ecological factors is not well known.

**Pathogenesis**. Both stages, larvae and adults, exert an irritative-inflammatory and mechanical action, which consist in the destruction of tissue on the migratory route and lung parenchyma. Consecutively, granulomatous reactions in the alveoli and bronchioles occur. The inoculation action of the larvae is responsible for fatal cases in animals with immunodeficiency.

**Clinical signs**. The disease progresses subclinically for a long time, especially in adult dogs, but pneumotharax may occur[85]. The animal becomes emaciated and will finally die.

In immunosuppressed puppies, severe pneumonia disorders occur: severe and rasping cough, dyspnea, tachypnea, abundant sero-mucous nasal discharge, hyperthermia, anorexia and anemia.

**Pathology**.

Depending on the species involved, the following lesions appear:

- the mediastinal and mesenteric lymph nodes are greatly enlarged in volume;
- tracheobronchitis with polypoid tumors at the bifurcation of the trachea caused by *F. osleri*;
- nodular pneumonia, atelectatic areas, granulomatous alveolitis and bronchiolitis produced by *F. hirthi* and *F. milksi* infections;

Bahnemann and Bauer[21] have differentiated four types of lesions:

- round, nodular subpleural foci, individual, blackish, 0.5-1 mm in diameter;

- round, whitish, raised foci, individual or in small groups, placed in the middle of the emphysematous areas, with a diameter of 1-2 mm;
- irregular, slightly round foci, glassy, white, with a gray-brown center, slightly blurred and 2 to 10 mm in diameter;
- confluent foci, white-reddish, mottled, the area measuring up to 14 mm in diameter , with a coarse consistency;

Histopathology consists in discrete granulomas, peribronchiolitis, perivasculitis, interstitial pneumonia, pleural and interstitial fibrosis, epithelial hyperplasia, and squamous metaplasia[247].

**Diagnosis.** Clinical signs are indicative, many other diseases of carnivores being expressed by respiratory symptoms.

Coprological examinations via the Baermann method are less useful because of the low motility of *Filaroides* spp. larvae. For this reason a zinc-sulfate flotation technique is used.

Necropsy allows one to see the lesions of the lungs and the nodules at the tracheal bifurcation or in the bronchioles. Bronchoscopy and thoracic radiography may also be useful diagnostic aids.

***Differential diagnosis*** includes other respiratory helminthosis, bacterial, viral or *a frigore* pneumonia.

**Treatment.** The following are used, with good results:

- ivermectin at a dose rate of 0.2 mg/kg bw has a high efficiency causing the dissapareance of symptoms within a fortnight[55];
- fenbendazole, 50 mg/kg bw, per os, daily, for 14 days or three weeks, cleared a dog of infection[400,95];

Other therapies are based on the use of levamisole, thiabendazole, oxfendazole, albendazole and doramectin[74,196]. All these therapeutic protocols have variable rates of success, some of them requiring high doses or long periods of administration.

**Control**.

General measures of sanitation and frequent removal of feces from cages are indicated. Mollusk control for heteroxenous species, with copper sulfate, is useful. Infected adult dogs should be treated before their incorporation into the breeding program, or euthanized. Filaroide-free pups should be separated from adults and kept in conditions whereby the possibility of contamination is avoided.

A chemoprophylactic control program may be applied in kennels. It is based on the use of albendazole in all stud dogs and all nonpregnant, nonlactating brood bitches. The dose rate is 25 mg/kg bw, per os, twice daily for 5 days, for two periods at a 2-4 week interval between them. This program has reduced the mortality in two kennels from 45% and 78% before, to 0.2% and 24% after its application[173].

## 3.13. Angiostrongylidae

The Angiostrongylidae family includes a large variety of lungworms characterized by the presence of a typically well-developed, or, on the contrary, reduced caudal copulatory bursa and a vulva placed at the posterior end, near the anus. They are biohelminths, their life cycle involving gastropods as intermediate hosts. They affect marsupials, insectivores, rodents and carnivores.

The family contains an unclear number of genera, varying between 7 and 20, because some authors may prefer to recognize genera or subgenera. *Angiostrongylus* and *Aelurostrongylus* are important genera, from the point of view of veterinary medicine.

### 3.13.1. Angiostrongylosis in dogs

The *Angiostrongylus* genus includes parasites of rodents and carnivores which inhabit the lung and pulmonary or mesenteric arteries of their hosts. It comprises around 19 species, recognized worldwide. Morphologically, they are characterized by a well-developed caudal,

bursa, set off from the body, with long or short spicules, with a vulva and an anus which is not placed terminally, and perianal papillae.

**Definition.** Angiostrongylosis is an emerging bio-helminthosis of dogs and other canids, expressed by respiratory and cardiovascular disorders. The disease is widespread, but in Europe its incidence is higher in the southern regions. It is caused by infection with *Angiostrongylus vasorum*.

**Etiology.** The genus is divided into two major clades based on molecular differentiation. The first clade includes *A. cantonensis* and *A. malaysiensis* while the second contains *A. costaricensis* and *A. vasorum*[157]. The disease is caused by *Angiostrongylus vasorum* which is called "the French heartworm" in the United Kingdom, because it was discovered in France at the begining of the 19$^{th}$ century.

***Morphology*.** The adults have a cylindrical, slender, pinkish body, and the sizes are 14-16/0.25-0.42 mm in the case of males and 15-21/0.28-0.56 mm in the case of females. The aspect of the body is similar to that of *Haemonchus contortus*, having a "barber pole" appearance because of the white reproductive tract that is intertwined with the red intestine[58]. The anterior end is simple, with an oral opening without labia. At the posterior end, the males have a well-developed bursa, and two long spicules, while the vulva is placed in the posterior half of the body.

The first larval stage is cylindrical, coiled, rarely straight, with sizes ranging from 310 to 400 μm long and 14 to 16 μm wide[437]. The tail is sharply pointed and has a distinct notch on the dorsal surface and a secondary, much smaller indentation on the ventral side. The larvae do not have a distinct cephalic knob on their head[344].

The ***life cycle*** is heteroxenous and indirect, involving an intermediate host, represented by the terrestrial and aquatic snails or slugs. Unnecessary paratenic, or transport hosts, such as frogs (*Rana temporaria*), may be involved in the life cycle. The adults inhabit within the pulmonary arteries and heart of the canids. The females lay eggs that are transported via the bloodstream to the lung capillaries where they develop and the first larvae $L_1$ are released. These larvae penetrate the walls of capillaries and alveoli, entering into the lower level of the respiratory tree. Further, they move through the bronchioles, bronchi, and trachea to the pharynx where they are swallowed and excreted in the environment by the feces. Thereafter, the first-larval stages from the environment contaminate their intermediate hosts, either by active penetration of the muscular foot, or by being ingested by the host when it feeds. A large number of genera are involved as IH: *Arion*, *Arionater*, *Deroceras*, *Limax*, *Helix*, *Biomphalaria*, *Bradybaena*, *Laevicaulus*, *Prosoples*, *Achatina* and *Subulina*[224]. Inside the gastropod, the larvae molt twice and develop into infective $L_3$ larvae, phenomenon influenced by several factors such as temperature, host species and age[368]. Contamination of canids occurs by ingestion of an infected intermediate or paratenic host. The third larvae ($L_3$) may leave the body of IH and then contamination is direct[23]. After contamination, the $L_3$ larvae penetrate the wall of intestines and migrate to the mesenteric lymph nodes where they molt twice and develop into immature $L_5$ adults. The juvenile $L_5$ will continue their migration via the portal system through the liver and caudal vena cava to the right ventricle and pulmonary arteries, where they develop into mature adults. The prepatent period varies between 28 to 108 days[58] and, once infected, an animal will excrete larvae throughout its entire lifespan[363].

**Epidemiology**

***Geographical distribution*.** The disease is spread in regions with a wet and mild climate, favorable for IH development. It is widely distributed in Europe, North and South America and Africa. In Bavaria, Germany, a prevalence of 7.4 % and 0.36% was recorded

in dogs[29,462]. In other European countries, the prevalence in dogs was 4.0% in England[338], 2.2% between 2003 and 2007, or 3.5% and 9.8% in Denmark[528,563,540] and 1.1% in Greece[390]. In foxes, the prevalence varied between 5.0% in Hungary[504] and 92.9% in Denmark[540]. In the Avalon peninsula of Newfoundland, Canada, the prevalence was 7.92%, 16 of the 202 dogs being positive[114].

***Sources of contamination*** are the diseased foxes and dogs, or those with a latent form, on the one hand, and the intermediate or paratenic hosts, on the othe hand.

***Susceptibility*.** Domestic dogs (*Canis familiaris*) and red foxes (*Vulpes vulpes*) are the most important and common definitive host for *A. vasorum*. The disease was also diagnosed in other species: crab-eating fox (*Cerdocyoun thous*), hoary fox (*Dusicyon vetulus*), wolf (*Canis lupus*), European badger (*Meles meles*), European otter (*Lutra lutra*), ferret (*Mustela putorius*), coyote (*Canis latrans*), domestic cat (*Felis domesticus*) and it was transmitted experimentally in the jackal (*Canis aureus*), Nile rat (*Arvicanthis niloticus*) and in the African desert fox (*Fennecus zerda*)[58,268]. Responsiveness is increased in young canids.

***Route of contamination*:** ingestion of intermediate gastropod host containing $L_3$ is the most important route of contamination. Ingestion of $L_3$ liberated from the body of IH is another possibility. Ingestion of paratenic hosts may intervene as a third way of contamination.

***Resistance*.** This species is sensitive to variations in ambient temperature. Thermal tolerance limits vary between -4°C and +18°C[268,59].

**Pathogenesis.** Immature adults exert an inflammatory action which elicits a response of the lung parenchyma consisting in foci of interstitial pneumonia. Irritations of the arterial walls consist of coagulopathies. Mechanical traumatic action is expressed by tissue destruction and hemorrhage on the migration routes, particularly in the lung. Aberrant migrations of adult worms and larvae in the eye, brain, spinal cord, left ventricle, femoral artery, intestine, liver, pancreas, skeletal muscle have been recorded. Inoculated microbial flora may complicate the inflammations, causing pneumonia and bronchopneumonia.

**Clinical signs.** The clinical signs vary greatly from a subclinical form to a fatal condition, and it is possible for the signs to remain unnoticed for months or years. The clinical symptoms are respiratory distress, dyspnea, coagulopathies, edema, cardiac failure, coughing, nasal discharge, gagging, depression, ataxia, unilateral central blindness, epileptic seizures, various cranial nerve deficits, vestibular signs, proprioceptive deficits, ataxia and paraplegia, subcutaneous hematomas, melena, haemoptysis, vomiting, anorexia, weight loss, stunted growth and reduction of exercise tolerance[58,294,135,223].

**Pathology.** The lesions are very diverse and consist in interstitial pneumonia, pulmonary hemorrhage, fibrosis and granulomas, hydrothorax, hemothorax, thrombotic endarteritis and occlusion of the pulmonary artery, hydropericardium, glomerulonephritis with mild granulomas in the kidneys, ascites, haemorrhagic diatheses (petechiae, ecchymoses, hematomas and bleedings in abdominal and thoracic cavities), subdural hemorrhage, uveitis[381,413,58].

**Diagnosis.** Clinically, the dominance of cardiovascular and pulmonary disorders is indicative. The Baermann test is widely used for fecal examination, being simple and rapid. Because the shedding of larvae is intermittent, samples from three consecutive days should be tested. The first-larval stage can also be highlighted by tracheal wash, bronchoalveolar lavage, fine needle lung aspirates and by routine urine analysis. Thoracic radiographs assess the severity of the infection but do not clarify the etiology. Necropsy allows highlighting of the lesions and adult parasites.

Molecular techniques (PCR) and serology (ELISA and Western blot analysis) have been used, with elevated sensitivity and specificity, to identify the parasites.

***Differential diagnosis*** includes: dirofilariosis - more serious circulatory symptoms and the presence of microfilariae in the blood; spirocercosis - esophageal and gastric disorders; filaroidosis - predominantly pulmonary disorders and the larvae may be microscopically differentiated; heart failure and pneumonia with a different etiology.

**Treatment.** Thiazole derivatives, benzimidazole and avermectins are used. The literature recommended the followingeffective drugs:

- levamisole at a dose rate of 7.5 mg/kg bw for 2 days, then 10 mg/kg for 2 days expressed a 100% efficiency[489];
- fenbendazole, 50 mg/kg bw for 5–21 days had an 80% efficacy[103];
- ivermectin, 0.2 mg/kg sc, weekly, for 4 weeks, healed all diseased animals[70];
- milbemycin oxime, 0.5 mg/kg bw weekly, four times, expressed a 93.75% efficacy[114];
- imidacloprid 10% associated with moxidectin 2.5%, 0.1 ml/kg, single topical dose, has shown an 85.1% efficacy[579];

**Control** of the disease is based on prophylactic anthelminthic treatment. Environmental contamination may be avoided by removing the dog's feces, which also stops the lifecycle of *A. vasorum*. Removal of snails and slugs in recreational areas intended for dogs by the use of molluscicides is not feasible, being risky for other components of the flora and fauna. Isolates of *Duddingtonia flagrans*, *Monacrosporium thaumasium*, *M. sinense* and *Arthrobotrys robusta* fungi, are efficient in the capture and destruction of *A. vasorum* $L_1$ in the environment[76,77]. Dog owners' awareness and periodic Baermann tests in areas with a high risk of the disease may reduce its prevalence.

### 3.13.2. Aelurostrongylosis in cats

The *Aelurostrongylus* genus belongs to the family of Angiostrongylidae and is characterized by a significantly reduced caudal bursa as compared to the *Angiostrongylus* genus, stout spicules and a vulva and anus not placed terminally. It comprises parasites of the lungs of felids, mustelids and rodents.

**Definition.** It is a bio-helminthosis that affects mainly stray cats, espressed by a chronic respiratory syndrome, but it is sometimessubclinical. It is particularly prevalent in Europe and North America.

**Etiology.** The disease is caused by *Aelurostrongylus abstrusus* (the cat's lungworm), a parasite of the bronchioles and alveolar ducts of domestic cats. Other important species of the genus are *A. falciformis* which occurs in the lungs of badgers (*Meles meles*) in Europe and, *A. pridhami* having the same habitat, in wild mink (*Mustella vison*) in North America.

***Morphology*.** Parasites have a cylindrical body and measure between 4 to 7 mm long (males) and 9 mm (females). At the posterior end, males have a small copulatory bursa without distinct lobes, but with visible rays. Spicules measure from 100 to 130 μm and are sub-equal. The vulvar opening is placed in the posterior half of the body. Eggs are sub-spherical and measure 80 x 70 μm. The sizes of $L_1$ larvae range from 300 to 390 μm long and 20 μm wide and have an undulating and notched tail with a dorsal spine[484].

***The life cycle*** is indirect, involving slug and snail species as intermediate hosts. In addition, many paratenic hosts, represented by rodents, frogs, lizards, snakes or birds, may be involved. The adult parasites live in the lung, located in the terminal respiratory bronchioles, alveolar ducts and pulmonary alveoli. Oviparous females lay eggs that embryonate and hatch in the lungs. The first-stage larvae are liberated in the airways, and pass out in feces. They penetrate IH

(*Agriolimax*, *Helminthoglypta*, *Helix*, and *Acathina*) and develop into the infective $L_3$ stage following two successive molts. Cats are infected by eating intermediate or, perhaps frequently, paratenic hosts. Endogenous migration is incompletely known, but the larvae enter into the lining of the digestive tract at different levels (esophagus, stomach, intestine). In 8 to 9 days pi, after two molts, the adults are fully developed. The prepatent period varies between 33 and 36 days, rarely reaching 60 days. The lifespan of adult parasites reaches 2 years.

**Epidemiology**

***Geographical distribution*.** The disease has a cosmopolitan distribution even if it is considered a sporadic disease. Data regarding its geographic prevalence is listed in table 13.

***Sources of contamination*** are the infected animals that pollute the environment and the intermediate and paratenic hosts, which infect the cats. Infected cats may produce eggs for over one year, the peak occurring 60-120 days postinfection[430].

**Table 13.** Geografical distribution of aelurostrongylosis

| Country | Region / period | Prevalence (%) | Author |
|---|---|---|---|
| Albania | Tirana area / 2008-2009 | 50.0 | Knaus et al., 2011 |
| Argentina | Buenos Aires / 2005 | 2.6 | Sommerfelt et al., 2006 |
| Australia | Christmas Island | 25.0 | Adams et al., 2008 |
| | Victoria, New South Wales | 14.0 | Coman et al., 1981 |
| Brazil | Cuiabá, Mato Grosso | 1.37 | Ramos et al., 2013 |
| Colombia | Quindío Province / 2008 | 0.82 | Echeverry et al., 2012 |
| Croatia | Zagorje – Zagreb / 1990-1998 | 22.0 - 0.38 | Grabarevic et al., 1999 |
| Germany | 2003–2007 | 5.6 | Taubert et al., 2009 |
| | Lower Saxony / 2006-2007 | 1.0 | Becker et al., 2012 |
| | 2009-2011 | 6.6 | Barutzki and Schaper, 2013 |
| | 2003-2010 | 0.5 | Barutzki and Schaper, 2011 |
| Hungary | western Hungary / 2011 | 14.5 | Capári et al., 2013 |
| Italy | Abruzzo, Marche, Apulia | 17.6 | Traversa et al., 2008a |
| | central Italy | 16.0 | Iorio and Traversa, 2008 |
| | Marche, Abruzzo, Apulia / 2009-2010 | 8.54 | Di Cesare et al., 2011 |
| | Pisa district, Tuscany / 2008-2010 | 1.2 | Riggio et al., 2013 |
| | Milan / 2008-2010 | 2.9 | Spada et al., 2013 |
| | Rome, Lazio region | 18.3 | Traversa et al., 2008b |
| Holland | | 2.6 | Robben et al., 2004 |
| Portugal | Porto / 2003-2005 | 17.4 | Payo-Puente et al., 2008 |
| | Lisbon / 2009-2011 | 12.4 | Waap et al., 2013 |
| Qatar | Corniche, Al-Matar, Al-Sadd / 2005 | 7.5 | Abu-Madi et al., 2007 |
| Romania | Transylvania / 2007-2009 | 5.6 | Mircean et al., 2010 |
| Spain | North – Central | 2.0 – 4.3 | Miró et al., 2004 |
| USA | New York / 2006-2010 | 6.2 | Lucio-Forster, Bowman, 2011 |
| | New York / 2009-2010 | 9.0 | Gerdin et al., 2011 |
| | Alabama | 18.5 | Willard et al., 1988 |

***Susceptibility***. Domestic cats (*Felis catus*) are susceptible, the kittens being the most sensitive. Infection is also diagnosed in wild felid species such as the Siberian tiger (*Panthera tigris altaica*), the Amur cat (*Felis bengalensis euptilurus*), the Eurasian lynx (*Lynx lynx*) and the wildcat (*Felis silvestris*)[218,518,519] (personal unpublished data).

An outdoor lifestyle, the environment (rural or urban area), the presence of respiratory symptoms with a different etiology, and young age are risk factors which favor the disease, increasing the receptiveness of the animal[545,356].

***Route of contamination*** is oral, by eating infected intermediate or paratenic hosts.

***Resistance*** of the exogenous larvae is superposable over that of snails, IH, temperature being the limiting factor. The optimal tolerance interval varies between 18.8 and 29.5°C when 50% of larvae of *A. abstrusus* reached the infective stage, while only 17.8% developed at temperatures of 6.7–22°C[136].

**Pathogenesis.** The inflammatory action exerted by the eggs shed in the bronchioles and the migration of the first stage larvae ($L_1$) up the bronchial tree is expressed by lesions in the alveoli, bronchioles and local arteries[541]. Inoculation of bacteria by the larvae in their migration is evidenced in the case of secondary pneumonia following gastro-intestinal salmonellosis[26]. Adults, by their mechanical action, may cause an obstruction of the bronchiolar lumen and compensatory emphysema.

**Clinical signs.** Often, infection with *A. abstrusus* is clinically unapparent. In its mild form, respiratory symptoms may appear and disappear gradually or suddenly. However, cough, sneezing, mucopurulent nasal discharge, reddish sputum, dyspnoea, tachypnea, open-mouthed abdominal breathing, bronchial crackles, heart murmur, loss of appetite, even anorexia, weight loss, adynamia, and even death are common clinical signs.

**Pathology**. The parasite causes nodular pneumonia with greyish, raised subpleural nodules, 1-10 mm in diameter, releasing a milky exudate rich in eggs and larvae, when incised. The nodules may coalesce, causing large foci and confluent areas of consolidation[99]. These areas may calcify in chronic infections. Other lesions are: bronchiolitis and peribronchiolitis, frothy fluid in the lumens of the trachea.

**Diagnosis.** Clinically, the disease is suspected in patients with pulmonary syndrome. Microscopic methods (Baermann, sedi-mentation-flotation with zinc sulphate solution) allow the identification of the larvae in feces based on morphological characters. Necropsy reveals nodular pneumonia.

Other methods of diagnosis are: stereo-microscopic examination of bronchoalveolar lavage (BAL) fluid, cytologic examination of BAL, thoracic computed tomography, angiographic computed tomography, thoracic radiographs, histologic examination of lung tissue, serology (ELISA), molecular biology (PCR). The Baermann technique is considered the most sensitive test for the detection of the *A. abstrusus* infection[308].

***Differential diagnosis*** includes afrigore pneumonia, tuberculosis, pleurisy and other cardiorespiratory nematodosis.

**Treatment** is based on benzimidazole derivatives and avermectines. The following substances and commercial drugs are used:

- fenbendazole, a granulated formulation of 22.2% active substance, at a dose rate of 50 mg/kg-bw/day, 3 days, caused a temporary decrease in the number of *A. abstrusus* larvae[434];
- imidacloprid 10% / moxidectin 1% (Advocate®, Bayer) according to label instructions, cause a 100% reduction of larval counts[543];
- emodepside 2.1% / Praziquantel 8.6% spot-on (Profender®, Bayer), administered

once at the licensed dose demonstrate an efficacy of 99.38% against *A. abstrusus* infection[544];

- ivermectin, 200 micrograms/kg bw followed by a second treatment at a dose rate of 400 micrograms/kg bw eliminated infection with *A. abstrusus*[289];
- selamectin 45 mg (Stronghold®, Pfizer), two spot-on administrations, 23 days apart expressed an efficacy between 59% and 98%[259];

**Control**. There is no effective protocol to prevent infection of cats. It is impossible to control the snail populations in the environment. Chemoprophylaxis would probably be effective, but it is uncommon in veterinary practice.

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# 4. Strongyloidoidea

The Strongyloidoidea superfamily is included in the Rhabditida order, Cephalobina suborder and is divided in three families, more or less: Steinernematidae, Rhabdiasidae and Strongyloididae. The inclusion of two other families, Panagrolaimidae and Alloionematidae, in this superfamily, is controversial; there is also the version of the superfamily Panagrolaimoidea as systematic taxa in which they are comprised.

It comprises parasites characterized morphologically by a mouth opening without processes of the lips, an amphidelphic and didelphic reproductive apparatus in females and a monorchic one in males, which have no copulatory bursa. The cuticle has narrowly spaced striations. In terms of life cycle, they are parasites of insects and other animals characterized by the presence of the "Dauer" stage. This is an arrested development stage which develops as a response to harsh environmental conditions[29,30].

This taxon represents a group of nematodes, zooparasites and zoopathogens, of which the most important from a medical veterinary point of view is the genus *Strongyloides*, whose members cause strongyloidosis.

Its name is derived from the Greek, in which *strongylos* means round and *eidos* shape, which etymologically means round shape and refers to the cylindrical body of parasites.

## 4.1. Strongyloidosis in animals

The family Strongyloididae consists of heterogonic parasites (a generation of parasites is followed by a free-living generation). According to Anderson et al.[1], the family includes three genera: *Parastrongyloides*, *Leipernema* and *Strongyloides*, the last comprising species that are important to human and animal health.

**Definition**. The disease is a zoonosis caused by nematodes from the genus *Strongyloides*, which manifests itself clinically by skin, respiratory and digestive disorders in young animals, poorly maintained in terms of hygiene and food. It is a cosmopolitan disease, spread around the globe, with an uneven distribution depending on the conditions and level of social life and the development of animal husbandry. The incidence of the disease in humans is higher in tropical areas, but in animals it is also frequent in temperate conditions.

**Etiology**. The *Strongyloides* genus contains approximately 50 species, widely prevalent, parasites of the gastrointestinal tract in mammals, birds, reptiles or amphibians[56]. The most important species in veterinary medicine are:

- *S. stercoralis*, parasitizing the intestine in humans, primates and dogs;
- *S. fülleborni*, common species in chimpanzees and baboons, may cause infections in humans;
- *S. ransomi* is an important parasite of piglets in tropical areas;
- *S. westeri*, parasite of the small intestine in foals, zebra and, possibly, pigs;
- *S. papillosus*, is the common species of large and small ruminants, but can be found in the gut of pigs, rabbits, and rats;
- *S. myopotami*, located in the gut of coypu, better known for the skin disorders it causes;
- *S. martis*, detected in the small intestine of mustelids, considered to be a synonym of *S. mustelorum*[26];
- *S. ratti*, a common nematode of the rat's digestive tract;
- *S. avium* affects birds, domestic and wild fowls, localized in the caecum and small intestine;

***Morphology***. Parasitism is only achieved by parthenogenetic females capable of mitotic reproduction, without males.

Morphologically, they have a small cylindrical body with lengths ranging between 2 and 7 mm and 0.05-0.06 mm in diameter. At the posterior end, it has a blunt-ended tail. At the anterior end, it has a very small buccal

capsule, also called the stoma, whose morphology is a criterium for species identification.

The stoma of the *Strongyloides* genus, in the apical view, can have four distinct forms depending on the name, number, size, shape and attachment site of submarginal and/or intra-stomal linguiform or verruciform projections: simple, angular (*S. martis*), complex (*S. papillosus* and *S. myopotami*), and simple but with esophageal teeth (*S. ransomi*)[50].

The esophagus is observed through the transparent cuticle. It is elongated, straight-sided (filariform) measuring 0.6-0.8 mm in length, extended throughout the anterior third of the body[55,56]. The vulvar opening is placed at approximately two thirds along the body length, in the anteroposterior direction. The females do not contain male gonads and there are no male parasites.

The females are ovoviviparous; the typical egg is oval-shaped, has a thin shell and is embryonated when shed, measuring 40-60 x 20-36 μm in size. It contains a larva folded on itself, with a "U-shaped" appearance.

***Life cycle***. Members of the genus *Strongyloides* have a particular life cycle in which parasitic parthenogenetic females and environmental free stages, males and females, succeed. The exogenous phase may evolve in two ways: heterogonic, when free-living adults and sexual reproduction are developed, and homogonic, when direct infective $L_3$ larvae are formed. Control of this differentiated exogenous evolution is achieved by extrinsic factors, with particular reference to ambient temperature and oxygenation, or by intrinsic factors, involving the immune status of the host and nervous system of the larvae[54]. The eggs shed by parthenogenetic females may evolve as males, females or infective $L_3$ larvae. Exogenous temperature influences the development of female progeny or infective $L_3$ larvae while the immune status determines the evolution of male progeny. Ambient temperature, around 20°C, variable from species to species, is the limit of differentiated evolution. Below 20°C, mainly infective $L_3$ larvae will develop, the cycle being homogonic, and above 20°C, preponderantly females will evolve. In immunologically intact animals, most of the larvae will develop into males. In previously infected animals, which have an enhanced immune response, more larvae develop into free-living males than in naïve animals, for all *Strongyloides* species[15,54].

Immunosuppression of the host reduces the proportion of larvae that develop into free-living males[20].

Environmental oxygenation and thickness of the feces layer also influence the way of exogenous development. Females develop only under semiaerobic conditions in the thick smears or overlaid feces. If these conditions are lacking, the $L_1$ larvae, initially hatched, will become infective filariform $L_3$ larvae[19].

Intrinsec control of the pathway of the free-living stages is also realized by the two classes of neurons placed on amphidia of larvae, ASF and ASI, which act together[3].

Parasitic females develop in the mucosal lining of the proximal part of the small intestine in hosts where they feed on the tissue of the internal organs, which include the intestines and the lungs. They lay embryonated eggs which are passed in the feces. In the external environment, the eggs hatch and release the first-stage larvae ($L_1$). They may develop into infective third-stage larvae ($L_3$), below 20°C (homogonic cycle), or into free-living males and females (heterogonic cycle), above 20°C.

The homogonic (or direct, or asexual) evolution consists in $L_1$ molting twice via $L_2$ into the infective filariform $L_3$ stage. The heterogonic (or indirect, or sexual) cycle consists in three successive molts of $L_1$, resulting in $L_2$-$L_4$ stages and, finally, rhabditiform mature males (haploid) and females (diploid), which represent the free-

living adult generation. The males copulate females and these will lay eggs which hatch and release a new generation of $L_1$. These larvae molt twice, turning into filariform infective $L_3$ stages, i.e., contaminant elements. The $L_3$ larvae leave the mass of feces in which they have evolved and move away. This behaviour enhances their chance to find a host. The majority of *Strongyloides* spp. beget only one free-living generation; however, up to nine generations are possible.

The animals become contaminated, through multiple ways: percutaneously, perorally, transmammarily (galactogenic), transplacentally or by autoinfection. The most common is the penetration of skin (percutaneously) by infective $L_3$ larvae.

Multiple ways of internal migration are also possible, varying from one species to another. The following have been confirmed:

- percutaneous contamination and lung migration through blood circulation in *S. stercoralis* and the majority of *Strongyloides* species. The $L_3$ larvae penetrate the blood capillaries in the skin and migrate to the heart through the posterior vena cava or hepatic portal system, right ventricle, pulmonary artery, lung parenchyma, alveoli, where they break their wall and go out into the respiratory tree. They move up the trachea and pharynx and will be swallowed, thus reaching the intestine;
- oral contamination is performed during feeding with milk or by fodder. The larvae pass through the mouth and penetrate the mucosal lining of the pharinx or esophagus (being destroyed by gastric secretions). They reach the lungs migrating through the bloodstream. After that, via the bronchi, trachea and pharynx, they are swallowed and reach the intestine;
- migration through muscle tissue - is demonstrated in *S. venezuelensis* in rodents, where larvae were found in muscles after percutaneous infection[65];
- migration through the naso-frontal region (confirmed for *S. ratti* $L_3$ larvae), from where they are presumably swallowed and reach the intestine[66];
- transmammary contamination is favored by the dormancy state or arrested development of $L_3$ larvae. It presumably consists in stopping the migration through the mammary gland and the larvae will stay in hypobiosis until lactation. During lactation, the larvae re-activate and continue their migration to the newborns. This stage is evidenced in almost all species which affect domestic animals, *S. ransomi*, *S. westeri*, *S. papillosus*, *S. stercoralis*, in *S. fuelleborni* of humans, several species affecting livestock and *S. ratti*, *S. venezuelensis* in rats[2,25,32,36,52,61,69]. Nevertheless, transmammary contamination is demonstrated in dog and foal;
- several authors proposed transplacental transmission in order to explain the early infections in young newborn animals[11,62]. It is demonstrated in pigs infected with *S. ransomi*[61];
- autoinfection is an interesting way of contamination in which eggs hatch and the first-larval stage develops in the gut. Filariform $L_3$ infective larvae develop in the intestine and later invade the intestinal mucosa or perianal skin, and perform a lung migration before establishing themselves in the intestine;

During all these migrations, $L_3$ molt once resulting in $L_4$ and, finally, in mature females. The prepatent period is variable from one species to another, the interval ranging from 3 to 17 days.

**Epidemiology.** Three major mechanisms are involved in the epidemiology of infection. These include the existence of free-living heterogonice stages that ensure the survival of non-parasitic forms for a while, multiple routes of contamination, and a very short prepatent period.

***Geographical distribution***. In the context mentioned above, *Strongyloides* spp infections have a worldwide distribution.

Regarding the infection with *S. ransomi*, in Europe it has been diagnosed in former Czechoslovakia (0.7%)[27], Romania (20% breeding sows, 8-20% weaned piglets, 2.5-5% fatteners, personal unpublished data), but it was found to be lacking in piggeries in the Netherlands[14]. In the Nordic countries (Denmark, Finland, Iceland, Norway and Sweden), the overall prevalence has recorded low values, ranging from <0.1% to 3.5% in boars and fatteners. The infection was not diagnosed in Finland, while Iceland is at the opposite end of the scale, with high values, ranging between 4.4% and 11.8% in lactating sows and in weaners[48].

*S. stercoralis* is present in all tropical and subtropical regions of the world but several areas of low endemicity are spread in countries of Europe (Italy, France, Spain, Switzerland, and Poland), the United States, Japan, and Australia. It can also occur in temperate climates. It is primarily spread in areas rich in dogs, where humans and animals frequently interact. In North America, it is found especially in large cities, but a high prevalence is also recorded in Asia, Africa, South America, and in parts of the former Soviet Union[47].

*S. papillosus* is distributed worldwide, particularly in warm, humid areas.

*S. avium* is spread in tropical and subtropical areas, preferentially in Africa, recording a low prevalence of 2% in Ghana[43], 9.96% in Kenia[22], 1.1% in Uganda[57], 11.1% in Nigeria[6] or 67.7% in roosters and 53.3% in hens, in Malaysia[44].

*S. westeri* is spread throughout the world, registering a prevalence of 1.5% in foals in central Kentucky and Pakistan[33,49], 7.2% in horses and 12.34% in donkeys in Turkey[68], 6.05% in the Sudano-Guinean climatic zone of Cameroon[28], 17.2% in North Gujarat, India[42] or 20% in Southern Ethiopia[40].

The data set out above demonstrates that the species of the *Strongyloides* genus are spread mainly in tropical and subtropical regions characterized by warm weather and moisture.

The ***sources of contamination*** are the parasitized animals, sometimes humans, fodder and litter containing $L_3$. Mechanisms of dissemination of the parasites amplify during spring and autumn when the exogenous parasitic cycle occurs directly. The amount of environmental pollution in infected foals can reach 30.000 fecal EPG[12,51], then it can decrease to under 17.000 EPG. Farming of young animals (piglets, lambs, calves) in unsanitary shelters with wet floors stimulates the appearance and severe evolution of the disease.

***Susceptibility*** of animals depends on multiple intrinsic (species, sex, age, breed, pregnancy) and extrinsic (management, climate, malnutrition, evolution of other diseases and parasite control program) factors[49,5,69]. The youth of all species, especially piglets, calves and foals, in the first months of life, is very vulnerable. Males seem more susceptible than females, but data obtained worldwide, especially in the case of horses, does not confirm this. The breed also plays a role in the different levels of sensitivity to infection. *S. ransomi* evolve more severely in the Hampshires breed, intermediate for crossbreds, and least severely for Durocs[24].

***Routes of contamination*** are: percutaneous, peroral, transmammary, transplacental and autoinfection.

***Resistance***. Temperature, humidity and direct sunlight are the environmental factors that have the most pronounced impact on the free forms of the *Strongyloides* genus. All these factors have favorable individual values for each species, but several common features can be differentiated.

The optimal temperature range in the case of the exogenous development is between 23 and 25$^{o}$C, when the hatching is done in 6-10 hours, the development of the adult is

completed in 42-48 hours, and infective filariform larvae appear after 68 hours. Development is considerably slowed between 15 and 16°C. Hatching requires 24 hours; the development of adults requires 96 hours and that of the infective larvae, 6 days. At least 20 hours were needed for the hatching of the first egg between 10-11°C, 73 hours for the development of the first adults and 166 hours to the first occurrence of infective larvae. In contrast, at 40°C and above, there is no evidence of any development of the exogenous stages[9]. Free-living males and females prefer an ambient temperature of around 30°C, while filariform infective $L_3$ develop better at 20°C[41].

In reference to humidity, the eggs do not develop below 87% relative humidity and between 25 to 30°C. The eggs may survive for 30 hours at 81% and for a maximum of 18 hours at 73%. The larvae exhibit poor resistance to desiccation[39].

**Pathogenesis**. The strength of the pathogenic effects exerted by larvae during migration or by female parasites in the intestines depends on the intensity of parasitism and the general condition of the host. Three stages of parasitic aggression can be distinguished: invasive, pulmonary, and intestinal.

The invasive stage caused by larvae in the skin and subcutaneous tissue consists in traumatic action, expressed by haemorrhages, swelling and tissues damage. The inoculation action, with bacterial input, complicates the pathogenic effects and causes local inflammation. In the pulmonary stage, the larvae traumatize lung tissue expressed by lung infiltrates and wheezing. The mechanical-traumatic action of juvenile or adult females, during the intestinal phase, is expressed by sloughing of patches of mucosa and ulcers. Chronic fibrous inflammations are caused by the females. Inoculation of bacteria in the intestinal lesions can lead to septicemia and death of the animal. Parasitic metabolic products have general toxic effects on the host organism and particularly on digestion and absorption, accentuating malabsorption.

**Immunity.** The immune mechanisms are intensely studied in infections with *S. stercoralis*, the common species in humans and carnivores. The acquired resistance against filariform infective $L_3$ stage is mediated by the B lymphocytes while activated eosinophils stimulate T cells to develop antigen-specific immune responses. Eosinophils also operate as an antigen presenting cells for the induction of the primary and secondary Th2 immune responses, indicating an essential role of these cells in the interface between innate and acquired immune responses[21].

Complex larval antigens determine the formation of allergic, precipitating and protective antibodies in animals. These induce resistance to reinfection of the hosts. Trans-colostral immunity transfer is proved in *S. ransomi* infections of piglets[38]. Vaccination of pigs using infective and attenuated larvae is followed by a strong protective state caused by the metabolic larval antigens[37].

**Clinical signs**. The disease evolves clinically expressed in lambs, piglets, young coypu, rabbits, dogs, and only rarely in calves and foals. The clinical pattern consists in a succession of cutaneous manifestations, respiratory disorder and digestive symptoms correlated with larval migration and the development of females in the gut; however several particularities depending on the species have been recorded. Cutaneous disorders consist in erythema, papules, itching and dermatitis, which are transient, often not observed. These are followed by transient respiratory symptoms with cough, dyspnoea and fever or feverish states. Finally, certain digestive symptoms are expressed, namely: a capricious appetite, mucous, hemorrhagic, smelly and blackish diarrhea, excessive weight loss, anemia and hypothrepsia. The disease may come to a fatal end in 2-3 weeks

or up to 2 months when animals become cachectic, non reactive.

Infection with *S. papillosus* starts with a dermatitis, which may evolve to foot rot in sheep, followed by inconstant digestive disorders. Intermittent diarrhea containing blood and mucus, loss of appetite, even anorexia, and weight loss may occur. Sudden death following cardiac arrhythmias (ventricular fibrillation preceded by sinus tachycardia) has been recorded in lambs and calves[64,67].

*S. westeri* larvae cause, during their migration, skin irritation and dermatitis followed by respiratory distress. Adult worms produce erosion of the intestinal mucosa with acute diarrhea that may lead to weakness and emaciation.

In the initial stage of infection with *S. ransomi*, dermatitis appears and may resemble sarcoptic mange. The respiratory stage of migration is inexpressive, but the digestive phase is expressed by diarrhea, dehydration, general unthriftiness, loss of weight, listless and dull animals, inappetence, adynamia and death with a high mortality rate, of around 50%.

*S. stercoralis* causes loss of appetite, watery or mucoid diarrhea, dysentery, dehydration, loss of weight, listlessness, weakness and death.

During infections with other species, which are important to veterinary medicine, there may appear bloody diarrhea in birds infected with *S. avium*, local dermatitis in *S. ratti*, larval penetration and hyper-responsivity of the airways and death in *S. venezuelensis* infection.

**Pathology**. The lesions, discrete in moderate infections, may sometimes get worse, in that there appear papules or sinuous haemorrhagic cords in the skin, dermatitis in the sub-abdominal, perineum, sternum and limb regions. Micro-haemorrhages or swelling and exudate containing eosinophils may occur in the lung, caused by larvae. Catarrhal or hemorrhagic enteritis, ulcers, bowel wall edema and parasitic granulomas are caused by the *Strongyloides* spp. parthenogenetic females.

In *S. papillosus* infections, the typical lesions are: dermatitis, erosion of the intestinal mucosa, local haemorrhages and enteritis. *S. ransomi* larvae cause dermatitis, hemorrhages in the lungs, and the females cause petechial hemorrhages in the intestinal mucosa and enteritis. *S. avium* females cause enteritis and a thickening of the walls of the cecum with the disappearance of the typical pasty cecal contents, the cecal discharge being thin and bloody. *S. stercoralis* infections are mostly nonpathogenic, but in heavy infections there may appear an extensive loss of the intestinal surface. The migrating larvae may also damage the lung parenchyma. Infections with *S. ratti* and *S. venezuelensis* are associated with dermatitis and eosinophilic pneumonia, without obvious intestinal damages.

**Diagnosis.** Epidemiological data (affecting youth grown in precarious hygiene and nutrition conditions) and the clinical exam (the triad of digestive, skin and lung disorders) are indicative. The coproscopic examination using ovoscopic (flotation tests) or larvoscopic (Baermann) methods is a method of certainty in the case of the intestinal form. The diagnosis of dermatitis is difficult due to the short period needed for larval penetration and secondary infections. For the accuracy of the necropsy, scrapes from the affected intestinal segments are sampled. These are examined under a microscope or magnifying glass highlighting the adult parasites. Immunodiagnosis by different methods (IFI, ELISA) proves the presence of specific antibodies.

***Differential diagnosis*** includes colibacillosis, salmonellosis, eimeriosis, cryptosporidiosis, other gastrointestinal helminthosis, viral enteritis, specific or afrigore lung diseases, scabies, drug dermatitis, allergy and eczema.

**Treatment.** Imidazothiazole and benzimidazole derivatives, and avermectins are generally, effective against infections with *Strongyloides* spp. Particularly, the following have been tested for each species of *Strongyloides*:

***S. ransomi***

- fenbendazole, 3 and 5 mg/kg of body weight, respectively, on 3 successive days, expressed different efficacy: 59% at 3 mg/kg and 81% at the second dose[59];
- ivermectin, 100, or 500 microgram/kg of body weight demonstrated 66% to 100% efficacy[60];
- doramectin, at the rate of 300 micrograms/kg bw was 99.9% and 100% effective in natural infections and 100% in induced infections[58,70];

***S. westeri***

- ivermectin, 200 mcg per kg body weight, injected intramuscularly, showed more than 99% efficacy in foals[31,35];
- ivermectin, 1.87% commercial paste formulation at the dosage 0.2 mg ivermectin per kg applied orally demonstrated a 99.2% efficacy[10];
- moxidectin, 2% gel formulation at the dosage of 0.4 mg moxidectin per kg bw, applied orally was 100% effective[10];

***S. papillosus***

- fenbendazole and febantel, each at a dose rate of 5 mg/kg bw in sheep and goats have reduced the worm count by 89%, and 85% respectively[16];
- ivermectin, 200 micrograms/kg of body weight demonstrated a 99.8% efficacy in sheep[71];
- ivermectin at 50 micrograms/kg bw has a 97% efficacy in goats[63];
- moxidectin, 0.2 mg/kg bodyweight, orally, was only 76% effective against adult parasites in lambs[4];
- mebendazole, 15.0 mg/kg bodyweight, orally, was 58% effective in lambs[4];
- eprinomectin 5%, 1.0 mg eprinomectin/kg, in an extended-release injection (ERI) showed an efficacy of over 98%[45];

***S. stercoralis***

- albendazole in a dose of 100 mg twice daily for three days, prevents the subsequent development of infection in normal and immunosuppressed dogs[18];
- paraherquamide, an oxindole alkaloid metabolite of Penicillium paraherquei and P. charlesii, at a dose rate of 2.0 mg kg bw, single oral dose, expressed a good efficacy (91%)[53];
- ivermectin, 200 micrograms/kg of body weight was 100% effective in removing adult parasites from the intestinal tract of the experimentally infected dogs[34];
- thiabendazole, once a day for 3 consecutive days at 50 mg/kg and fenbendazole, once a day for 3 days at 50 mg/kg removed adult parasites from dogs[17,23];

**Control**. General hygiene measures, ensuring the physiological comfort and improvement of qualitative and quantitative nutrition are required.

Hygiene measures include: maintaining the floors and bedding dry, removing feces, and applying current disinfection procedures. The raising of young animals in cages (piglets), indoors on a wire mesh floor (lambs), on a steel mesh grate (calves), and in mesh cages (animal fur), is a technological barrier to invasion. Human safeguards are needed against S. stercoralis infections, in kennels and in hunting dogs.

Periodic deworming in infected units leads to the disappearance of the disease. Controlled release capsule (CRC) pr boluses may be used in the case of ruminants as method for long-time control. A capsule based on ivermectin (IVOMEC® MaximizerTM CR Capsule for Sheep, Merial Ltd.) prevented the establishment of *Strongyloides papillosus* by >99% as compared with the untreated animals[46]. Tannins introduced in feed (18 g of *Acácia negra* containing 18% of condensed tannin/animal/week), for 12 weeks, cause the

decrease of the fecal egg count throughout the experiment. This substance demonstrates an antiparasitic effect, and therefore represents an alternative for worm control in sheep[7].

Evasive grazing can be recommended in ruminants as the only control measure of the S. papillosus infection, considering that the larvae emerge within 2 weeks on pasture and their survival is short[13]. Nematophagous fungus *Arthrobotrys oligospora* at a concentration of 2000 conidia/g feces eliminates more than 99% of infective larvae, providing a practical biological control agent against *S. papillosus*[8].

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# 5. Ascaridoidea

This superfamily comprises some of the largest polymyarian nematodes, parasites of the small intestine in most species of domestic animals. From a morphological point of view, they are characterized by a cylindrical, equally calibrated and whitish body. They have variable sizes and the mouth opening is surrounded by three lips. Biologically, they are characterized by a monoxenous life cycle, the embryonated egg representing the contaminant element. Paratenic and transport hosts may intervene. Each species realizes a particular migration, which is responsible for the typical clinical signs of disease. The generic name of the disease caused is ascaridoidosis, but there are specific names, depending on the species involved.

The new systematics of the superfamily, proposed by Fagerhholm[24], involves splitting it into 4 families (Heterocheilidae, Ascarididae, Anisakidae, Raphidascarididae), which is sustained by the molecular analysis of Nadler[57,58] and Nadler and Hudspeth[59]. This new classification eliminated two families accepted by Anderson et al.[4]: the Crossophoridae and the Acanthocheilidae, and proposed a new one: the Raphidascarididae. Anyway, more than 50 genera are described in this superfamily.

## 5.1. Ascarididosis in mammals

The Ascarididae family is of interest to veterinary medicine because it contains the genera and species that parasitize domestic animals: *Ascaris*, *Parascaris*, *Toxocara* and *Toxascaris*. These parasites cause ascarididosis in mammals. They are characterized by well-defined lips at the anterior end, surrounding the oral opening, a curved posterior end with two spicules on the small curvature, and a monoxenous life cycle.

Adult parasites have strong host specificity, while the larval stages have no specificity and may develop in diverse mammalian hosts. In these accidental hosts the larvae exert pathogenic effects, known as "*visceral larva migrans*".

**Definition.** These diseases are geo-helminthoses caused by nematodes included in the Ascarididae family of the Ascaridida order, which affect and determine morbidity especially in young mammals, evolving subclinically in adults. Sometimes, these diseases evolve as technopathy in large-scale farming systems. Adult parasites live in the small intestine and cause digestive, respiratory, nervous and general disorders. They are more common in malnourished animals and poor housing conditions.

**Etiology.** The family Ascarididae is divided into 4 subfamilies: Toxocarinae, Multicaecinae, Ascaridinae, and Angusticae-cinae[4]. Each subfamily comprises, in turn, several genera.

The subfamily Toxocarinae includes 3 genera, the most important being *Toxocara, which* contains parasites of terrestrial mammals. The former *Neoascaris* was subjugated to *Toxocara* by Warren[96] due to the fact that the differences are not significant enough to warrant a separate genus. The subfamily Ascaridinae includes 5 genera, *Parascaris*, *Ascaris* and *Toxascaris* being the most important ones for domestic animals. These genera are represented by the following parasite species in domestic animals:

- *Ascaris suum*, develops in the small intestine of wild and domestic swine; occasionally it is an incidental parasite of sheep and cattle.
- *Parascaris equorum*, is localized in in equines, in the small intestine, and only rarely in the stomach.
- *Toxocara vitulorum* (syn. *Neoascaris*), occurs in the small intestine of cattle.
- *Toxocara canis* and *T. cati*, parasitize in the small intestine of canids and cats, *T. canis* also causing visceral larva migrans in other species.

- *Toxascaris leonina*, lives in the gut of felids, sometimes canids.
- *Baylisascaris procyonis*, parasite of the rabbit.

***Morphology*.** The species of the family Ascarididae have a stout cylindrical body, equally calibrated, slightly sharp at the ends, whitish to pinkish in color. At the anterior end, the mouth opening is bounded by three lips. The posterior end of the male is curved, crutch-shaped and has two spicules and pericloacal papillae on the lower curvature. The posterior end of the female is straight and sharp. The sizes of ascarids vary from species to species with a pronounced sexual dimorphism, the females being larger than the males.

*A. suum* (figure 26A) males measure 15 to 31 cm long and 2 to 4 mm wide and the females 20 to 49 cm long and 3 mm to 6 mm wide. The mouth is surrounded by three equally calibrated lips. The color of the cuticle is pinkish. The spicules are stout and measure 2.0 to 3.5 mm in length. The vulva is placed in the anterior-to-middle part of the body. Eggs have a yellow-brownish thick shell with small mammillated proteinaceous knobs arranged as a coat that covers the exterior part of the shell. Eggs are oval-shaped and measure 50 to 80 µm long by 40 to 60 µm wide. The eggs are not embryonated when passed (figure 27.1).

*Parascaris equorum* (figure 26B) has a stout body, being one of the largest ascarid species. The size of the male varies between 20 to 27 cm in length and 3 to 4 mm wide and that of the female, from 35 to 40 cm in length by 5 mm wide. The lips are highly developed, prominent, having the aspect of a cudgel at the anterior end. The eggs are brown, round, 90 to 100 µm in diameter and have an albuminous, thick and slightly pitted shell, the granular content being condensed into the center of the egg (figure 27.2).

The size of *Toxocara vitulorum* is similar to that of *A. suum*; it has a stout whitish body and semitransparent cuticle, small lips and blunt posterior end. The eggs are subspherical in shape, 80 to 90 µm in diameter, and the shell is finely pitted (figure 27.4).

Males of *Toxocara canis* (figure 26C) measure 8 to 14 cm in length by 0.2 – 0.25 mm in diameter, and females measure 10 to 18 cm in length and 0.25 to 0.3 mm wide. The body is pale pink, curved ventrally at the anterior end and posseses cervical alae. The posterior end of the males is ornamented with narrow and finger-like appendages, caudal alae and two small winged spicules. The vulvar opening is situated in the anterior quarter of the body. The eggs are subglobular with a variable diameter, between 75 to 85 µm, and the surface of the shell is pitted (figure 27.3).

Adults of *Toxocara cati* (figure 26D) are very similar to those of *T. canis*. They can be differentiated by the aspect and sizes of the cervical alae in *T. cati, which* end abruptly and are shorter and broader than those of *T. canis*. The spicules of *T. cati* are longer than those of *T. canis*. The length of the parasites varies between 3 to 7 cm in males and 4 to 10 cm in females. The males have the same appendages as *T. canis*. The eggs are smaller, measuring 70 µm long and 65 µm wide, and the shell is more finely pitted (figure 27.5).

*Toxascaris leonina* (figure 26E) is morphologically similar to *T. canis*, but it is a bit smaller, the male measuring 2 to 7 cm in length, and the female, 2 to 10 cm. The anterior end of T. leonina is straight and the spicules are wingless. Eggs are subglobular, 75 to 85 µm long by 60 to 75 µm wide, and their shell is nonpitted and smooth (figure 27.6).

The female of *Baylisascaris procyonis* measures 20 to 22 cm long and the male is 9 to 11 cm long. Pericloacal roughened areas are present at the posterior end of the male. The egg is oval, brown, 63 to 88 µm in length and 50 to 70 µm wide, has a thick shell and contains a single large, embryonic cell.

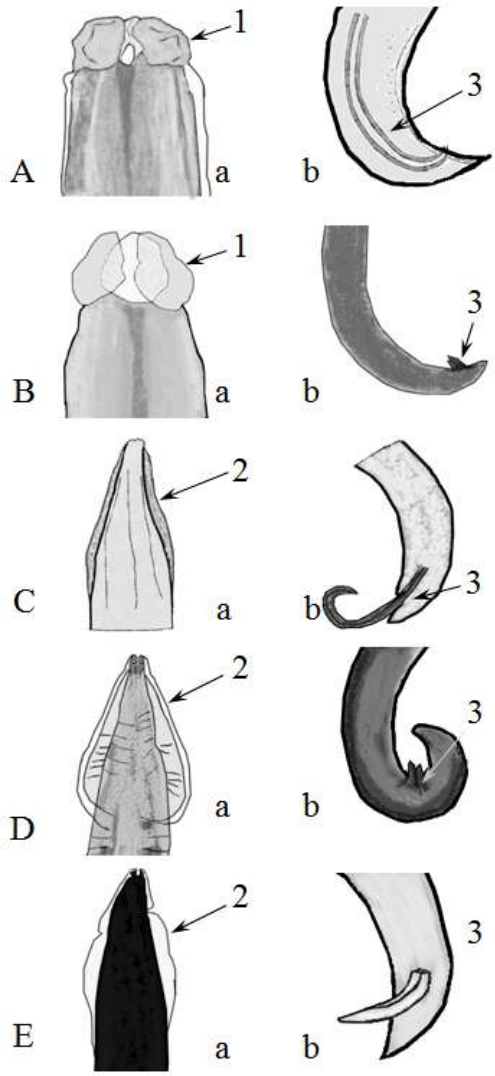


**Figure 26.** Morphology of ascarids: A. *A. suum*; B. *P. equorum*; C. *T. canis*; D. *T. cati*; E. *T. leonina*; a. anterior end; b. posterior end; 1. lips; 2. cervical alae; 3. spicules;

The ***life cycle*** is homoxenous; it takes place by alternating the parasitic stages with the exogenous phases. Adults develop in the small intestine, particularly in the duodenum, where they feed on the intestinal chyme. They may migrate erratically in the stomach, esophagus, bile duct and duct of Wirsung in heavy infections. The females lay eggs that are passed in the environment through feces. The eggs embryonate in proper ambient conditions represented by variable temperature, between 28 and 30°C and 95 to 100% R.H. in all species. Slightly acidic soil stimulates a relatively rapid development of eggs[99]. The first-larval stage remains inside the egg and molt once resulting in the second larval stage, that does not leave the egg. Thus, a contaminant element represented by the embryonated egg that contains the second larval stage ($L_2$) is developed. Animals become infected by consuming embryonated eggs. The eggs hatch and the larvae penetrate into the intestinal wall. Further, the larvae migrate differently, depending on the species.

In *Ascaris suum* and *Parascaris equorum* infections, the larvae accomplish a ***lung–tracheal migration***. It consists in the movement of the larvae to the liver via the portal system, reaching the right ventricle, pulmonary artery and lungs. The larvae leave the bloodstream through the alveoli wall and migrate up the trachea and pharynx. Here, they are swallowed and return to the gut where, following a final molt, they maturate. The prepatent period varies between 42 to 56 days in *A. suum* and 72 to 115 in *P. equorum*.

Species of the genus *Toxocara* (*T. canis*, *T. cati* and *T. vitulorum*) perform migrations differentiated by the age and physiological state of the animals.

In adult animals, the larvae perform a ***somatic migration***. The $L_2$ larvae enter into the intestinal capillaries and follow the same route as in the previous migration, up to the lung. They return in the left heart through pulmonary veins and disseminate into the body by the systemic circulation and remain in the same stage after arriving in the tissues. In pregnant bitches, the larvae pass the placental barrier and localize in the liver of fetuses until birth. Postpartum, the larvae continue their migration to the lung, trachea and intestine. This systemic migration facilitates transplacental and transmammary contamination, considering that the larvae

which migrate through the mammary gland are transmitted to the newborns after birth. Paratenic and transport hosts may intervene in the transmission of *T. canis*.

In young animals, 5 to 6 weeks to 3 months of age, the hatched larvae perform a lung–tracheal migration.

*T. cati* has a completely different life cycle, meaning that transplacental infection does not occur and the larvae perform a lung-tracheal migration.

The prepatent period is variable, between 30 days in *T. canis*, 55 in *T. cati* and 70 in *T. vitulorum*.

The eggs of *T. leonina* hatch in the gut, and the larvae penetrate the wall of intestine where they remain for about 2 weeks. They return and mature in the lumen of the intestine, performing a so called ***local migration***. The prepatent period is 50 to 63 days.

The larvae molt twice on the migratory route in the course of all these types of migration. The first molting usually occurs in the lung (or wall of the intestine for *T. leonina*), and the second in the lumen of the gut, followed by the development of mature adults. The lifespan of adult parasites varies between 9 and 12 months.

**Epidemiology**

***Geographical distribution.*** All species involved in the etiology of ascaridiosis are cosmopolitan species, widely prevalent among domestic and wild animals. The prevalence varies depending on species and region.

Infections with *Ascaris suum* were recorded in the last ten years throughout Europe. The prevalence was between 1.5%[22] and 7% in sows[26] in Germany. In the Netherlands, the parasite was found in 50% of free-range farms, 72.7% of organic and 11.1% of conventional farms, the fatteners being significantly more infected[21]. In England, the national monitoring program of *A. suum* infections performed in abattoirs revealed a prevalence of around 4% between 2005 and 2010[83]. *A. suum* was found in 76% of the Danish industrialized sow farms[29]. In Romania, a variable prevalence was recorded for *A. suum* infections, i.e., between 4 to 40% in weaned pigs and 5 to 37.5% in fatteners, depending on the breeding system, i.e., large farm or household, respectively[15].

Worldwide, the infection was also diagnosed in Tanzania (44.3%), Burkina Faso (40%), Kenya (28.7%), Uganda (40%), Japan (14.7%), China (12.18%) and Korea (17.6%)[31,41,50,64,65,90]. This data demonstrates that African countries continously record a high prevalence, explainable, probably, by the existence of moist and warm biotopes, favorable for the development of the eggs.

*Parascaris equorum* was identified in 22.4% of the foals in central Kentucky in 2003 and 39% in 2004[43,45], 0.9% of horses in Germany between 1998-2002 and 11.3% over a 17-month period in an abattoir[22,73], 12% in working horses slaughtered for meat in Poland[39] and in 5% of equines in the State of São Paulo, Brazil[71]. The prevalence of infection in donkeys was 51.1% and 16.2 % horses in Ethiopia[27], 23.3% in Mexico[28], 21.6% in working horses in Lesotho[95] and 12.2% in working horses in Urmia, northwestern Iran[92].

*T. vitulorum* occurs in regions located up to 50$^{o}$ north and 40$^{o}$ south latitude[93]. Its prevalence varied between 0.0% in dairy cattle and 1.8% in beef cattle from Costa Rica[34]. In the periurban zone of Bamako, Mali, the prevalence of infection in calves varied between 0.9 and 7.6% according to age[97]. The overall prevalence of infection was 0.77% in creole Calves of Guadeloupe[48]. The prevalence in calves in north central Florida differed according to age: 17.6% in calves less than 3 months of age, 0.4% in calves 3-4 months of age and 0.9% in calves over 5 months old[16]. The same age-dependent variation was recorded in southern Punjab, Pakistan, the prevalence being higher in calves (25.6%) than in adult cattle (8.1%), the differences also occuring in the case of

buffalo: 35.4% in calves and 4.3% in adults[5]. The mean prevalence of *T. vitulorum* in five provinces of northern Lao PDR was 25.5% in buffalo and 20.9% in cattle[72].

*Toxocara canis* is widely spread and recorded different values of prevalence in dogs, worldwide: 2.2% or 6.1 % in Germany[8,22], 25.0% in Osaka Prefecture, Japan[38], 12.4% in hunting dogs in Denmark[2], 13.0% in central Italy[77], 5% in Costa Rica[86], 36.4% in dogs, in the North West Bank, Palestine[69], 15.5% in Minas Gerais State (southeast Brazil)[30], 6.2% in a rural community of Yucatan, southern Mexico[80], 7.6% in dogs from Zambia[66], 20.62% in Western Pomerania, Poland[94], 75.7% in dogs in Tirana, Albania[98], and 26.9% in dogs in Romania[55].

*Toxascaris leonina* and *Toxocara cati* were diagnosed in stray cats in the Lisbon Metropolitan Area, Portugal, scoring a prevalence of 1.4% and 10.8%[18]. These species have recorded low values of prevalence, 0.2% for *T. leonina* and 0.8% respectively for *T. cati*, in feral cats from urban and suburban districts of Qatar[1]. In private-household cats which visited veterinary clinics in Japan, the prevalence was 6.2% in *T. cati* and 0.2% in *T. leonina* infections[32]. Both nematodes were also diagnosed in Finland, the prevalence recorded being 5.4% in *T. cati* and 0.2% *T. leonina* infections[61]. In the northern region of the Nile delta, Egypt, *T. cati* recorded a prevalence of 9.0% and *T. leonina* 5.0% in stray cats[37].

The data presented above proves the global spread of infections due to ascarids, caused by the great ecological plasticity of the exogenous elements that are able to develop in adverse environmental conditions.

***Sources of contamination*.** The perpetuation of the parasites in nature through the development of their perennial life cycle is ensured by the existence of two categories of sources: those that pollute the environment and those which contaminate the animals. The environment pollution rate depends on the sexual longevity and prolificacy of the females and differs from species to species. Egg-production in *A. suum* is extended for a period of 55 weeks, registering a peak of 27 million eggs daily during the 14th week[68]. Total egg output through feces during 24 hours in *P. equorum* infection varied from 2.690 to 1.115.400[47]. The egg count per *T. vitulorum* female per day registered a mean value of 110 000 ± 58 000[78]. *T. canis* females maintained *in vitro* conditions in an RPMI 1640 medium have expressed a maximum production of 16900 eggs/female/24 hours[101].

The food and water that contain embryonated eggs are the main sources of animal contamination. The hair of adult dogs infected with embryonated eggs at a rate of 36.2% may be a source of contamination for puppies[91]. In species with systemic migration (bitch, cow), pregnant females are sources of contamination for fetuses and newborns in the neonatal period. The earthworms *Lumbricus terrestris* may serve as paratenic hosts or even intermediate hosts for *Ascaris suum*, being the source of animal contamination[81].

***Susceptibility*.** The youth from birth up to 5 or 8 months, or 2 years in horses, is more responsive, in all species. The morbidity of adults is lower. A number of factors increase responsiveness: malnutrition, intercurrent illness, physiological factors (pregnancy), immunosuppression, etc. Neonatal exposure is an important risk factor for newborns, being able to cause the increase of persistence and size of adult worm burden[53]. The keeping of horses on silvopasture has determined the highest prevalence of the ascarid eggs in feces[25].

***Route of contamination*** is oral by ingesting embryonated eggs that contain the second larval stage.

***Resistance*.** The increased resistance of the eggs recognized by their ability to survive in unsuitable environmental conditions facilitates the emergence of diseases, after several years, in the same foci. It is known that, in a

favorable environment, the survival of the eggs lasts up to five years. There are also natural ecological factors or artificial elements in the environment that destroy the eggs. The majority of studies focus on highlighting the resistance of *A. suum* eggs to the action of various environmental factors. Low temperature, between -10 and - 20 oC, slows down the development of the eggs of *A. suum* and reduces their capacity to embryonate[20]. The high hydrostatic pressure at a dose rate of 241 megapascals (MPa) or more for 60 s inactivates the eggs of *A. suum,* which lose their ability of embryogenesis[82]. Ensiling conditions do not destroy the eggs of *A. suum* even if their viability is diminished[12]. The eggs of the same species were destroyed in biodrying compost, the high temperatures and continuous drying being the major factors of the inactivation[13]. The combined action of urea, pH and temperature can inactivate the eggs of *A. suum*. High pH and 1% or 2% addition of urea at 24oC inactivate the eggs within 1 month[67]. Among disinfectants, the quaternary ammonium salt has no effect on the *A. suum* eggs at 22$^{o}$C at a 10-minute exposure; povidone-iodine at 100%, 50%, 10%, and 1% has also no effect on the eggs at 22$^{o}$C for 5, 15, 30, 60, or 120 minutes; phenol (5%) and cresol (3%) inactivated 100% the eggs[40]. All eggs of *A. suum* are completely destroyed in 3 hours in anaerobic digestion conditions at 55$^{o}$C. The incubation at 37$^{o}$C does not affect the survival of the eggs during the first 48 hours. 10 days are needed for the complete inactivation[35].

The elements of the flora and fauna of the aquatic environment exert different actions on the eggs of ascarids. Some species of algae damage the eggs at early stages of embryogenesis or in its late stages. Other species are neutral towards the development of eggs. The season, through differences in gas exchange, influences the development of eggs. The lysozyme excreted by the mollusk exerts an antiparasitic activity against egg development[62].

Some species of fungi can inhibit the growth of ascarid eggs. The mycelium of two fungal species, *Metarhizium flavoviride* and *M. anisopliae,* inhibits the development of eggs[33]. *Trichoderma* spp., *Fusarium complex solani* and *Acremonium* spp. fungi exert an ovicidal activity on *Toxocara canis* eggs in the soil[17]. *Pochonia chlamydosporia* fungus negatively influenced the development of *T. vitulorum* eggs[11].

From an epidemiological point of view, the pathogenicity of the *Toxocara* larvae in humans should be considered, because ingestion of embryonated eggs by humans cause *visceral larva migrans*, with multiple clinical signs.

**Pathogenesis.** Pathogenic mechanisms are correlated with the evolutionary stage of the parasite. The larvae, during migration, predominantly exert mechanical-traumatic, allergic and inoculation actions. On the other hand, large adults located in the small intestine perform preponderantly mechanical-obstruction, spoliation, allergic and toxic actions.

Traumatic action of the larvae consists in tissue destruction and hemorrhages in the liver around the intralobular veins. In the lung they damage the blood vessels causing petechial hemorrhages. In the case of somatic migration, these hemorrhagic lesions may appear in the brain, muscle and other organs in which the larvae migrate. Allergic action is developed by the larvae, especially in re-infections, and consists in eosinophilic granuloma formation, mainly in the lung. Inoculation action is demonstrated for many bacterial infections (*Salmonella* spp., *Escherichia coli*, and *Streptococcus pneumoniae*), amoebae in the liver, pneumotropic viruses and fungi[9].

The mechanical action of the adults is due to the mobility of the ascarids, their large size; massive infestations in some situations are

reflected by a brutal mechanical action, with catarrhal enteritis, forming of large balls of parasites that cause obstructions, occlusions and blockage of the intestinal transit or, rarely, perforation of the intestinal wall. Erratic movements in the bile ducts, Wirsung duct, in the stomach or esophagus cause obstruction of their lumen and dyskinesia, respectively jaundice and pancreatitis. The adults affect the resistance of the gut wall to the pressure and cause it to decrease significantly[51].

Spoliation is favored by the localization of the adults in the small intestine, especially in the duodenum. They consume large amounts of substances from the intestinal content, selectively amino acids, carbohydrates, lipids, vitamins (group B, C) and minerals, causing deficiency metabolic disorders (hypoglycemia, rickets, hyperkeratosis).

The allergic action follows the hypersensitivity of the organism caused by the antigens of adults and is clinically expressed by urticaria, edema, haematological changes (eosinophilia), asthma and seizures.

Toxic effects are due to the metabolic products, especially ascaron, a toxic peptone present in coelomic fluid, and other endotoxins, released after death, and disintegration of ascarids. Some toxins neutralize the digestive ferments causing disorders such as diarrhea, coprostasis and malabsorption by alteration of membrane permeability[36]. The absorption of toxins from the intestine induces blood circulation disorders (hypotension, bradycardia), seizures, epileptic phenomena, alteration of hematopoiesis, anemia, poikilocytosis and anisocytosis. Some toxins have insulinotropic actions that aggravate hypoglycemia.

**Immunity.** The infected host develops a strong immune response against parasite antigens. Immuno-protective, para-immune and allergic phenomena are involved. Post-infection resistance demonstrates the intervention of innate immunity or acquired premunition immunity. Passive acquired immunity can be induced by transmmamary transmission of the antibodies through the colostrum, and it has been demonstrated in piglets and puppies[60]. Cross-resistance between *A. suum* and *Nippostrongylus brasiliensis* infections was demonstrated in mice[23]. It is experimentally proved that antigens obtained from the eggs of *A. suum* induce a very good immune protection[87].

**Clinical signs.** The clinical signs are more severe and polymorphous in young mammals and attenuated, uncharacteristic in adult animals. They are dominated by the digestive symptoms preceded by respiratory signs. Feverishness or fever meay appear in bacterial superinfections. The nervous, metabolic and skin disorders may occur during the evolution of the diseases. Some particularities depending on species, age and the intensity of parasitism have been recorded.

The piglets and youth between 3 and 8 months are predominantly affected by *A. suum*. Respiratory signs occur 2 weeks pi, consisting in an initially dry cough followed by a productive cough. Superinfections aggravate respiratory signs. The digestive symptoms appear subsequently, with abdominal bloating, constipation alternating with diarrhea, bulimia, weight loss, stopped growth, anemia and rickets. In massive infections appear colics, jaundice and death consecutive to bowel obstruction. Nervous signs consist in epileptic seizures, intra or post-prandial convulsions and often peri-umbilical itchy skin may appear. In adult pigs, the signs are frequently inconspicuous.

*Parascaris equorum* infection develops in the foal at the age of 3 to 12 months. Incubation varies between 12 and 20 days. The severe pulmonary signs appear during spring and autumn. Subsequently, digestive disorders occur: capricious appetite, diarrhea alternating with constipation, dense and dry feces covered by mucus, colic, sometimes pica, abdominal bloating, growth retardation and anemia. The skin lacks elasticity and horripilation occurs.

Intestinal wall rupture may evolve with symptoms of peritonitis, and chronic rickets. In adult horses the disease is benign or inexpressive.

*Toxocara vitulorum* infection affects calves from the neonatal period up to 8 months of age. The neonatal forms evolve in an acute and toxic manner, with severe depression, adynamia, profuse diarrhea, hypothermia and death within 2 to 3 days. Digestive disorders evolve in the young animals: decreased appetite, anorexia, polydipsia, bloating, diarrhea, and colic; they often occur after the suckling period. The animals lose weight and their growth stagnates.

Toxocariasis in dogs evolves from the neonatal period (at 2-4 weeks) until adulthood. It may evolve severely, expressed by anorexia, dysgeusia, vomiting, abdominal bloating, coprostasis, dysenteric diarrhea (liquid faeces, yellowish, smelly), colic and dehydration. Epileptic seizures and rabies-like symptoms can evolve, followed by normal behavior. Pruritus and urticaria are present. Malnutrition causes deficiency disorders such as rickets, hyperkeratosis, growth stagnation and hypochromic anemia, favoring the development of other diseases (Carre disease, infectious gastroenteritis). Respiratory signs are rarely reported in dogs. In cats, the disease occurs after weaning, and is expressed by predominantly digestive and general disorders, similar to those of the dog.

The complications of ascaridiosis may occur in mammals in massive infections with adult parasites that cause subocclusion, obstruction and intussusception, with serious disorders, pains and colic, especially in foals, calves and puppies. Intestinal wall rupture and peritonitis may evolve in foals. Obstruction of the bile duct, biliary stasis and jaundice are relatively common in piglets. Bronchopneumonia following bacterial and viral superinfection may evolve in all species.

The "*visceral larva migrans*" can be detected in various animal species, but it is important in human pathology.

**Pathology.** The lesions can be systematized in two categories: caused by larvae during migration and by adults, respectively, in the intestine. The larvae cause damages with reduced severity at the first infection, consisting in linear or petechial hemorrhages and necrosis in the liver and lung. The lesions are more severe in reinfection due to the allergic action and are represented by edema of the intestinal mucosa, infiltrations in the mesenteric lymph nodes, bronchopneumonia, lobular pneumonia, hepatitis followed by cirrhosis, encephalosis with eosinophilic granuloma and pancreatitis.

Adult parasites cause catarrhal duodenitis and jejunitis, intestinal obstruction, volvulus and intestinal perforation with peritonitis, liver cirrhosis, pancreatitis in erratic movements in the Wirsung duct and jaundice of the connective tissue in the bile duct occlusion.

**Diagnosis.** Intra vitam is difficult to achieve. It may be suspected based on the respiratory disorders in young animals kept in poor conditions of hygiene and nutrition. The intestinal disease may sometimes be easily diagnosed in dogs, cats or piglets when their vomit contains adult ascarids or when adults are spontaneously eliminated through feces. Identification of characteristic eggs in the feces using flotation techniques is a method of certainty (figure 27).

Necropsy allows the observation of the adult parasites in the lesions in the intestinal lumen. Serological methods have been tested (indirect immunofluorescence, ELISA, indirect hemagglutination test) in swine, carnivores using various allergenes obtained from eggs, larvae or adults.

***Differential diagnosis*** includes broncho-pneumonia with a different etiology, digestive helminthosis, food poisoning, colics caused by other factors.

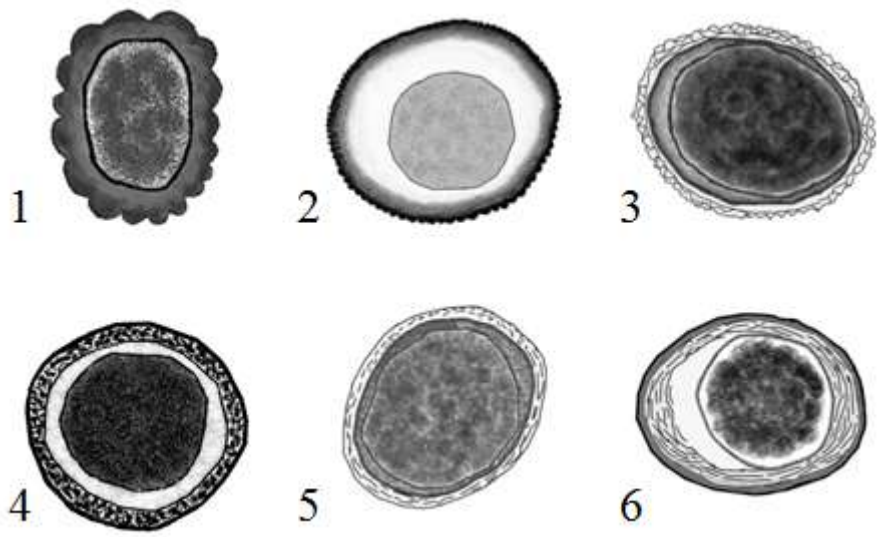


**Figure 27.** Eggs of ascarids species: 1. *A. suum*; 2. *P. equorum*; 3. *T. canis*; 4. *T. vitulorum*; 5. *T. cati*; 6. *T. leonina*;

Nervous syndromes need to be differentiated from Aujeszky's disease and sodium chloride poisoning in pigs. Toxocarosis in dogs and cats must be differentiated from rabies, toxoplasmosis, Carre disease, epilepsy.

**Treatment.** Imidazothiazole and benzimidazole derivatives, avermectines and the ancient piperazine salts are the drugs most widely used in animals. The doses and efficacy expressed by different active substances in natural and experimental infections with ascarids are shown in table 14.

**Control.** The complex preventive measures cover some general available actions, as well as other more specific actions. The first category includes the hygiene of the shelters, body and food. Specific measures refer to regular deworming of animals and disinfection of pens, paddocks and maternities.

Deworming differs by species. Anthelmintic treatments of pigs are performed at 5 to 6 days before new entries in the shelters and at 2 to 3 months of age in piglets. The first deworming of calves must be applied at 2 or 3 weeks of age in order to prevent the development of *T. vitulorum* adults, consecutive to transplacental or transmammary infections. The first anthelmintic treatment of foals is made at 3 months of age and twice per year in adults, during the spring 14 days before pasturing and in autumn, 14 days after stabling. The puppies and kittens are dewormed at 2 or 3 weeks of age against T. canis fetal contamination, contamination which can also be acquired via the milk. Adult dogs and cats are treated quarterly.

Deworming will be followed by mechanical cleaning and disinfection by flaming or using disinfectants applied at high temperature. Among the disinfectants, cresol compounds have an ovocidal effect at high concentrations[54].

Destruction of the eggs in the environment by artificial methods is virtually impossible. They are characterized by a high viability in the environment, up to 4 years. However, direct sunlight and dry soil will destroy the eggs in a few weeks.

Rotation of pens, preferably every 10 days, and the access of the youth to new pastures that were not used previously by the adults, will raise the degree of animal protection.

**Table 14.** Anthelmintics used in treatment of ascaridiosis in mammals

| substances | dose rate (mg/kg bw)/efficacy (%)/author | | | |
|---|---|---|---|---|
| | ***A. suum*** | ***P. equorum*** | ***T. vitulorum*** | ***T. canis, T. cati, T. leonina*** |
| piperazine dihydrochloride | 200/99-100[88] | | 200-500/98-99[84] | |
| dichlorvos | 17.0/100[49] | 20.0/100[47] | | |
| trichlorfon | | 40.0/100[8] | | |
| levamisole | 8.0/97.9[49] | | 7.5/97*/83**[79] | |
| febantel | | | 6.0/100*[79] | |
| febantel-pyrantel-praziquantel | | | | 15-5-5/ 80-100 Tc Tl[56] |
| thiabendazole | | 44.0/100[46] | 66.0/35*[79] | |
| fenbendazole | 3.0/92.4[49] | 10.0/80.0[44] | 5.0/85[16] | |
| oxibendazole | | 10.0/97.0[44] | | 15/97.6 Tc/ 100 Tl[70] |
| oxfendazole | 30.0/100[3] | 10-50/100[19] | 4.5/89**[79] | |
| pyrantel pamoate | | 13.2/97.3[75] | 250/animal 97*/100**[79] | |
| emodepside + praziquantel | | | | 3.0+12.0 96.8-100.0 Tc, Tl[76] |
| ivermectin | 0.3/100*/ 90.3**-94.4**[10] | 0.2/96.9 – 100 [7,42,100] | 0.2/99.9[7] | |
| moxidectin | 1.25/98.3[89] | 0.4/100[14] | 0.2/99.5[7] | |
| doramectin | 0.3/100[74] | | 0.2/98.7[7] | |
| eprinomectin | | | 0.5/100[6] | |
| selamectin | | | | 6.0/93.9-100 Tc, Tl[52] |
| spinosad + milbemycin oxime | | | | 30-45+0.5-0.75 93.3-100 Tl, Tc[85] |

SD – single dose; * efficacy against immature parasites; ** efficacy against mature parasites; Tc *Toxocara canis* / *T. cati*; Tl *Toxascaris leonina*;

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# 6. Heterakoidea

The superfamily Heterakoidea is included in the order Ascaridida and contains parasites of caecum in birds and the large intestine in mammals. In amphibians and reptiles they are restricted to terrestrial feeders. The taxon is divided in three families: Ascaridiidae, Heterakidae and Aspidoderidae, the first two being important to veterinary medicine. The family Ascaridiidae contains the genus *Ascaridia*, its members causing ascaridiosis in birds, and only rarely in mammals. The family Heterakidae includes the subfamilies Spinicaudinae, Meteterakinae, parasites of reptiles and amphibians, and Heterakinae. The genus *Heterakis* is included in the last subfamily and contains parasites in birds and one species in mammals.

Heterakoids are characterized by small, well-developed lips that surround the mouth opening, an infundibular stoma and an esophagus divided into three parts. The male has a circular pre-cloacal sucker and two spicules. The female is oviparous and lays unembryonated eggs. They are monoxenous parasites; contamination is performed by consuming embryonated eggs.

## 6.1. Ascaridiidae: ascaridiosis in birds

The family Ascaridiidae contains only one genus, *Ascaridia*. The species of this genus are common parasites of the small intestine of fowls and have a cosmopolitan distribution. Morphologically, they are characterized by large and stout lips, club-shaped esophagus, without a posterior bulb and with an absent anterior cuticular flange. They are monoxenous geo-helminths. The disease in birds is called ***ascaridiosis*** according to SNOAPAD and must be differentiated from the infection with *Ascaris suum*, which is called ***ascariosis***, the parasite belonging to another superfamily.

**Definition.** It is a cosmopolitan intestinal helminthosis affecting wild and domestic birds, causing disease and mortality in chickens and a subclinical evolution in adults. The disease is prevalent worldwide, the incidence in some regions ranging from between 5 or 10% to over 40%. Prevalence is higher in chickens in traditional backyard farms, but foci also occur in large industrial farms, in chickens kept on permanent litter.

**Etiology.** The nematodes found in the small intestine, members of the genus *Ascaridia*, are:

- *Ascaridia galli* (syn. *A. lineata*, *Heterakis granulosa*) affects domestic chickens, guineafowl, turkeys, pigeons, ducks, geese, and game birds and it is found in the small intestine. It may migrate erratically in the esophagus, crop, gizzard, body cavity, liver, oviduct and egg[10,51].
- *A. dissimilis* is reported in the lumen and wall of the small intestine in turkeys.
- *A. numidae* (syn. *H. numidae*) is localized in the lumen of the small intestine, particularly in the jejunum, or the cecum in partridges (*Alectoris genus*) and guineafowl (Numididae family), and has been identified in plumed (*Guttera plumifera*), crested (*G. pucherani*) and helmeted (*Numida meleagris*) guineafowl.
- *A. columbae* are found in the lumen of the small intestine in pigeons and doves, but may migrate erratically in the esophagus, proventriculus, gizzard, liver, or body cavity[71].
- *A. compar* are localized in the small intestine of grouse, pheasants, partridges, and quail.

***Morphology.*** *A. galli* (figure 28) has an elongated, cylindrical, large, thick, and whitish to yellowish, semitransparent cuticle of the body, tapering towards both ends. The male measures 50 to 76 mm in length and 1.21 mm in width, while the female is 60 to 116 mm long and 1.8 mm wide. At the anterior end, the triangular mouth opening is

delimited by three denticulate and unequally calibrated lips, without an interlip. At the posterior end, the male has two narrow, fine, smooth, and membranous caudal alae or cuticular membranes and 10 pairs of papillae. The spicules are narrow, unequally calibrated, and blunt at the ends. The male has a preanal sucker, placed in an anterior position relative to the anus orifice. It is oval or circular and has a chitinous wall. The female has the vulvar opening in the anterior part of body. The females are oviparous. The eggs are oval-shaped, measuring 75 to 80/45 to 50 µm, unembryonated when laid and have a thick shell.

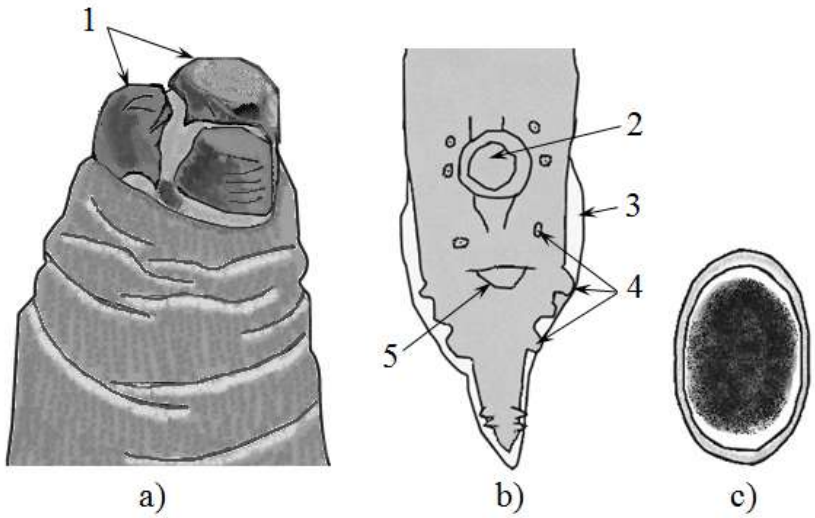


**Figure 28.** *Ascaridia galli*: a) anterior end; b) posterior end (male); c) egg; 1. lips; 2. preanal sucker; 3. caudal alae; 4. papillae; 5. anal orifice;

*A. dissimilis* is very similar to *A. galli*. The male measures between 35 and 65 mm long and the female is 50 to 105 mm long. The slender spicules have rounded ends and measure 1.3 to 2.2 mm long. Preanal papillae are differently placed in relation to the preanal sucker, compared to *A. galli*.

*A. numidae* is much smaller than *A. galli*. The male measures 19 to 35 mm and the female 30 to 50 mm long. Two papillae are placed preanally and 2 adanally. The spicules are 3 mm long and equal.

The *A. columbae* male size varies between 50 and 70 mm long, and the female is 20 to 95 mm long. The male has a fourth pair of ventral papillae placed adjacent to the anus, and the spicules are long (1.2 to 1.9 mm) and equal. The male of *A. compar* is 36 to 48 mm long and the female 84 to 96 mm.

***Life cycle*.** The species of *Ascaridia* are monoxenous parasites. The adults live in the specific intestinal segments and feed on intestinal content. The unembryonated eggs that are laid by the females are passed into the environment through feces. They embryonate and the first-larval stage develop inside the eggs, in proper conditions of ambient temperature, humidity, aeration, and semiobscurity. The $L_1$ stages molt once and remain in the eggs, which results in the embryonated eggs that contain $L_2$, which is the contaminating element.

The birds become contaminated by ingesting embryonated eggs. The infective eggs hatch in the intestinal tract (duodenum). Some larvae penetrate the intestinal mucosa and molt to the third-larval stage. This stage returns to the intestinal lumen where they molt again in the fourth-larvar stage, which mature into adults.

The other larvae remain in the bowel lumen and mature after successive molts. Arrested development of $L_3$ larvae of *A. galli* may develop during the life cycle, the antibodies of the host being involved in the induction of this state[19]. The prepatent period varies between 1 and 3 months depending on the *Ascaridia* species and the age of bird. The eggs develop within 28 days at temperatures between 15 and 16°C; their development takes 8 to 10 days between 30 and 33°C and 80% humidity, and 10-12 days at 28°C. Earthworms and grasshoppers may intervene as potential paratenic hosts. They ingest the eggs, which remain infective to chickens.

**Epidemiology**

***Geographical distribution***. Infection with different species of *Ascaridia* is spread worldwide; different levels of prevalence have been recorded.

*A. columbae* has affected 1.8% of band-tailed pigeons (*Columba fasciata fasciata*) examined in Colorado, USA[50]. In wild doves (*Columba livia*) from the city of Santa Cruz de Tenerife, infection with this species recorded a 8% prevalence[11]. *A. columbae* occurred also in 26% of the white-winged doves (*Zenaida asiatica asiatica*) from Texas, USA[14].

*A. galli* was most prevalent in domestic fowl (*Gallus domesticus*) from Uganda (Ssenyonga, 1982), Turkey (16%)[30], India[70], Cameroon (51.6%)[40], and in grey-breasted helmet guinea-fowl (*Numida meleagris galeata*) in Nigeria[5]. *A. galli* recorded a variable prevalence, between 3.9 and 37.3% in commercial broiler chickens from Arkansas[69].

*A. dissimilis* was diagnosed in wild turkeys from Kentucky and Tennessee (83%), Connecticut (52%), Arkansas, USA[6,20,59].

*A. compar* was found in 33.33% of rock partridge (*Alectoris graeca saxatilis*) in the Trentino province of Italy[57].

*A. numidae* was identified in helmeted and crested guineafowls from Musina, Limpopo Province, South Africa[26].

Many other studies demonstrate the wide spread of the ascaridiosis in birds, worldwide.

***Sources of contamination*** are diverse and numerous, due to a broad specificity and the increased resistance of ascarids eggs. The most important are the diseased or clinically inapparent birds, dead birds and the visceral mass that contain adult ascarids, accessible to animal vectors. The droppings, litter, earthworms, grasshoppers, and other vectors that can convey the eggs represent additional reservoirs. The environmental pollution in contaminated flocks is high due to the high prolificacy of females, reaching 170.000 eggs per female. In normal environmental conditions, about 50-60% of the eggs laid by a female evolve, the remainder being destroyed. A higher concentration of infected eggs is consequently recorded, in the litter as compared with the ground. This may be explained by the higher (approximately 70 times) stocking rates inside the poultry house and by the long period spent by the litters within the house compared to the run[39].

***Susceptibility.*** There are significant differences in terms of the receptivity behavior of birds to the infection. Various stressors (overcrowding, thermal discomfort, thirst, immunosuppression and chronic diseases) accentuate susceptibility.

The chickens are, generally, more susceptible than adult birds. Among the adult birds, the hens are more easily infected compared with roosters. Within the species, differences of breed and individual sensitivity are recorded. The breeds with a high production of eggs, such as the Leghorn, are more susceptible to infection than mixed breeds (Orpington, Rhode Island). It seems that this resistance is, actually, genetically induced[53].

The undernourished bird populations with vitamin (vitamin A, B, B12), mineral and protein deficiencies are exposed to infection. Fodders that contain 11% protein determine the increase of infection intensity and prevalence compared to the chickens fed a

diet containing 19% of protein. The addition of vitamin B2 to the feed containing 11% protein induced a low intensity and prevalence of the infection[24].

An ascarid species related susceptibility is demonstrated. In *A.* galli infection, the chickens have manifested more severe clinical signs and lesions than turkeys and guinea fowls, while in *A. dissimilis* the chickens are resistant and the turkey's very receptive[21].

The breeding system is an important risk factor in poultry farming. The *A. galli* infection registered different prevalence rates depending on the poultry production systems: 63.8% in the free-range/organic systems, 41.9% in the deep-litter systems, 5% in the battery cages, 37.5% in the backyard system, and was not identified in the broiler/parent system[54].

The age of the birds is another risk factor that affects sensitivity, the prevalence rate being higher in growing chickens. In Morogoro, Tanzania, *A. galli* was more prevalent in growers (69%) than in adult (29%) free-range chickens[36]. The susceptibility of birds is not influenced by the age and sex of the animals, in the case of *Ascaridia* infections, other than *A. galli*. No significant differences were found in the prevalence of *A. columbae* between adult (42.0%) and young pigeons (41.9%), or males (46.7%) and females (38.2%)[62].

The season influences the evolution of infections, the prevalence rate being higher in the autumn compared with the summer (Senlik et al., 2005).

***Route of contamination*** is oral, through ingestion of infective eggs. Consumption of earthworms or grasshoppers is another way of contamination for birds.

***Resistance***. The dissemination and remanence mechanisms of the foci of the disease are also conditioned by the resistance of eggs against the interaction of ecological factors. The factors involved in the survival of the eggs may be divided into two categories: extrinsic and intrinsic. Extrinsic factors are the ecological ones, temperature, humidity, pH and oxygenation. Age and anthelmintic resistance are important among the intrinsic factors.

Generally, the eggs of *Ascaridia* spp. are considered highly resistant to environmental conditions. They may survive for several months in suitable conditions of moisture and temperature.

The temperature is the most important factor in terms of egg resistance. The eggs do not develop for 42 days between 5°C and 10°C. Development occurs in 7 days at 30°C. The decrease of temperature determines a prolonged period of egg development, as follows: 25°C, 14-days; 20°C, 21-days and 15°C, 90-days. The lowest temperature favorable for the development of the eggs is 15°C. The upper limit of the temperature range at which the eggs may develop is above 35°C[68].

Around 95% of the eggs develop in 90% relative humidity; under 90% R.H., 97% of the eggs were completely developed; several eggs survived in 70% R.H. after 16 days. At 0% and 50% RH all eggs were dead[68].

*A. galli* eggs are very sensitive to detergents, sodium n-octyl-sulfate and alkyl-aryl-sulfonates being the most active[25].

The eggs in the environment are sensitive to the action of plants. Different extracts inhibit the development of *A. galli* eggs. Dust, fresh juice and extract of bishkatali (*Polygonum hydropiper*), neem (*Azadirachta indica*) and papaya (*Carica papaya*) impregnated in litter can be used for inhibition[23].

**Pathogenesis.** Populations of worms act by complex mechanisms, causing intestinal disorders similar to infections in mammals. The pathogenicity is due to mechanical interventions, inflammation, spoliation action, toxic and inoculator effect. The mechanical action is due to the large sizes of the parasites and consists in intestinal blockage. The parasites may migrate erratically in the oviduct due to a less effective treatment,

which does not kill the worms. Subsequent inclusion in the egg may occur[56]. Local inflammation is due to the penetration and development of larvae deep inside the intestinal mucosa. Local inflammation is due to the penetration and development of larvae deep inside the intestinal mucosa, but other inflammatory processes, such as liver foci, may be caused by the *Ascaridia* spp.[45]. The adults consume intestinal content and despoil the hosts by significant amounts of carbohydrates, calcium, phosphorus and vitamins (A, B1). Consequently, the growth of the animals is delayed, there occur rickets, secondary hypotrepsy, a decrease in eggs production, all these favoring the emergence of other diseases. Parasitic toxins cause metabolic disturbances and thymus atrophy. The adults and larvae of *Ascaridia* spp. may inoculate bacteria (*Salmonella enterica*) or viruses (viral arthritis/tenosynovitis in chickens - reovirus, encephalomyelitis virus - pirocnavirus, avian infectious bronchitis virus - coronavirus)[7,33]. Despite its inoculation effect, *A. galli* demonstrate antibacterial properties, causing a frequency and a low amount of microorganisms in the intestinal content in *A. galli* infected hens[49].

**Immunity.** Although it is a less studied field, the immune mechanisms identified in birds infected with *Ascaridia* spp. prove the development of both types of immunity, i.e., humoral and cellular. *A. galli* stimulates a strong antibody response. The IgG antibodies are detected in blood and yolks for a period of 105 days postinfection[38]. The cell-mediated immune mechanisms develop during *Ascaridia* spp. infections[37].

**Clinical signs.** The disease evolves severely in chickens, and subclinically, unapparently in adults. In heavy infections of the chickens the symptoms consist in adynamia, misconduct, decreased appetite, and diarrhea. Chickens lose weight, stagnate in development, and become anemic and emaciated. The disease persists and becomes chronic. In advanced stage, paresis, pseudoparalysis of wings, pica, cachexia, and increased mortality can occur. Egg production drops in laying hens.

**Pathology.** *A. galli* causes catarrhal or hemorrhagic enteritis, intestinal obstruction, atrophic thymus glands[55]. In pigeons, it is responsible for liver microlesions: fatty degeneration and areas of coagulation necrosis of the hepatic cells, mononuclear and polymorphonuclear cellular infiltrations in the necrotized areas. In the lung of pigeons, hemorrhagic areas, congested blood vessels, and haemosiderosis are commonly found. Mononuclear and polymorphonuclear cellular infiltration developed in the peribronchiolar tissue and in the interalveolar septae. Necrosis in the intestines, kidneys and myocardial cells are diagnosed[2]. *A. dissimilis* causes hepatic granuloma in turkeys with the appearance of white foci[44].

**Diagnosis.** The clinical picture during summer in chickens and autumn to winter in adult birds is indicative. Identifying the eggs in feces using flotation tests has the disadvantage of possible confusion with eggs of *Heterakis* spp. The egg of *Ascaridia* spp. has convex sides, while the egg of *Heterakis* spp. has slightly flat and parallel sides. Necropsy is a method of certainty and allows the observation of lesions and adult parasites in the intestinal lumen.

***Differential diagnosis*** includes other chronic gastrointestinal helminthosis and hypo-vitaminosis. In chickens it will be differentiated from eimeriosis, trichomoniasis, histomoniasis, and spirochaetosis.

**Treatment.** Highly-effective medications that include active ingredients of imidazothiazole, benzimidazoles and avermectins derivatives are widely used:

- fenbendazole, 5 to 10 mg/kg bw, was found to be >98% effective in the treatment of turkey ascaridiosis[73]. At dose rates of 60.6 ppm and 30.3 ppm, the efficacy was 99.2 - 100% and 69.0 - 89.6%, respectively[58]. At 100 mg/kg bw, it eliminated *A. galli* in 221 captive birds of six orders and 38 different species[32].

- ivermectin, 0.3 mg/kg bw, subcutaneously, was 90 and 95% effective against immature and adult worms, respectively[63].
- piperazine dihydrochloride, 64, 100 and 200 mg/kg was 86%, 60% and 100% effective against immature *A. galli*[43]. A higher dose of 500 mg/kg bw had a 61-83% efficacy in older chickens[52].
- pyrantel tartrate at dose rates of 50, 75, 100 and 125 mg/kg bw showed a 43.9, 82.1, 92.8 and 99.1% efficacy on the third stage larvae of *Ascaridia galli*[47]. A reduced dose of 15 mg/kg bw was 18 to 100% effective in chickens treated at 10, 20, 30 and 40 days pi. At a dose rate of 25 mg/kg, it was 14-44, 100, 100 and 99-63% effective[48].
- tetramisol, 40 mg/kg bw reached 89-100% efficacy in young as well as older chickens[52].
- metriphonate, 50 mg/kg bw had no effect against *A. galii* in chickens[52].
- levamisole at a dose rate of 16 mg/kg bw in the drinking water was not shown to be highly efficacious, varying between 54 to 86%[72].

**Control.** Management is important in the control of the disease. Technological measures are important. Chickens should be separated from adult birds. Optimal conditions of microclimate, food hygiene, floors and litter should be ensured Pens should be well cleaned and drained, rotated and deep, and the litter must be kept dry. Droppings should be removed from bird houses and chemo-prophylaxis must be applied. Disinfection will be performed periodically or at the end of each technological process after depopulation of the halls, according to the principle "all in, all out".

## 6.2. Heterakidae: heterakiosis in birds

The family Heterakidae is morphologically characterized by a mouth opening surrounded by rounded lips not connected by interlabial lobes. The esophagus is short and stout and has a tri-valved posterior bulb. It includes the subfamily Heterakinae, whose members have broad caudal alae equipped with long, narrow papillae. It mainly includes parasites of birds, and, rarely, mammals[3]. The subfamily includes three genera of which the most important one is *Heterakis*, which contains parasitic species on ground-feeding birds, especially Galliformes, and some species in mammals. The members of this genus cause the disease called heterakiosis.

**Definition.** Heterakiosis is a geohelminthosis spreaded throughout the world that affects Galliformes, rarely Anseriformes. It evolves in all poultry farming systems as well as in intensive units. The disease evolves as state of latent parasitism or it manifests itself clinically in chickens, showing severe symptoms in pheasant chicks. It is caused by worms of the genus *Heterakis*, being involved in the development of histomoniasis in broiler turkeys.

**Etiology.** The species involved belong to the genus *Heterakis* and are characterized by an unequal body, pointed at the posterior end. Ontogenesis is typical, monoxenous. The species are:

- *Heterakis gallinae* (syn. *H. gallinarum*), a cecal nematode of poultry (in ground feeders), mainly chickens, turkeys, but also in ducks, geese, grouse, guinea fowl, partridges, pheasants, quail, turkeys and other wild Passeriformes; it is spread worldwide;
- *H. isolonche* in the ceca of pheasants, quail, turkeys, grouse, prairie chickens, and ducks;
- *H. dispar* in the ceca of ducks and geese; it is relatively nonpathogenic;

Among species involved in mammals, Smales mentions *H. spumosa* and *H. fieldingi* in the colon and caecum of rodent species[64].

***Morphology.*** *H. gallinae* has a cylindrical body, slightly unequally calibrated, tapered and sharpened at the posterior end, threadlike in females, and slightly curved dorsally. The male measures 7 to 13 mm long and the female is 10-15 mm long. At the anterior end, the mouth opening is surrounded by three

small, equally calibrated lips. The esophagus has a well-developed terminal bulb. Two narrow, lateral, smooth membranes are extended along almost the entire length of the body. The posterior end of males ends in a subulate point and they have two large lateral caudal alae, equipped with 12 pairs of pedunculated caudal papillae. The preanal sucker is well-developed and the spicules are unequal, the right one being larger (0.85–2.8 mm long) than the left one (9 0.3–1.1 mm long), which has a curved tip. The posterior end of the females is long, narrow and pointed, and the vulva is situated slightly posterior to the middle of the body. The eggs are oval-shaped, very similar with those of the A. galli, but with almost parallel sides, thick shell, unembryonated when deposited, and measure 63 to 75 per 36 to 50 μm.

*H. isolonche* is similar to *H. gallinarum*, but noticeable differences occur in the spicules. The size of the male varies between 5.9 and 15 mm in length, and the female is 9 to 12 mm long. At the posterior end, the male has a preanal sucker measuring 70 to 150 μm in diameter, and the symmetrical spicules are long (generally 1.4–1.9 mm) and equal. The eggs are 65 to 75 by 37 to 46 μm.

*H. dispar* is a bit larger than the previous species but similar in appearance, except for the spicules. The male measures 7 to 18 mm in length and has a large preanal sucker; its spicules are short and equal. The female size varies between 16 and 23 mm in length. The eggs are 59–62/39–41 μm.

***Life cycle.*** A biphasic life cycle is performed: a parasitic phase with larval and adult forms, and an exogenous one, in which the embryogenesis develops. Adult parasites live in their specific biotopes represented by the ceca of birds and feed on intestinal content. Oviparous females lay eggs that are passed in the environment through feces.

Embryogenesis consists in the development of the first-larval stage inside the egg and the first molt of $L_1$ resulting in infective egg that contains the second larval stage. Bird contamination is achieved by ingestion of infective eggs through fodder and water.

In the upper intestine, the eggs hatch and larvae reach the ceca. They burrow into the cecal mucosa where they molt and, at 12 days postinfection, return to the lumen, where they transform into adults that live free, not fixed on the lining. The prepatent period varies between 25 and 30 days.

Earthworms may intervene as paratenic hosts which consume the eggs of *Heterakis* spp. One of the first records of the phenomenon in literature refers to the earthworm dung, probably *Helodrilus parvus*[60]. The eggs may, in turn, serve as carriers for the protozoan *Histomonas meleagridis*[15].

**Epidemiology**

***Geographical distribution.*** Heterakiosis has a universal spread, its prevalence depending on the conditions in which the birds are kept, on the high density in paddocks and birds houses, on humidity, season, species, movements of wild birds and, not least, parasitic environmental pollution.

The prevalence was 24.0% in free range chickens in subtropical humid areas, in Jammu, India[27]. In coastal areas of South Africa, characterized by the same subtropical climate, the prevalence was higher, ranging between 80 and 94.4%[41]. In a temperate Mediterranean climate characterized by warm and humid summers and cool and damp winters, represented by the Samsun region in Turkey, the prevalence was 29% in scavenging chickens[30]. In semi-arid areas of Kenya, the prevalence in local scavenging chickens was 22.8%[42]. In the hot and dry climate of Jordan, the disease recorded a 33.0% prevalence in local scavenging chickens[1]. In chickens originating from comercial farms in Morocco, the prevalence was slightly reduced, namely 10%[17]. In commercial broiler chickens in northwest Arkansas, *H. gallinarum* was found only in

two companies (1.9 and 7.5% prevalence) of the 119 examined[69].

High levels of prevalence are also recorded in pheasant throughout the world: 37.25% in Eastern Europe (Poland and Romania)[67], between 78 and 100% in Britain[9], and 84.1% in pheasantries in Germany[13].

The information presented above demonstrates that infection with *Heterakis* spp. is more prevalent in pheasant than in poultry. High prevalences are recorded in warm and humid areas, more so in free range chickens than in commercial chickens.

***Sources of contamination*** are the infected birds that eliminate eggs and pollute the environment. Although the prolificacy of females is not great (around 617–621 EPG), heavy parasitism, with dozens of individuals per bird (79.2±66), increases the environmental pollution index[8]. The major sources of infection for poultry are infective eggs dispersed in the litters. These eggs are consumed via food or water. Earthworms, as paratenic hosts, may intervene mainly in the contamination of pheasants. Grasshoppers and flies could transfer eggs of *H. gallinarum* mechanically[12]. On the other hand, the eggs of *Heterakis* spp. are sources of contamination with *Histomonas meleagridis* in chickens.

***Susceptibility*.** The highest level of vulnerability occurs in pheasants, followed by chickens, web-footed birds (Anseriformes) being more resistant. Within the same species, the chickens infected for the first time are more sensitive, the disease evolving clinically, with a high morbidity rate. Re-infected young birds are more resistant than birds infected for the first time.

***Route of contamination*** is oral, through the consumption of eggs or earthworms with food or water.

***Resistance.*** The eggs of *H. gallinae* can survive in the ground for many years, especially on well-grassed ground. Areas of land with dense vegetation provide a better protection of the eggs against desiccation, extreme temperatures, or other organisms[34]. The resistance of eggs in different biotypes depends on the interaction of ecological factors and may reach a year, even 4 years. The eggs survive for 6 months at 4$^{o}$C and, during the winter on the ground covered by snow, they remain viable until the following spring[35]. They are resistant to conventional disinfectants.

**Pathogenesis.** Pathogenesis is dominated by the mechanical and irritating-inflammatory effects, which are more pronounced in the entero-parietal stage of larvae. These consist in a thickening of the walls, mucosal petechiae and the development of nodules in the mucosa and submucosa. Hepatic granuloma may appear in chickens, and verrucous lesions develop in pheasants. The great importance of these cecal worms is represented by the carrier role of the eggs for *Histomonas meleagridis* that cause the blackhead in turkeys.

*H. isolonche* is highly pathogenic for pheasants causing a mortality rate that exceeds 50%. Inflammatory action determines lymphocyte infiltration and the formation of nodules in the cecal wall, composed of granulomata and fibrous hyperplastic tissue[16]. The nodules may coalesce to form a thickened wall.

*H. dispar* is considered nonpathogenic.

**Clinical signs.** The disease evolves chronically in adult fowls and web-footed birds, without noticeable symptoms. In pheasants, especially chickens, the serious disease progresses with increased mortality. The clinical picture in this species is characterized by decreased appetite, greenish diarrhea, growth stagnation, weakness, anemia and increased mortality, if left untreated.

**Pathology.** *H. gallinae* causes in pheasants diffuse typhlitis with congestion, petechial hemorrhages, and a thickening of the mucosa. Mucosal and submucosal cecal nodules and hepatic granulomas develop in severe cases. In chickens, it produces catarrhal or

hemorrhagic typhlitis and a thickening of the cecal wall.

*H. isolonche* causes in pheasants verrucous typhlitis. Whitish nodules, miliary or pea grain size, give a crateriform aspect to the cecal mucosa. It can also cause the development of a neoplastic process[18].

**Diagnosis.** Clinically, it is difficult to be confirmed. A coproscopic examination and necropsy will be performed. Microscopically, the eggs will be detected using direct or flotation methods in the patent period. It is possible to confuse the eggs of *Heterakis* spp. with *Ascaridia* spp. eggs. The narrower eggs, having almost parallel sides, are *Heterakis*, while the convex sides are typical for *Ascaridia*.

Necropsy allows one to view adult parasites in the cecal lumen and in the lesions. The crushing of the whitish nodules, or mucosal scrapings and microscopic examination allow the identification of numerous larvae, eggs and adults.

The ***differential diagnosis*** will follow the evolution of histomoniasis, eimeriosis, trichomoniasis or capillariosis, associated or not with heterakiosis. These diseases may worsen and complicate the lesions, and, consequently, the symptoms.

**Treatment.** In the therapy of the disease, conventional medications are used, consisting of benzimidazole derivatives or avermectins, or modern alternative therapies. In the first category, the following demoinstrated an increased effectiveness:

- Flubendazole, 30 ppm achieved an overall efficacy of 99.2% against *H. gallinarum*[65]. The removal rate of fenbendazole for *H. gallinarum* varies between 78.6% at a dose rate of 15 ppm, for 3 days, and 100% at 120 ppm for 3 days and 45 ppm for 6 days[46]. At doses of 80 ppm for 3 days and 48 or 30 ppm for 5 days, it showed a 100% efficacy against *H. gallinarum*[74]. An even larger dose of this substance, of 100 ppm for 4 days, reduced natural infection with *Heterakis* spp. by more than 90%[29].
- Ivermectin 0.5 mg kg bw pour-on showed an efficacy rate of 59.14, 87.87, 97.65 and 99.57% in 1, 7, 21 and 28 days post treatment[28].
- Albendazole, 10 mg/kg bw, 2 consecutive days, expressed a 100% efficacy[22].
- Albendazole 10 mg/kg bw, levamisole 30 mg/kg bw and oxfendazole 7.5 mg/kg bw, all tested in the *H. gallinae* infection of peafowl (*Pavo cristatus*), expressed a variable but high efficacy, ranging between 95.6% for albendazole, 97.3% in levamisole and 98.88% in oxfendazole[4].

As a modern alternative therapy, various types of plant extracts are tested in terms of their anthelmintic activity.

- A natural plant extract named Parazitol, containing thymus (*Thymi herba*), 0.05 g/capsule (cps), propolis tincture 0.0005 g/cps, garlic (*Alii sativi bulbus*) 0.11 g/cps and aloe (*Aloe vera*) 0.03 g/cps, showed a moderate efficacy of 36% against *H. gallinae*[22].
- The ethanol extract of the root bark of *Millettia pachycarpa* at a concentration of 80 mg/ml caused destruction of the morphological structure, severe distortion in the cuticular organization throughout the body, collapse of the lips, contraction of the body, prominent folding of the cuticle at the cephalic region and extensive disintegration of the cuticle at the posterior end of *H. gallinae*. All these alterations are unsuitable for the survival of parasites[31].
- Crude aqueous extract of *Artemisia herba-alba* reduced the egg output of *H. gallinarum* by 97.78% and the worm burden by 96.07%, being one of the most efficacious plant extracts against the nematode[61].

**Control.** The measures available in the control of ascaridiosis in birds are also valid in the casse of this nematodosis. In addition, the pens should be cleaned so as to obtain improper conditions for the maintenance of earthworm populations. Control of the infection with *H. gallinarum* is only required when histomonosis is a major problem. It is based on maintaining proper hygiene conditions. It is necessary to segregate the species of birds from each other, to remove and dispose the litters from houses of poultry.

When all these measures are not enough to manage the disease, chemoprophylaxis may be applied.

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# 7.1. Acuarioidea

Superfamily Acuarioidea contains small to medium-sized nematodes that inhabit the upper alimentary tract mainly of birds, mainly waterfowl, several species being involved in mammals. Superfamily contains a single family recognized, the Acuariidae.

Morphologically, they are easily recognizable, due to the cordons that extend from, or are restricted at the cephalic extremity, having various aspects and associated ornaments which extend posteriorly from the oral opening.

Biologically, all acuarioids females are ovoviviparous, laying embryonated eggs that contain first-stage larva. The life cycle is diheteroxenous, differentiating the two general patterns of transmission, one in aquatic and the other in terrestrial environments[1].

## 7.1. Acuariidae: acuariidosis in waterfowl

Family Acuariidae is divided into 3 subfamilies (Acuariinae, Seuratiinae and Schistorophinae) and number approximately 40 genera and 300 species. The diseases caused by the members of the family are called acuariidosis.

Genera *Acuaria*, *Dispharynx* and *Echinuria*, are some of the most important from family. The diseases produced by the species included in these genera are named acuariosis dispharyngosis and echinuriosis, being important for veterinary medicine.

**Definition.** Acuariidoses are digestive biohelminthoses with seasonal evolution during the summer, that affect gallinaceous birds, waterfowl and pigeons. The diseases evolve frequently subclinically or are manifested in young birds.

**Etiology.** A large number of species are involved in the causation of disease, but the most important are:

- *Cheilospirura* (*Acuaria*) *hamulosa* inhabits the gizzard in galliforms: turkey, pheasant, quail grouse and guinea fowl.
- *Dispharynx nasuta* is localized in proventriculus in turkey, pheasant, partridge, quail, guinea fowl, grouse and pigeon.
- *Echinuria uncinata* parasitizes in esophagus, proventriculus, gizzard, and small intestine in duck and goose.

***Morphology.*** *C. hamulosa* has a cylindrical, stout, equal calibrated and whitish body, abruptly tapered at the anterior end. Male measures between 8.81 and 19.0 mm length and 0.27-0.31 mm maximum width; size of female varies from 9.76 to 25.0 mm length and maximum width between 0.27 and 0.54 mm[7,18].

At the anterior end, the mouth is bounded by two large triangular lateral lips. The worm has, at the anterior end, four waved cuticular cordons that extend posteriorly at least two-thirds the length of the body, without anastomosing or recurring anteriorly.

The posterior end of the male is tightly coiled and has two wide caudal alae and two unequal and dissimilar spicules. The left one is slender and measures between 1.48–1.74 mm length. The right is much smaller than previous, curved being only 0.22–0.26 mm long. Ten pairs of papillae surround the cloacal orifice, having a specific layout: three pairs are pre-cloacal situated, two pairs are ad-cloacal and five pairs are post-cloacal placed.

Posterior end of the female is pointed, and vulvar opening is situated near the middle of the body, posteriorly. The eggs are oval-shaped, thin shell, 40x27 μm being embryonated when laid.

*Dispharynx nasuta* has a cylindrical and stout body varying between 3.6 and 6.4 mm long and 0.14-0.30 mm width the male, and 3.26 to 7.84 mm length x 0.25-0.60 mm width, the female.

At the anterior end, the mouth is delimited by two pseudolabia, each equipped with one pair of large cephalic papillae and one discreet

amphid. The buccal capsule is short, and the cuticle surrounding it is transversely striated. It has four wavy and convoluted cuticular cordons that originate at dorsal and ventral sides of the mouth opening (the base of lips). Cordons extend posteriorly to the posterior segment of muscular esophagus; then anteriorly recurrent a short distance[18,19].

Posterior end of the male is coiled; it presents two well-developed caudal alae and a bluntly rounded terminal end. Nine pairs of papillae surround the anal orifice, 5 being postanal and four preanal. The spicules are unequal; the largest is slender and curved, measuring 0.4 mm length; the other is short, 0.15 mm long and canoe-shaped (navicular).

Posterior end of the female is short and tapered, and vulvar opening is placed in the fifth segment of the body, posteriorly. Eggs are ellipsoid, thick shelled, 33-40x17-26 μm and embryonated when laid.

*Echinuria uncinata* has a slender body, whitish, attenuated at extremities. The male is 8-12.7 mm long and 0.3-0.5 mm wide; female is 12-18.5 mm length and 0.7-0.9 mm wide[16,18].

Anterior end is round, and the cuticle is fine transverse striated and has four rows of spines. The mouth opening is bounded by two pseudolabia, each equipped with two cephalic papillae. Two pairs of cordons originate in the basis of pseudolabia and extend antero-posterior being not recurrent but anastomosed posteriorly.

Posterior end of the male is curved ventrally and shows 9 pairs of pedunculated papillae, five arranged post-cloacal and four pre-cloacal. The tip of the tail has a button-like process; the spicules are unequal, dissimilar; the right is wider and shorter (205-250 μm) than the left one (550-725 μm) which is slender and bell-shaped proximally.

Posterior end of the female is conical, short, and its tip is rounded. The eggs are oval-shaped 28–37x17–23 μm being embryonated when laid.

***Life cycle*** is indirect, diheteroxenous, realized through intermediate hosts. Adult worms live in their habitats where females lay embryonated eggs. The eggs are eliminated in the environment through feces. Intermediate hosts ingest the eggs; grasshoppers (*Conocephalus*), weevils (*Oxydema*, *Sitophilus*), beetles (*Tenebroides*, *Tribolium*), and sandhoppers (*Orchestia*) are IH for *C. hamulosa*, crustaceans (pill-bug, *Armadillidium vulgare* and the sow-bug, *Porcellio scaber*) are involved in *D. nasuta* development and water fleas (*Daphnia*) are utilized by *E. uncinata*[18]. The eggs hatch and larvae will penetrate the tissues of IH (muscle, hemocoel) where they develop becoming infective, following two molts.

Birds ingest infected arthropod and become contaminated. In piscivorous birds that do not prey such small intermediate hosts, amphibians and fish intervene as paratenic hosts. They consume arthropods and the larvae encapsulate in their digestive system retaining their viability and infectivity for the final hosts.

The third-stage larvae released from IH penetrate the mucosa of specific or adjacent (proventriculus for those that develop in gizzard) habitats. The larvae mature and become adults after two molts. Prepatent period varies between 30 and 50 days.

**Epidemiology**

***Geographical distribution*.** All species are worldwide spread recording different prevalences. In the state of Rio de Janeiro, Brasil, *C. hamulosa* prevalence in the pheasants was 14.3%; in chickens this value was 26.7%[7]. In India, the same species had 1.6% prevalence in backyard chickens in subtropical and humid zone of Jammu and 3.5% in the indigenous chicken of Kashmir Valley[9,14]. In chicken farms, in the Gharb region—Morocco, two acuarioids species were found: *C. hamulosa* (2.7%) and *D. nasuta* (5.3)[8]. In scavenger chickens in Amhara region, Ethiopia, *Dispharynx spiralis*

(syn. *D. nasuta*), another acuarioids species from the same genus, was more prevalent (2.62%) than *C. hamulosa* (0.75%)[6]. In chicken in the Van region, Turkey, only *D. nasuta* was identified (1%)[12]. In rural scavenging poultry, in Tanzania, *D. nasuta* has recorded 0% and 2.7% prevalence during the wet season and dry season, respectively, while the prevalence of *C. hamulosa* was 8.3% and 19.3%[13]. *E. uncinata* was identified in different wild waterfowl species: green-winged teal, *Anas crecca*, from southwest Texas (1%)[4], *Anser indicus* in the Lodz Zoological Garden, Poland[20], in Laysan ducks (*Anas laysanensis*) in Hawaii[17] and in waterfowl at Delta, Manitoba[2].

***Sources of contamination*** are the infected birds, intermediate and paratenic hosts.

***Susceptibility*.** A large number of domestic and wild species of birds are susceptible to infection. Young birds are most receptive.

Involvement of a high number of wild birds species increases the risk of transmission of infections and rate of the diffusion of the diseases. Infection with *D. nasuta* is identified in 51 species of wild birds belonging to 9 orders: Galliformes (14), Passeriformes (25), Columbiformes (3), Piciformes (3), Gruiformes (2), Charadriiformes Psittaciformes, Cuculiformes and Coraciiformes, each with one species. Infection with *E. uncinata* is reported in 67 species belonging to 2 orders: Anseriformes (66) and Charadriiformes (1)[5].

***Route of contamination*** is oral, by ingestion of intermediate or paratenic hosts.

***Resistance*.** Resistance of eggs is not very well known because they are consumed by intermediate hosts. It is estimated that their survival does not exceed 2-3 months, depending on environmental conditions in which they are exposed. Dry substrate and the direct action of solar radiation have the strongest adverse effects.

**Pathogenesis.** Parasites act mechanically obstructive, local, with narrowing of the lumen of proventriculus due to nodules formed by parasites. Irritative-inflammatory action is due to the striations and cuticular spines that produce catarrhal inflammations and edema of affected mucosa and hypertrophic processes during chronic evolution. Parasites have hematophagous nutrition exerting a spoliation action expressed by anemia, weight loss and emaciation. The intensity of parasitism determines the severity of pathogenic actions. Low infections with *C. hamulosa* cause little damage; in heavy infections, the wall of the gizzard may be severe affected. *D. nasuta* may cause serious damages to the wall of proventriculus due to the combined mechanical and inflammatory actions that consist in thickening and macerating of the wall. *E. uncinata* inoculate bacteria into the nodules formed in the wall of proventriculus.

**Clinical signs.** Generally, the infections may evolve subclinical a long time, but when parasitism in young fowls is massive, pale comb and wattles, growth stagnation, weakness, and diarrhea may appear. The mortality may vary between 15 and 90% in chicken flocks after 4 to 8 weeks of evolution.

*C. hamulosa* is, generally, nonpathogenic and does not cause clinical signs despite the severe lesions produced by worms[11,14].

*D. nasuta* is responsible for gradually droopiness and reduced activity of birds, retarded development in chickens and weight loss in adults despite the voracious appetite. Massive infections are exhibited by anorexia, emaciation and death.

*E. uncinata* infections in goslings and ducklings may rarely evolve directly with mortality, without previous clinical signs. Chronic form is expressed by listless, discoloring, untidy feathers, inability to flight, sternal decubitus position, weakness, awkward gait, with crossed legs, diminished appetite, lameness, difficulty in breathing, dysphagia with retching or choking when attempts to feed, emaciation and finally cachexia and death.

**Pathology.** *C. hamulosa* causes hemorrhages, nodular inflammation of the gizzard lining, with soft nodules that enclose parasites. Nodules may transform in ulcers, and mucosa and koilin become thickened.

*D. nasuta* produces ulcerative proventriculitis, multifocal petechial hemorrhages in the vicinity of worms, thickening, and maceration of proventriculus wall and the parasites are almost completely covered by the proliferated tissue. Proventricular glands are edematous, infiltrated and finally destroyed.

*E. uncinata* determine nodular pro-ventriculitis; in chronic form nodules may be transformed in abscesses. Sometimes, nodules become granulomas.

**Diagnosis.** Right diagnosis presumes the identification the eggs in the feces or the adult worms in their habitats: *C. hamulosa* in the gizzard, *D. nasuta* in the proventriculus and *E. uncinata* in the intestines.

***Differential diagnosis*** includes other diseases that affect anterior segments of the digestive system: capillariosis, amidostomosis, adenoviral gizzard erosion, microbial disorders.

**Treatment.** Treatment protocols are not developed for these parasites. Some drugs, accidentally tested against acuarioids in birds have demonstrated a good efficacy. Mebendazole, at a dose rate greater than 75 mg/kg body-weight for 5 to 7 days, showed some action against adult *D. nasuta*[3]. Ivermectin at 0.4 mg/kg given subcutaneous, once, monthly, revealed a good efficacy to control this lethal infection in African jacanas (*Actophilornis africana*)[15]. At a dose rate of 0.2 mg/kg bw, in conjunction with antibiotics, ivermectin has improved the condition of red-breasted goose (*Branta ruficollis*) and black-necked swan (*Cygnus melanocoryphus*) infected with *E. uncinata*, at the Whipsnade Zoo, UK[10].

**Control.** Because all these acuarioids species are bio-helminths, control of the intermediate hosts is necessary to prevent infections. Aquatic IH that intervene in the life cycle of *E. uncinata* are almost impossible to be controlled, thus, reduction of birds exposure has the same effect.

Periodical deworming of birds in the area where the disease evolves, followed by manure collecting and bio-thermal sterilization contribute to control of diseases.

It is envisaged the interruption of biological circuits of parasites in nature by confining animals to runs on bare ground and stopping the birds to graze or to access polluted pastures or pools.

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# 8. Habronematoidea

Superfamily Habronematoidea includes parasites in birds, mammals and fish, some of them very important of economically point of view. Morphologically are recognizable based on the presence of narrow pseudolabia and median lips. Biologically, are biohelminths having heteroxenous life cycle and paratenesis may occur in certain groups. Superfamily is divided into four families: Habronematidae, Hedruridae, Tetrameridae and Cystidicolidae[2].

## 8.1. Habronematidae: habronemosis in horses

Family Habronematidae contains three subfamilies: Habronematinae, Histiocephalinae and Parabronematinae. Its members are characterized by not globular and/or spiralled body, not inflated at the posterior end, and moderately sexual dimorphism. Pseudolabia are well-developed, large, cover median lips and show eight papillae on median lips. Family contains parasites of birds and mammals[3]. The diseases caused by the family members are, generically called habronematidoses. One of the most important in mammals is habronemosis of horses, produced by the members of genus *Habronema*.

**Definition.** It is a chronic biohelminthosis that affects equines, clinically characterized by gastric, cutaneous, conjunctival and respiratory disorders, with seasonal contamination during the summer, at pasture.

**Etiology.** The disease is caused by the following species:

*Draschia megastoma*, genus *Draschia*, is a common parasite of the stomach in horses, inhabiting especially into the fundus area.

Genus *Habronema* represented by following species: *Habronema muscae* and *H. microstoma* (syn. *H. majus*), all localized into the stomach.

***Morphology.*** *D. megastoma* has a medium-sized and whitish body. The male measure 7-13 mm length and the female is 10-20 mm long. At the anterior end has a well-developed buccal capsule. It is funnel-shaped, thickened anteriorly and devoid by teeth. At the proximal opening, the capsule is delimited by two unlobed lips (pseudolabia) equipped with sensory papillae. Two cervical lateral alae are present. The posterior end of the male is twisted and spiralled; anal orifice is delimited by 6 pairs of pedunculated papillae. The spicules are unequal, the left one being longer than the right. The ovoviviparous female has the vulvar opening in the middle of the body.

*H. muscae* is a bit larger than previous species, the male measuring 8-14 mm length and the female 13-35 mm. The body is yellowish to orange in colour. At the anterior end shows a cylindrical buccal capsule sometimes equipped with internal teeth, large trilobed or entire lips (pseudolabia) provided with papillae, and interlabia that are shields of cuticle which overlap dorsally and ventrally on pseudolabia. An unilateral cervical alae is present. The male has wide alae at the posterior end, a variable number of pairs of papillae, pre- and postanal and two unequal and dissimilar spicules. The tail has a twisted-spiral shape. Posterior end of the female is cone-shaped and vulvar orifice is placed in the middle region of the body. The female is ovoviviparous and lays embryonated eggs.

*H. microstoma* (Naem, 2007) has a cylindrical body, whitish, slightly narrowed at the anterior end. The female is 15.5 to 25.5 mm long and 193.0 μm wide and the male measures 16.5–22.0 mm long and 145.0 μm wide. At the anterior end has a single lateral alae. The mouth is surrounded by two bilobed lips, and numerous papillae are present. The posterior end of the male is spirally twisted, and the spicules are unequal calibrated. Six pairs of papillae surround the anal orifice.

Vulvar opening is located in the middle of the body.

***Life cycle.*** Life cycle is indirect, diheteroxenous. Adult parasites live in their

specific habitat, the stomach of horses and females lay embryonated eggs. The eggs hatch during intestinal transit or immediately after elimination through faeces. First-stage larvae are ingested by IH represented by the larval stages of flies. A wide range of species may intervene: *Musca domestica*, *M. tempestiva*, *M. vicinina*, *M. humilis*, *M. lusoria*, *M. terraereginae*, *M. ventrosa*, *Muscina stabulans*, *Stomoxys calcitrans*, *Lyperosia viritans*, *Pseudopyrellia* spp. and *Sarcophaga* spp. The larvae penetrate the hemocoel of insects and their metamorphosis is synchronized with insects' development. Infective stages $L_3$ are developed following two molts. The third stage will migrate to the head of insects and will be transmitted to a new horse when muscids feed on moist surfaces, such as nostrils or mouth, but eyes area or wounded skin may be, also, sites of larval transfer. The larvae that are deposited around the muzzle are swallowed and migrate to the stomach where become adults after two successive molts. The larvae that reach the eye or moist skin will not finalize their development but provoke an inflammatory syndrome called cutaneous habronemosis or summer sores. This may cause the death of larvae or the larvae may enter into the blood capillaries and migrate to the lungs where cause pulmonal habronemosis. The larvae may, also, reach the lung entering through the nostrils and migrating backward. Here, they can cause another condition, pulmonary or lung habronemosis. Erratically migration of the larvae through the brain, with development of an adult female, is registered in a mare[18].

**Epidemiology**

***Geographical distribution*.** Generally, the disease has a low incidence being reported during the summer as cutaneous habronemosis, and in autumn and winter as gastric form.

It is worldwide distributed, recording different values of prevalence in many countries of Eurasia, America, Australia and Africa, as are shown in table 15.

***Sources of contamination*** consist of horses with gastric habronemosis, which release embryonated eggs, and muscids, IH that transmit the disease. The infection rate in flies may reach 16.2%, the males being more infected (26.2%) than females (8.7%). The origin of flies is importantly regarding the rate of infection the flies trapped outside the shelters being more infected (20.9%) than inside the buildings (1.1%). The burden of parasites carried by the flies is generally, low, the maximum number of larvae per fly being 29[27].

***Susceptibility*.** The horse is more responsive than the donkey, within the family Equidae. The working animals, with skin wounds are more susceptible within the species than other categories (recreational horse, horse of exhibition). The animals kept on pasture represent another category of horses highly exposed to contamination. Transmission of disease inside the building is possible, but difficult to achieve, the activity of muscids being enhanced to pasture. Increasing the density of muscids population is a risk factor.

***Route of contamination*** in habronemosis is particular. It is not a transcutaneous contamination itself and also, no oral. It may be expressed as a transfer of the *Habronema* larvae during feeding of flies into moist areas of the body. The sites of larval penetration into the body, following this transfer, are very diverse: oral, conjunctival, ocular or aerial.

***Resistance*** of nonparasitic forms is directly influenced by temperature and humidity of fecal mass, reaching 30 days in summer conditions. At temperatures between 25-30°C the larvae survive 6 to 7 days. At 5°C, in vitro, they remain viable for 28 days. Infective $L_3$ larvae are very sensitive to dryness and die in a few minutes on dry substrates, outside the body of IH. The larvae survive longer and cause diseases on moist substrates such as

**Table 15.** Prevalence of habronemosis in horses

| continent | country | species identified | prevalence% | author |
|---|---|---|---|---|
| Africa | Morocco | *H. muscae, H. majus* | 95.8; 75.6 | Pandey et al., 1981 |
| | Ethiopia | *D. megastoma, H. muscae* | 100; 100 | Getachew et al., 2010 |
| | Cameroon | *Habronema spp.* | 2.99 | Lem et al., 2012 |
| South America | Brazil | *H. muscae* | 5 | Pereira and Vianna, 2006 |
| North America | United States, Kentucky | *Habronema spp.* immature, *H. muscae*, *D. megastoma* immature, adult | 24; 38; 13; 62 | Lyons et al., 1983 |
| Australia | Queensland | *D. megastoma, H. muscae* | 39; 43 | Mfitilodze and Hutchinson, 1989 |
| | Victoria | *D. megastoma, H. muscae, H. majus* | 5; 13; 2 | Bucknell et al., 1995 |
| | Perth | *D. megastoma, H. muscae* | 66.2; 35.3 | Dunsmore and Jue Sue, 1985 |
| Asia | Saudi Arabia | *H. muscae, K. megastoma* | 22.2; 4.4 | Al Anazi and Alyousif, 2011 |
| | United Arab Emirates | *H. muscae* | 36.7 | Schuster and Sivakumar, 2013 |
| Europe | Poland | *H. majus, H. muscae* | 16; 8 | Gawor, 1995 |
| | Sweden | *H. muscae* | 1.1 | Höglund et al., 1997 |
| | The Netherlands | *Habronema spp.* | 4.3 | Borgsteede and van Beek, 1998 |
| | Germany | *H. majus, H. muscae, Habronema spp.* | 8; 26.5; 5.5 | Rehbein et al., 2013 |

horse lips, skin wounds, conjunctival and pituitary mucosa[19].

**Pathogenesis.** Major pathogenic action of habronematids is the irritative-inflammatory which consists in congestion, petechiae, ulcers and disseminated nodules in the skin, gastric mucosa, lung parenchyma or conjunctival mucosa. Gastric nodules gradually increase in size, become spongy, cavitary and areolated structures the worms living protected in created cavities. Gastric nodules reach the size of a hen's egg and acts mechanically, obstructing the pyloric sphincter or causing gastric wall rupture. Inoculation action is prominent in pulmonary nodules that are superinfected and transformed into abscesses.

**Clinical signs.** The clinical picture is polymorphic, depending by evolutionary form and intensity of parasitism. The disease is expressed by cutaneous, conjunctival and pulmonary disorders caused by the larvae and gastric symptoms produced by the adult parasites.

***Conjunctival habronemiasis*** is expressed by visible granulomas disseminated on conjunctival mucosa, associated with epiphora, photophobia, and squinting. The larvae are visible, occurring on the eyelids, itself, on the third eyelid or on the conjunctiva.

***Cutaneous habronemosis*** is called also summer sores or jack sores, swamp cancer, bursati and granular dermatitis. Commonly affected areas include legs (cannon, stifle), penis, preputial sheath, eyes, neck and dorsal sides, and any open skin wounds. It is manifested by granulomas and excoriations on the skin being caused by infective larvae that penetrate wounded skin. Lesions are itchy or painful, so the animals bite themselves; the

scratching may be intense, the wounds bleed or suppurate, skin swells and ulcers are developed. Wounds heal as advancing to the winter. Dysuria may appear in stallions or geldings which present wounds on the penis, but sex and age do not influence the evolution of disease, all horses being susceptible to infection. Skin disease has a recurrent character; the wounds appear during the summer, attenuate in winter and worsen in the next summer.

***Pulmonary habronemosis*** is commonly asymptomatic; rarely the animals express cough and/or abundant nasal discharge.

***Gastric habronemosis*** evolves subclinically or is expressed by digestive disorders during autumn or winter. The animals show capricious appetite, sometimes pica, polydipsia, feverish, constipation alternating with diarrhea and colic syndrome due to the pyloric obstruction and severe stomach indigestion.

**Pathology.** Lesions correlates with the clinical form and parasitic stage involved. Depending of the clinical evolution, are revealed:

- granulomatous conjunctivitis and keratitis in ocular habronemosis;
- nodular, granulomatous and ulcerative dermatitis, tracks of necrotic debris, granulation tissue, skin hyperplasia, and festering wounds in cutaneous form;
- nodular and purulent bronchitis, pulmonary abscesses in the lung;
- nodular gastritis, granulomatous masses in the stomach mucosa, pyloric stenosis or obstruction and stomach wall perforation in gastric habronemosis;

**Diagnosis.** Clinical examination may guide the diagnosis; nodules, pruritus, itching, wounds, and greasy granulomas are indicative. Identification of eggs or larvae in feces using flotation tests or larvoscopic method allows an undoubted diagnosis. Biopsy or skin scrapings are required to reveal larvae in lesions, allowing a definitive diagnosis. Pulmonary habronemosis is diagnosable only through necropsy.

***Differential diagnosis.*** Gastric form includes other helminthoses, gasterophilosis and colic syndrome with another etiology. Cutaneous habronemosis needs differential diagnosis by ulcers from trypanosomosis, parafilariosis and cutaneous wounds (harness). Pulmonary habronemosis must be differentiated by glanders, lung granulomas caused by larval stages of *Dyctiocaulus arnfieldi*, *Parascaris equorum* and *Strongyloides westeri*.

**Table 16**. Active substances tested in therapy of habronemosis

| group | active substance | dose rate (mg/kg bw) | efficacy (%)/author |
|---|---|---|---|
| organophosphate | dichlorvos | 31 | 0[25] |
| benzimidazole derivates | oxibendazole | 5, 10, 15, 20 | 0[21] |
| | oxfendazole | 10 | 96-99[14] |
| | cambendazole | 20 | 97[16] |
| avermectins | ivermectin | 0.2 sc | 86[12] |
| | | 0.2 im | 100[8] |
| | | 0.2, paste | 99.6[7] |
| | moxidectin | 0.3-0.4 gel | 99[28] |
| | | 0.4, paste | 100[4] |
| | | 0.4, paste | 99.5[7] |

**Treatment.** Habronemosis therapies tested are shown in table 16.

**Control.** Three measures are essential in controlling the disease:

- Periodical deworming of animals. Quarterly frequency is indicated. Ivermectin and moxidectin are recommended due to their high therapeutical efficacy.
- Fly Control. Fly repellents, fly strips, fly collar and topical solutions, especially those that cover the belly are useful. Fans mounted on the doors of stables will prevent the access of flies in building.

Topical Wound Care. Treatment of the open wounds discourages the flies to land and to release the larvae into the tissue, protecting the animals.

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# 9. Filarioidea

Filariids worms are nematodes that belong to the superfamily Filarioidea, Order Spirurida. This superfamily includes 2 families, Filariidae (two subfamilies, five genera) and Onchocercidae (8 subfamilies, 80 genera)[2]. More recently, subfamily Setariinae, formerly included in family Onchocercidae, was raised in rank being considered a family, according to Myers et al.[104].

## 9.1. Onchocercidae: onchocercidosis in animals

Family Onchocercidae contains about 70-8o genera organized in 7 subfamilies, formerly Setariinae subfamily being accepted as family. Subfamilies Dirofilariinae and Onchocercinae are important for veterinary medicine because they include parasitic species in domestic mammals and poultry. The other families (Oswaldofilariinae, Icosiellinae, Waltonellinae, Splendidofilariinae and the Lemdaninae) contain parasites to amphibians, reptiles, wild birds and several species in mammals.

They are parasites of all tissues, organs and systems in the body of definitive hosts, but each species has a preferred site. Larval stage, called microfilariae, lives and circulates through the blood of the definitive host, facilitating the takeover by its hematophagous vector host. Many species of hematophagous arthropods are involved as vectors in the biology of onchocercids, fleas, mosquitoes, blackflies, horse flies, lice, ticks and other mites.

### 9.1.1. Onchocercidosis in horses

Onchocercoses of horses are biohelminthoses that evolve during the summer, sporadically or endemically, determined by nematodes of the genus *Onchocerca*. The diseases manifest clinically polymorphic due to different locations of the parasites in the connective tissues of the nuchal ligament (Horse Fistulous Withers) and connective tissues in the distal limbs.

#### *9.1.1.1. Cervical onchocercosis in horses (Neck threadworms, fistulous withers)*

**Definition.** It is a summer parasitosis in equines with chronic evolution, rarely acute, characterized by inflammation of the cervical ligament and withers. The evolution of disease can sometimes be discrete or even unapparent.

**Etiology.** The disease is caused by *Onchocerca cervicalis*, found deep in the connective tissues of the nuchal ligament.

***Morphology.*** The parasites have a whitish body, long, threadlike and coiled. The sexual dimorphism is pronounced; the female measures about 30 cm length while the male, smaller, is only 6 or 7 cm long. The cuticle is thick, transversally striated and shows spiralled thickenings. At the anterior end, the mouth is lacked the lips or prominent papillae in both sexes. In females, the vulvar opening is situated at about 500 μm distance from the anterior end. The posterior end of males is coiled, without caudal alae. The anal orifice is surrounded by at least 5 papillae, and the spicules are unequal calibrated, the left one being larger than the right, measuring between 320 to 360 μm. Microfilariae are filiform, 207 to 240 μm long, not sheathed.

***Life cycle.*** is diheteroxenous. The adults inhabit in the connective tissues of the cervical (nuchal) ligament where feed on host tissues. The viviparous females produce larvae (microfilariae) which enter the circulatory system and travel to the skin. They agglomerate into the blood capillaries, in the dermis and epidermis, and here are ingested by their intermediate hosts, *Culicoides* (midges, *C. nubeculosus, C. variipennis, C. victoriae, C. obsoletus* and *C. parroti*)[76,84,102] and/or *Simulium* (black flies) during their feeding. The larvae develop in their body, moulting twice, and migrate to the mouthparts of insects as the third-infective larval stage ($L_3$). During of a new feeding, the dipterans

transmit the infection to another horse. In the new host, infective larvae migrate to their specific habitat, mature and will reproduce at 6 months pi.

**Epidemiology**

***Geographical distribution*.** The disease is cosmopolitan, with incidence during the summer. It is diagnosed in horses, in Brazil, the prevalence of microfilariae being 17.9% and 16.6% of adult[92], in southeastern and midwestern United States recording a 51.4% prevalence for cutaneous microfilariasis[27], in the eastern United States (61%)[86], in Gulf Coast area (76%) and Louisiana (82.4%)[77].

It is not a major disease in temperate countries due to the specific habitats of intermediate hosts characterized by moisture, water vegetation, damp soil and elevated temperature. During the winter, the isotherm of 10$^{o}$C is considered the lower limit for survival and continuous activities of mosquitoes during the winter[98].

***Sources of contamination*** are diseased horses, which are the source of infection for vectors. Intermediate / vector hosts, in turn, are sources of infection for healthy horses.

***Susceptibility*.** Receptivity, it seems that increases with age, the prevalence being higher in horses over 6 years of age, comparing to those between 1 to 5 years of age. The prevalence of infection related to age groups was 10% in horses less than one year old, 28% in horses one to five years old, 48% between six to 15 years old, and 90% in horses over 16 years old[127].

***Route of contamination*** is transcutaneous through the biting of the intermediate hosts.

***Resistance*** of the parasites is conditioned by the resistance of dipterans.

**Pathogenesis.** Pathogenic actions are induced by the complex activities of adult parasites and microfilariae. They act local, mechanic and irritative-inflammatory, on cervical ligament, causing diffuse swelling in the region of the withers. Microfilariae produce nodules that calcify over time, increasing the consistency of the ligament.

Parasites can transmit and inoculate various bacterial agents. There is a link between Brucella abortus and equine fistulous withers where Onchocerca spp is involved[25]. Pyogenic flora may be also transferred by worms, complicating the pathological processes causing septicemia, phlegmon of withers, necrosis of ligament and spinous process with fistulization. Poor hygiene especially in the region of withers, nutrition deficiencies and exploitation using improper harnesses accentuate the pathogenicity of parasite.

**Clinical signs.** The clinical sign most commonly seen in onchocercosis, or equine nuchal disease, is fistulous withers[112]. Poll evil (a painful condition in equids that consists in an inflamed bursa at the anterior end of the neck, between vertebrae and the nuchal ligament) may be present. Despite the high prevalence of infection in horses, in many areas, both symptoms may be rarely seen. Microfilariae of *O. cervicalis* are incriminated in pruriginous dermatitis, periodic ophthalmia and some lesions of eyes, as keratitis and iriditis, but numerous other microfilariae may be involved. Cutaneous onchocercosis or summer dermatitis caused by dermal migration of *O. cervicalis* microfilariae is called also summer mange or allergic dermatitis in horses.

**Pathology.** Mild infections are expressed lesional through mineralization (ossification) in the nuchal ligament, caseous and calcified foci surrounding the dead parasites, tissue hyperemia, roughened surface of the supraspinous bursa, fibrous nodules, gelatinous mass in areolar connective tissue or liquefactive necrosis around viable worms, discolouration and hyaline degeneration of adjacent ligaments.

The severe lesions are developed in massive infections: necrosis of the nuchal ligaments, partial rupture of ligament and developing of seroma at the site of infection, extensive

calcification of disintegrated worms, necrosis and cavitation of the nuchal ligament.

Histopathologically, microfilariae cause perivascular mononuclear dermatitis and eosinophilic dermatitis. The adult worms are situated in tunnels, into the ligament, being associated with areas of calcium deposition between the elastic bundles and eosinophils, macrophages, epithelioid, giant and plasma cells infiltrations in connective tissue. Foreign-body reactions are developed around dead worms or parts of their bodies.

**Diagnosis.** Clinically, fistulous withers is diagnosed without difficulty, but clarification of the etiology can be problematic due to the multiple causes involved. Microscopic examination will clarify the etiology.

Skin biopsy of the affected areas is done, in order to detect microfilariae. Samples are dilacerated in saline and then leave few hours (6) at 37°C. Then are examined under a microscope using a low power objective (10x).

Skin scrapings are done in order to identify microfilariae during migratory phase through the skin. The scraping must be lightly and the tissue fluids expressed are transferred and examined in wet mounts.

***Differential diagnosis*** of fistulous withers is difficulty due to low opportunities of detecting the adult parasites within nuchal ligament. Cutaneous form is mistaken for urticaria or allergic dermatitis caused by hematophagous arthropod. The biopsy can differentiate these diseases.

**Treatment.** The usable management and medication depend by clinic form. The anthelmintic treatment is enough in uncomplicated onchocercosis. If phlegmons, fistulous withers or septicemia, had been developed, the surgery is mandatory, associated with antibiotic, sulfonamide or corticosteroids therapy.

There are numerous treatments which expressed a high efficacy of avermectins against *O. cervicalis*:

- Ivermectin, paste or injectable formulation, at a dose rate of 0.2 mg/kg bw per os, acts against microfilariae in the skin and blood circulation causing the disappearance or pronounced reduction in their number, at varying intervals of time post-treatment[45,63,78,117]. It has no efficacy against adult worms.
- Moxidectin in single doses of 0.3, 0.4, or 0.5 mg/kg bw has expressed a 100% efficacy in eliminating microfilariae of O. cervicalis from skin biopsies[99].
- Moxidectin 2% oral gel and ivermectin 2% oral paste, both products designed to treat horses, were equally 100% effective against *O. cervicalis* microfilariae[90].

**Control.** Control actions against mosquitoes should be applied in endemic areas. The horses must be protected by keeping into the shelters during the middle of the day when insects fly around the flocks on pastures. As such, nocturnal grazing is practiced.

Screening tests and periodic external treatments using insecticides should be considered. Collars impregnated with insecticides are useful. Hygiene of the skin is very important, and skin traumas must be avoided. Surgical intervention must be realized in severe cases of fistulous withers.

### *9.1.1.2. Onchocercosis of tendons*

**Definition.** It is a summer parasitosis rarely diagnosed in equines characterized by asymptomatic evolution or tenosynovitis localized in the suspensory ligament of fetlock, and tendons of the flexor muscles of the limbs.

**Etiology.** The disease is caused by *O. reticulata*, which locates into the connective tissues in the distal limbs.

***Morphology*.** The male measures 15-27 cm length and the female is 40 to 70 cm long. The body is cylindric, slender, threadlike and whitish. The cuticle is thick and presents transverse striations and spiralled thickenings that may be interrupted at the lateral fields. It is similar with *O. cervicalis*, without lip-like structure, at the anterior end. At the posterior

end, the males is strongly curved, flattened and has two narrow alae and two unequal calibrated spicules, the left one being longer and measuring 248-294 μm. Asymmetrically arranged papillae surround the anal opening. The posterior end of the female is bluntly conical, and the vulva is anteriorly placed, postoesophageal. The length of microfilariae varies between 330 and 370 μm.

***Life cycle.*** Parasites develop into the suspensory ligament of the fetlock, the flexor tendons and their sheath in horses, asses, mules. The larvae disperse into the synovial fluid of the joint, tendon sheaths, dermal lymph and blood capillaries near the site of adult worms. Intermediate hosts (*Culicoides* spp. - *Culicoides nubeculosus*) feed and take over microfilariae which develop in their body becoming infective. During a new feeding, the mosquitoes inoculate microfilariae to a new host. The optimal temperature for development is 25°C when the larvae reach the infectivity in 25 days. Prepatent period varies between 12 and 18 months and the patent period lasts few years[2].

**Epidemiology**

***Geographical distribution.*** The disease is prevalent in those areas that ensure optimal conditions for development of *Culicoides* spp. In Queensland, Australia, the prevalence of infection was 79.8%[119]. In Southern Darfur State, western Sudan, the prevalence was 0.7% from September 1998 to August 1999[42]. In the Urmia area of Iran, the prevalence was 3.7% between December 2006 to November 2007[41].

The other aspects of epidemiology, sources of contamination, susceptibility, route of contamination, and resistance are similar to those described to cervical onchocercosis.

**Pathogenesis** and **pathology.** The parasites act mechanical and irritative-inflammatory on the tissue in which they are located. They produce irritation of the nerves causing pain and lameness, but usually the infection evolves subclinical, without macroscopic signs. Agglomerations of parasites form nodules on the surface of tendons. These nodules diminish and disappear after 5 - 6 months, or will transform in parasitic fibroids followed by calcification. However, the hypertrophy of ligament persists. Inoculation action is remarkable.

**Clinical signs.** Diseased animals present painful and rough swelling of metacarpal, ligament and tendon regions during the warm season. Locomotor ataxia, severe lameness, arthritis and periarthritis, occur. In the septic complications, purulent collections are formed. These can open spontaneously or can complicate by phlegmon of the limb and become chronic with fistulization. Fragments of parasites may be seen into the pus.

Microfilariae are responsible for cutaneous disorders, so called summer itching, in the lower regions of the body, sides of abdomen, thorax, linea alba and limbs.

**Diagnosis.** Clinically, it is difficult to determine. Microscopic examination of lymph or skin fragments collected by biopsy, from the affected regions, reveal the presence of microfilariae in infected animals, thus being confirmed onchocercal etiology.

***Differential diagnosis.*** Cutaneous form must differentiate by other skin diseases: mange, lice, ringworm, and allergic dermatitis. Locations in musculoskeletal structures, tendons, ligaments, adjacent connective tissue must be differentiated by to the injuries, cutaneous habronemiasis, sarcoid, pythiosis, keloid scars, and excessive granulation tissue.

**Treatment** is based on avermectins associated with symptomatic therapy.

**Control** is similar to that described in cervical onchocercosis.

### 9.1.2. Onchocercidosis of cattle

**Definition.** It is a chronic parasitosis that evolves during summer, affecting cattle. It is caused by species of the genus *Onchocerca* which have different locations in the body of

the definitive hosts and varied geographical spread.

**Etiology.** The species involved are:

- *Onchocerca gutturosa* (syn. *O. lienalis*, Eichler, 1973a) located in ligamentum nuchae, gastrosplenic ligament and connective tissue adjacent to these ligaments.
- *Onchocerca dukei* is localized in muscle connective tissue.
- *Onchocerca gibsoni*, found in connective tissue
- *Onchocerca ochengi* has, as specific habitat, the scrotum, the udder and connective tissue.

***Morphology*.** The worms are encased in dense connective tissue; it is very difficult to collect intact worms, so that, almost all studies are done on parts of the parasites, their complete length being partially unknown.

*O. gutturosa*. The most typical morphologically feature is the presence of a guttural dilation at the anterior end, near the nerve ring, in both sexes. The body of parasites is cylindrical, whitish, slightly wavy and filiform.

The males measure 27 to 45 cm length[40], or 20-33 mm[33] and 78-163 μm wide, being smaller than females. The anterior end of the male is tapered, without transverse striations, and the mouth is simple and terminal surrounded by small papillae. The posterior end of the male is coiled, ventrally curved and blunt ended. The cuticle is thin, and its thicknesses are prominent in the middle part of the body. At the posterior end, the male has two unequal spicules, the left one being longer than the right. Both spicules are slightly arched. The anal orifice is surrounded by papillae.

The length of the female is more than 46 cm length (maximum length of a fragment collected intact from females) and 229-370 μm diameter. El-Sinnary[40] shows that the length varies between 20 and 59.5 cm and the females are between 28 and 46 cm according to Eberhard[33]. The anterior end is transverse striated. The cuticular ridges become more and thicker to the middle of the body and disappear before the tail of the worm that is blunt. Sizes described by Taylor et al.[141] vary between 2 and 6 cm long in males and females are longer than 60 cm. Microfilariae are unsheathed, and their length vary between 186-264 μm.

*O. gibsoni* (240-280 μm) has larger microfilariae than *O. gutturosa* (186-264 μm)[13].

***Life cycle*.** Adults develop in specific habitats in cattle and microfilaria, in peripheral blood vessels, with greater frequency in the auricular region. Intermediate hosts, *Simulidae* (*S. ornatum*) ingest the larvae from blood capillaries during feeding[133]. Bain[4], considered that *O. gutturosa* in transmitted by *Culicoides nubeculosus* that has another feeding behaviour and sites, different by *S. ornatum*. *O. gutturosa*, which develop in *Simulium* spp., was also transmitted by *Culicoides* spp., in Japan[136]. This feature is also considered as criterium of differentiation between *O. gutturosa* and *O. lienalis*, previously considered as synonyms[36]. Development of infective stages ($L_3$) requires between 14 and 25 days. The optimal growth temperature is 23°C when the larvae become infective in 13 to 15 days[37]. Hematogenous contamination occurs during a new feeding of IH on healthy cattle. Inoculated larvae travel to specific habitat where they mature.

**Epidemiology**

***Geographical distribution*.** The disease is spread in geographic areas where the intermediate hosts develop.

In Africa, is reported from Cameroon (85%)[146], Sudan[39], Ethiopia[43], Kenya and Somalia[23], Nigeria (40%)[109], Uganda[15], Ghana[140], and Tanzania[103].

In Europe, infection with *O. gutturosa* was found in South-East England (58%) in slaughtered cattle[38], in north Wales[94], in Germany, transmitted by both vectors, *S. ornatum* and *C. nubeculosus*[30], in Poland[28].

In United States, the infection with *O. gutturosa* is present in Minnesota cattle[116], Florida and Georgia[44].

***Sources of contamination*** are the infected animals and intermediate hosts. The microfilariae of *O. gutturosa* agglomerate in the skin of definitive hosts in the central area of the umbilicus or head skin, where intermediate hosts preponderantly feed. The intermediate hosts (*S. ornatum*) may ingest between 1 and 331 microfilariae with a mean of 18.9 per fly[37].

***Susceptibility*.** Rate of infection with *O. gutturosa* differs between age groups, adult cattle being more infected than young animals. In subtropical areas, the disease recorded high prevalence than temperate regions due to the richness of biotopes favourable to IH development.

***Route of contamination*** is transcutaneous via intermediate host bites.

***Resistance*** of parasites is conditioned and superimposed to those of intermediate hosts. It is shown that ambient temperature influences the behavior of microfilariae into the skin of the definitive host. The seasonal variations of some factors suggest that microfilariae are only available for ingestion during the period of vector activity. When the ambient temperature decreases and intermediate hosts disappear, the microfilariae migrate into the deeper regions of the skin of cattle[37].

**Pathogenesis.** The pathogenesis is similar to that described in onchocercosis of horses. The parasites act mechanically by compressing the surrounding tissue, irritative-inflammatory, toxic and inoculatory.

**Clinical signs** depend on the species involved and location. Phlegmon of the withers, painful tenosynovitis of the stifle that causes lameness and hypertrophy of the limb muscle may occur.

**Pathology.** Microfilariae produce nodular dermatitis in corporal regions that register high densities of larvae (the skin of the ventral midline). Adults determine chronic periostitis, tendinitis, lateral collateral and nuchal ligament inflammations. Connective tissue that surround cervical ligament is edematous, rarely hemorrhagic and contains adult parasites that can sometimes form rough nodules. Content of the nodules is liquid, gray, formed by necrotic tissue and portions of destroyed worms. Calcification processes of parasites and nodules often occur.

Histologically, micro galleries caused by the parasites are bounded by histiocytes, lymphocytes, eosinophils and fibrous tissue. Eosinophils may be seen sometimes on the cuticles of worms, and partial or complete calcifications, other times.

**Diagnosis.** Accurate diagnosis is based on skin biopsy method. Portions of skin were obtained from the ventral abdomen. The tissue is dissociated in saline and examined under a microscope. Microfilariae are revealed in infected animals.

***Differential diagnosis*** includes mycobacterial infection (tuberculosis) especially in mineralized lesions of onchocercosis[31]. Other diseases of which must to differentiate are mange, lice, setariosis, parafilariosis and rare localizations of *Echinococcus* spp. in tendons, ligaments and associated tissues.

**Treatment.** The new tendency aims to inactivate bacteria of the genus *Wolbachia*, endosymbionts of filariids, due to the resistance to avermectins developed by the worms in recent years. These bacteria essentially intervene in worm reproduction affecting the fertility, development, survival and development of parasite pathogenicity. Doxycycline administered for 4 to 8 weeks destroys endosymbiotic bacteria. This will affect for long-term the fertility of parasites causing sterility. Moreover, the adult parasites age and die[67,68,75,142].

**Control** of disease aims the vectors control and animals chemoprophylaxis[140]. Vectors control consist in the destruction of larval stages of arthropods (*Culicoides* and *Simulium*), intermediate hosts, which develop

into the water. So, aerial dispersion of larvicides express good results even it is expensive.

Chemoprophylaxis aims the reduction of circulating microfilariae. About 5000 molecules have been screened, and approximately 100 were selected for improvements. Finally, only 6 compounds were optimized, emodepside being one of them. All these compounds are effective microfilaricide in some filariids species. Moxidectin is another drug that expressed a high microfilarial efficacy.

### 9.1.3. Onchocercosis in dogs

**Definition.** It is a recently accepted disease, specifically, in the last 15 years, consecutive to reporting of an increasingly number of dogs which had ocular manifestations associated with observation of parasites, easily removed, from the surface of the conjunctiva.

**Etiology.** It is suspected that the disease is caused by *Onchocerca lupi* originally described from the wolf (*Canis lupus*)[122]. Species originating in dog resemble morphologic with *O. lupi*, and, molecularly, the two species from canids have an unique nucleotide sequence within the genus[34,25, 131]. Moreover, the host range is similar and very narrow in both species[124]. However, it is not fully confirmed that the disease in dogs is caused by *O. lupi*. As such, we refer to species as *Onchocerca* sp.

***Morphology*** (according to Egyed et al.[34], and Komnenou et al.[79]). Parasites have a white, slender, thread-like and fragile body. The male measures between 43 and 50 mm length by 0.1-0.2 mm diameter. The females were not yet completely collected; thus, the longer fragments preserved measure 100–165 mm and the maximum diameter found varies between 0.2 and 0.4 mm.

The anterior end of the male is rounded. The cuticle is thick and shows faint transverse striations. At the posterior end, the male has papillae which surround the anal orifice and two unequal spicules. The left one is curved, tapered and measures 160 to 203 μm long and the right only 75 to 94 μm.

The anterior end of the female is rounded and shows the vulvar orifice located at about 1 mm distance from the anterior end. The cuticle has small ridges, which become taller in the posterior direction. The tail end is blunt and present transverse striations of the cuticle.

Microfilariae are straight, unsheathed and measure 98 to 118 mm long by 5–7 mm wide.

***Life cycle*.** The life cycle of *Onchocerca* sp. from the dog is not completely known. It may be similar to those of other *Onchocerca* species, being an indirect cycle. It involves blackflies (*Simulium* spp.) and/or midges (*Culicoides* spp.) as intermediate hosts. The prepatent period may last several months and the patency several years[124].

**Epidemiology**

***Geographical distribution*.** Since was the first time described, the disease was recorded only in 64 dogs, until 2008, originating in Southwestern United States (Arizona, California, Utah), central and southern Europe (Hungary, Germany, Switzerland, Greece and Portugal) and a wolf from Gruziya[130].

***Sources of contamination*.** Generally, diseased dogs, or those with unapparent forms, are the source of spreading the disease via infected arthropods. The insects are, in turn, source of contamination for healthy dogs.

***Susceptibility*.** It is believed that *Onchocerca* sp. affects only canids. The disease is already described in dogs and wolves, but it is very probably that the wild reservoir, represented by jackals, coyotes, maybe foxes, plays an important role in epidemiology of infection.

The age influences the susceptibility, the most sensitive group being represented by adult dogs, around 5.3 years[149].

***Route of contamination*** is transcutaneous.

***Resistance*** of parasites is correlated with survival of intermediate hosts.

**Pathogenesis.** The parasites act mostly irritative-inflammatory upon conjunctiva and surrounding tissues. They also can inoculate bacteria that complicate the lesions.

**Clinical signs.** There is only one case in literature expressed as dermatitis and subcutaneous nodules protruding into the tracheal lumen, dyspnoea, asphyxia, and death of the dog[114].

The rest of the dogs expressed an ocular form characterized by an acute evolution with conjunctival congestion, ocular discharge, hyperlacrimation, periorbital swelling, photophobia, granulomatous formations on the conjunctiva, localized or generalized corneal oedema and exophthalmos[65,126,149].

**Pathology.** The lesions that accompany the acute form are conjunctivitis, corneal ulcer, granuloma or cyst formation around the worms, blepharitis, anterior or posterior uveitis, protrusion of the nictitating membrane[58,135,149].

**Diagnosis.** Clinical signs and gross lesions are indicative, but the rarity of disease makes the few doctors, even ophthalmologists, to think about this diagnosis. Laboratory diagnosis aims to identify the adults or/and larvae in the lesions or blood.

Morphological identification of adult parasites is relatively easy, based on the ridged appearance of the cuticle, whitish and filiform body. It is, however, difficult to observes and collects the parasites which are frequently confused with fragments of gauze used in surgery.

Identification of microfilariae is based on superficial skin biopsy ("skin snip technique") made from the skin of the head and abdominal region where the larvae accumulate in high concentrations[74].

***Differential diagnosis***. There are no data regarding differential diagnostic of canine onchocercosis due to the recently discovery of the disease, and low number of cases registered. However, majority of the ophthalmic diseases of the dog need to be included here.

**Treatment.** There are no bibliographic references about drug therapy of the disease the only method applied so far consisting of the surgical removal of the nodules containing the worms[79]. It is likely that antibiotic therapy, which aims the endosymbiotic bacteria *Wolbachia*, having a role in homeostasis of parasites, induces disappearance of infection consecutively to female infertility, aging and death of worms.

**Control.** Control methods are still unknown. Insect repellents may protect the dogs against the attacks of the vectors.

### 9.1.4. Dirofilariosis in dogs

**Definition.** A series of filariids belonging to the family Onchocercidae parasitize in domestic and wild carnivores in Europe. They cause important diseases, some severe, locating in the various body regions. The females are ovoviviparous and lay the first-larval stage, known as microfilariae which is located in the blood (e.g. *Dirofilaria*, *Acanthocheilonema*) or the skin (e.g. *Cercopithifilaria*)[2,100].

**Etiology.**[2,53]:

- *Dirofilaria immitis*, located in the pulmonary arteries and right heart[144];
- *Dirofilaria repens* develops into the subcutaneous connective tissue[100];
- *Acanthocheilonema* (Syn. *Dipetalonema*) *reconditum*, parasite in subcutaneous connective tissue and muscle fascia[132];
- *Acanthocheilonema dracunculoides* localized into the peritoneal cavity;
- *Cercopithifilaria* (syn. *Acanthocheilonema*) *grasii* inhabits subcutaneous connective tissue;

***Morphology*.** Generally, filariids worms are long nematodes with a relatively small diameter and a pronounced sexual dimorphism, the males being often much smaller than females[100].

At the anterior end, the mouth opening is not surrounded by lips and continues directly with the esophagus that is divided into two

segments, muscular, placed anteriorly, and posterior glandular. Cephalic papillae are well developed. The females have the vulvar opening situated into the anterior third of the body in the majority of species[2,100].

*Dirofilaria immitis* is a slender, long and threadlike nematode; the females measure between 250 and 310 mm length and 1 to 1.3 mm wide, and males are 120 to 200 mm long and 0.7 to 0.9 mm in diameter (Manfredi et al., 2007). The cuticle is generally smooth, with fine transverse striations. The posterior end of the males shows parallel ridges with variable length[46,143].

The anterior end is thin and rounded; the mouth opening is circular, terminal situated. It is surrounded by 4 pairs of small cephalic papillae, situated into the median plane, and two large lateral papillae. The mouth continues with the esophagus that is divided into a muscular segment and glandular one without a clear separation between the two. The vulvar orifice opens near the esophageal-intestinal junction[46].

The posterior end is smooth and rounded in females; it is spiralled in males and has two lateral narrow alae, and ventral, pre, para and postanal papillae. Spicules are unequal calibrated and gubernaculum absent[91].

Microfilariae vary between 290 and 330 μm length and 5 to 7 μm width. Cephalic extremity is tapered, and the tail is straight, sharp-pointed[91].

*Dirofilaria repens* is a relatively small nematode. Adult females have 100 to 170 mm length and 4.6 to 6.5 mm width and males are smaller than females, measuring 50 to 70 mm length and 3.7 to 4.5 mm wide[91].

The cuticle has longitudinal striations and ridges and fine transverse striations, their maximum thickness ranging between 0.028 and 0.035 mm in males and 0.047 to 0.060 mm in females[17,29].

Anterior end and mouth opening are rounded, and oral aperture is surrounded by six pairs of papillae. The esophagus is divided into the same segments as previous species. Vulvar opening is situated at 1.4 to 1.9 mm behind the anterior end[29].

Posterior end is rounded, slightly curved ventrally in females and spiralled in males. The male has two well-developed lateral alae and asymmetrical pre and postanal papillae, ventrally situated. Spicules are unequal, the left being more developed[29,91].

Microfilariae measure 290-360 μm length and 5-8 μm width. The anterior end is rounded, and the tail is thin and sharp, curved as an umbrella handle[29,91].

*Acanthocheilonema reconditum* is a relatively small-sized nematode, the females measuring 17 to 32 mm length and 13 mm the males (Stansfield, 1991). Microfilariae measure 250-280 μm length and 4-5 μm width. Their body is curved; anterior end is blunt and has a cephalic hook. The posterior end is commonly curved[87,132,137].

***Life cycle.*** The life cycle is diheteroxenous and consists of five stages, which develop in vertebrates definitive hosts, and in hematophagous arthropods that act as an intermediate host and vector[50].

*Dirofilaria immitis* typical definitive host is the domestic dog (*Canis familiaris*), but it seems that all members of the genus *Canis* can develop patent infections being the wild reservoirs. Felids, including domestic cats, may develop infections, but as the fox, tend to do not become reservoirs[95]. Infection has been reported in mustelids, bears, panda bears, seals, sea lions, coati (*Nasua nasua*), rabbits, horses, primates, humans, infections being are nonpatents[91,95].

*Dirofilaria repens* parasitizes the subcutaneous connective tissue in dogs (*Canis familiaris*). It was reported in cats, common genet (*Genetta genetta*), lions, foxes and humans[2]. Although the parasites usually do not reach the adult stage in humans, at least three microfilaraemia cases have been reported in Europe[50].

Adult parasites are localized in different organs and tissues of the host, the microfilariae being present in the blood (*Dirofilaria*, *Acanthocheilonema*) or skin (*Cercopithifilaria*). During feeding, hematophagous arthropods (mosquitos) take over the larvae through the blood. In their body, the larval stages grow and develop up to stage 3 ($L_3$), which is infective[2]. During of new feedings, mosquitoes transfer the larvae to the new host through the bite site[16].

Microfilariae of *D. immitis* were found to be able to develop to the infective stage ($L_3$) in more than 70 species of mosquitoes, but few of them are considered as major vectors[72]. *D. repens* has, as an intermediate host, mosquitoes of *Aedes*, *Anopheles*, *Culex*, *Mansonoides* and *Armigeres* genera[91]. The larvae reach also, the infective stages, in *Haematopota variegata*, a tabanid species, in experimental conditions[24].

*D. immitis* larvae remain at least 3 days at the inoculation site where moult becoming the fourth-larval stage, $L_4$. They undertake massive migrations through the subcutaneous tissue and muscle. The fourth moulting takes place at 50-58 days post-infection, becoming $L_5$, immature adults[83]. After the last moulting, immature nematodes migrate from muscle, probably via the venous circulation, to the pulmonary arteries, reached at 85-120 days pi. Here, they grow and mature, reaching the maximum length at 6 months pi[2,12,81]. Prepatent period varies between 6 and 9 months[2,147].

The $L_3$ larvae of *D. repens* develop into the subcutaneous connective tissue; they do not perform long migrations. The larvae moult twice and become mature adults[91]. They are to be found more frequently in the trunk, rarely in the head and limbs[147]. Prepatent period is 27 to 34 weeks[2,147].

*Acanthocheilonema reconditum* develops, up to the infective stage, into the fat cells in fleas (*Ctenocephalides canis*, *C. felis*, *Pulex irritans*) or lice (*Heterodoxus spiniger*)[2,106]. *A. dracunculoides* is transmitted by ticks (*Rhipicephalus sanguineus*) or flies (*Hippobosca longipennis*)[2,105,111].

*Cercopithifilaria grasii* is transmitted by the tick *Rhipicephalus sanguineus*, becoming infective in their body in about 30 days[14].

**Epidemiology.** General interest on canine filarioidoses tended to focus only on *Dirofilaria immitis* infection due to increased pathogenicity, and hence, its importance in veterinary medicine[26].

***Cardio-pulmonary dirofilariosis.*** *D. immitis* is spread in all continents. In Europe heartworm disease is diagnosed more frequently in the southern part of the continent, in Italy, Spain, Portugal and France. The areas with the highest prevalence are situated along the Po valley in northern Italy. There are reports from Turkey, Greece and some Eastern European countries. Cases have been diagnosed in dogs, in northern countries such as Austria, Germany, Norway, but they were either imported from Mediterranean areas, either have traveled with owners in such areas. A possible local case was diagnosed in Switzerland[51].

***Transmission of D. immitis in Europe: areas and periods of risk.*** In temperate areas, the climate controls and imposes seasonal transmission of *D. immitis*. The rate of larval development in IH body, the number of vector generations per year and transmission of *D. immitis* are conditioned by the presence and abundance of vectors and temperature[49,50,53]. The risk period is variable, being longer in the southern and eastern Europe[53]. In northern, east and southeast Europe, the risk of transmission is present in May, along the Adriatic Sea (Albania, Croatia), in Greece, south and southeastern areas in Bulgaria, Romania and in Ukraine. The risk of transmission of infection increases significantly in Germany, Poland and northeast until July, reaches the peak in August and begins to declines in September. The risk remains high in Greece, Bulgaria and

along the Adriatic Sea during October and confines to southern Greece in November[49].

***Dynamics of infestation with Dirofilaria immitis in dogs in Europe*.** The dynamics of the spatial distribution of *D. immitis* in European countries is characterized by two trends: the increasing of the prevalence in most endemic areas and advancing of distribution areas to the north and east. Thus, the previously free regions have become endemic areas after 2002[101].

Factors that have contributed to the spread of the parasite in the free areas are the climate change and movement of dogs across the continent. The propagation of parasites is virtually assured when are introduced into new geographical areas by the presence of susceptible vectors and favorable thermal conditions. The transport networks, the commerce and insecticide resistance of intermediate hosts also facilitated the spread[50,51].

***Cutaneous filarioidosis*.** *Dirofilaria repens* is found in Europe, Africa and Asia[91]. The species has returned recently to the attention of researchers due to its increased zoonotic potential, a high number of human cases being reported (372 cases in 25 countries during 1995-2000). For this reason, the infection is considered an emerging zoonosis[113]. Although the thermal conditions necessary for the development are similar, *D. repens* seems to spread faster than *D. immits* in the north and north-east of Europe. In areas where both species are present, *D. repens* has a higher prevalence[50,113]. Outbreaks of the disease were recorded in the period 1995-2000 in Belgium, Bulgaria, France, Greece, Italy, Romania, Russia, Serbia, Slovakia, Slovenia, Spain, Ukraine and Hungary[113]. In addition to these countries where were also confirmed human cases, the presence of parasites in dogs was recorded in: Czech Republic[134], Croatia[32,150] and Germany[64].

*Acanthocheilonema reconditum* is spread in Europe, Africa, India and North America[2]. The species was reported in dogs in Iran[118], Brazil[1] and Chile[87]. A human case with subconjunctival location of the parasite has been registered in Australia[71]. The prevalence has an increasing trend for this species[53] being registered different values in Europe: 16.5% in Campania[26], 1.4% in the city of Naples[120] in southern Italy, 3.7% in the Baix Llobregat, Spain[3] and 8% to beagle dogs in Greece[115].

*Acanthocheilonema dracunculoides* is spread in Africa and Europe. It is frequent in Spain and Portugal[2], with prevalence of 2.7% in the Baix Llobregat, Spain[3].

*Cercopithfilaria grasii* is found in Europe and Africa[2]. It was reported in Italy[14].

***Route of contamination*** is transcutaneous through the bites of intermediate hosts.

***Resistance*.** Resistance of larval stages is conditioned by the survival of intermediate hosts that is influenced by the climate factors, the temperature and humidity being the most important.

**Pathogenesis.** Pathogenic effects induced in the host organism are well known in cardiovascular infection and less in the other. Parasites adults and microfilariae act upon their hosts on multiple ways.

*Irritative-inflammatory* action is the most important. It is reflected on blood vessels causing endarteritis, endocarditis, platelet adhesion and extravasation of fluid in the perivascular space. Under the influence of platelet growth factors, smooth muscle cells proliferate and migrate from tunica media to intima; in this way, the lumen and arterial compliance are reduced. Reduction of arterial compliance and blood vessel diameter have, as a consequence, the pulmonary hypertension, an increased left ventricular afterload and right heart dilatation, so called pulmonary heart disease or "cor pulmonale"[60,144].

*Spoliation* is due to their haematophagous nutrition that causes anemia. *Mechanical* action consists in obstruction of the right ventricle and pulmonary artery, and fragments

of dead parasites may cause embolism in the pulmonary capillaries and coronary arteries with severe circulatory consequences. The *toxic* action is induced by the metabolic products and endotoxins; they affect vascular permeability and general metabolism. Parasitic *antigens* induce specific antibody development. A large number of parasites are destroyed after treatments and large amounts of antigens are released into the blood circulation, triggering anaphylactic phenomena.

In *D. repens* infections, pathogenic effects are caused by the presence of microfilariae in the capillaries, movement of adults into the connective tissue, under the skin, allergic reactions to microfilariae and $L_3$-$L_5$ larvae and toxins released by parasites[138,139].

**Clinical signs.**

***Dirofilaria immitis, heartworm disease*.** The majority of affected dogs do not show clinical signs for long periods (months even years). Signs appear gradual and may debut with chronic cough, followed by dyspnea, weakness and sometimes faintness after exercise. Rales in the diaphragmatic lobes are noted at auscultation. Distension of jugular venous and retrograde venous pulse, splenomegaly, hepatomegaly and ascites, poor appetite and weight loss develop as the cardiac insufficiency occurs[12,144]. The dogs may present acute dyspnoea, fever and hemoptysis when a large numbers of parasites die, due to the thromboembolism[12,144]. Sometimes, the parasites express erratically migrations with ectopic locations, in eyes, different arteries or veins than the pulmonary[20,85,128]. Some dogs develop hypersensitivity[60].

***The clinical picture of cutaneous filarioidosis*.** Signs occur mainly in summer and autumn due to the increased number of microfilariae. These are recurrent during the first 2 to 3 years, and then become permanent[138,139]. The signs include pruritus, erythema, papules, focal or multifocal alopecia, rarely hyperkeratosis, crusts, nodules, acanthosis, eczema, pyoderma and edema[137].

*Acanthocheilonema reconditum* is not associated with clinical signs. In massive infections cutaneous signs, as pruritus and dermatitis associated to emaciation were recorded[9].

*Acanthocheilonema dracunculoides*, in a similar way as A. reconditum, do not causes clinical signs in the majority of infected dogs. Microfilaremia may be associated with pruritus, erythema, alopecia or ulcerative lesions of the skin. Some dogs present ataxia and incoordination, probably due to erratic migrations and compressions on nerves[10]. Massive infections were sometimes associated with pleural effusion, dyspnea and cyanosis[123].

**Pathology.** Although the name "heartworm disease" suggests a primary cardiac implication, the first lesions occur in the pulmonary arteries and lung parenchyma[60,144]. The lesions, often chronic, are characterized by the presence of parasites up to 50 individuals in the form of a ball in the right ventricle and pulmonary artery. They are associated by ventricular dilatation, endocarditis and myocarditis, pulmonary endarteritis with with thrombi in which the parasites may be observed. Pulmonary congestion and infarcts in the appropriate areas of thrombosis and bronchopneumonia may be observed following stasis.

Microfilariae have a minor pathogenetic role, but can sometimes be associated with punctiform hemorrhages in the encephalon and spinal cord, liver and splenomegaly, ascites, pneumonia, proliferative glomerulonephritis, interstitial nephritis and fibrosis[20,60].

**Diagnosis.** Epidemiological data associated with symptoms have indicative value. Identification of the larvae in blood is the diagnosis of certainty.

Demonstration of microfilariae in peripheral blood can be achieved by several means: fresh blood examination directly between the slide and coverslide, fixed and stained smears, modified Knott's technique for microfilaria or filter technique for microfilaria. The lack of microfilariae does not exclude a prepatent infection. Microfilaremia does not correlate with the number of adults; generally, high microfilaremia in dogs signifies carriers of a small number of adult parasites[52].

Thoracic radiography has been used in the past as a method of diagnosis, being now replaced by serological methods. However, it is a useful tool that provides information about the severity of the changes induced by parasites.

Echocardiography and electrocardiography were also used in order to reveal the alterations of cardiac functions.

Histochemical staining of microfilariae based on alkaline phosphatase activity is very specific but expensive method and requires experienced staff[52].

Several commercial ELISA and immunochromatographic kits for the detection of circulating antigens produced by adult females of *D. immitis* are developed. The presence of males is not detectable by this method. Antigens can be detected at 5 to 6.5 months after infection. Elimination of the antigens after the death of parasite is rapid; therefore these tests can be used to evaluate the success of treatment[52].

PCR methods are sensitive and very accurate but are expensive, require more time and specialized laboratories[52]. Recently, there have been developed tests to detect the simultaneous reactions of several species of filariids[82,121].

***Differential diagnosis*** includes spirocercosis, angiostrongylosis, filaroidosis, cardio-pulmonary syndrome with other causes, hepatitis, (non-) specific dermatitis, leishmaniosis. Currently used laboratory methods are angiography, indirect immunofluorescence, and indirect hemagglutination test using microfilarial antigens.

**Treatment.** Treatment of heartworm disease caused by *D. immitis* has two distinct aims, namely microfilaricidal and preventive therapy and adulticidal treatment.

*Microfilaricidal treatment* is applied to the dogs to which an antigen test was positive, demonstrating the existence of circulating microfilariae. At this category, a monthly macrolide administration aims to prevent further infection, reduce circulating microfilariae, and kill all larvae which are not yet susceptible to adulticide therapy. Adverse reactions are possible so that these dogs should be kept under observation. Emergency treatment for adverse reactions is based on anti-inflammatory corticosteroids with or without antihistamines. Dexamethasone at a dose rate of 0.25 mg/kg intravenously and diphenhydramine, 2 mg/kg intramuscularly, or prednisolone, 1 mg/kg, orally 1 hour before and 6 hours after administration of the first dose of prevention can be used[12].

Due to the anthelmintic resistance phenomenon that installs relatively quickly in macrocyclic lactones[48], it is very important to preserve their effectiveness against *Dirofilaria* larvae.

*Adulticidal treatment* aims to kill the worms and to prevent additional damage to the cardiopulmonary system. Although there are many studies that demonstrate the adulticide effect of some combinations of antibiotics, anthelmintics and symptomatic therapy, the only drug approved in United States for this purpose is the organoarsenic compound melarsomine dihydrochloride (Immiticide). Two doses of 2.5 mg/kg bw intramuscularly administered every 24 hours for two treatments expresses great efficacy, more than 96%. Repeating of the two-dose therapy in 4 months will increase the efficacy to 99%[12].

Despite that melarsomine is the single drug approved in the therapy of *D. immitis* infection, there are some other combinations

that have expressed an adulticide efficacy increased.

The combination of doxycycline at a dose rate of 10 mg/kg (once daily) for 30 days and ivermectin–pyrantel, 6g/kg of ivermectin and 5mg/kg of pyrantel every 15 days for 180 days is adulticide in dogs with *D. immitis*. The efficacy of therapy reaches 85.7% against adults and 100% against microfilariae, the treatment being well-tolerated[59].

Combination of ivermectin at a dose rate of 6 μg/kg per os, weekly, with doxycycline, 10 mg/kg/day orally from weeks 0–6, 10–12, 16–18, 22–26 and 28–34 has demonstrated a significantly and faster decrease of circulating microfilariae and a higher adulticidal activity. The efficacy was 92.6% against adult males and 69% against females, the average efficiency being 78.26%[7].

An important goal of adulticide therapy is to eliminate bacteria of the genus *Wolbachia*. These are endosymbiont in *Dirofilaria* genus and have a role in nematode biology. It locates in the hypodermis, the ovaries, the oocytes and embryos in the female uterus[5,19,80]. Elimination of bacteria by antibiotics can be effective adulticide and microfilaricidal by inhibition of larval moulting or blocking embryogenesis and female sterility[6,55].

The worms may be surgical removed using flexible alligator forceps.

Supplemental therapy consists of cardiotonic, vitamin therapy, corticosteroids, aspirin (antithrombotic agents), antibiotics (doxycycline), antihistamines, diuretics and recovery diet.

**Control.** *D. immitis* infection control, targets three major components: chemoprophylaxis, control of the vectors in the environment and wildlife.

Despite there are several excellent products to protect de companion animals, the method is not suitable for long-term due to the difficulties to apply the treatment in dogs without the owner and in wildlife. Control of microfilariae in infected animals can be realized using:

- Milbemycin D at doses varying between 1 and 5 mg/kg bw inhibits the embryonic development of microfilariae but may cause adverse effects in dogs[125].
- Moxidectin tablets given monthly for 5 consecutive months during the risk season prevent the heartworm infection in dogs, the results of testing for microfilariae and circulating adult female antigens being negative in all experimentally treated dogs[54].
- Imidacloprid/moxidectin topical solution administered according to the package leaflet had a 100% preventive efficacy in a controlled laboratory study against *D. immitis*, in dogs[8].
- Selamectin, a single topical application, at the recommended dosage and treatment interval, revealed a 100% efficacy in preventing the development of *D. immitis* in dogs and cats[96].

The control of mosquito in the environment by regular disinsections has a major beneficial effect on the transmission of mosquito-borne diseases, including dirofilariosis.

Wildlife is an important component that may acts as a reservoir. Some carnivores, as coyotes in United States, make difficult heartworms eradication due to their spreading, almost universal, in rural, suburban, even urban areas[12].

## 9.2. Setariidae: setariosis in horses and cattle

The family includes approximately 43 species located normally in the abdominal cavity of domestic and wild mammals, artiodactyls, equines and hyracoids. Normally, these parasites do not produce clinical manifestations in the abdominal localizations. There are some species with particular locations (e.g. in the eye) when clinical signs depend on the affected organ. The diseases are called setariosis.

**Definition.** It is a biohelminthosis that often evolves without clinical manifestations affecting the equines, cattle and rarely other ruminants. It is caused by nematodes of the

genus *Setaria*, which develops in the serous or in different organs.

**Etiology.** It is produced by:

*Setaria equina*, affect horses, parasitizing in the peritoneal and rarely pleural cavity, in the lung, testis, the anterior chamber of the eye, and the larvae in the blood.

*Setaria labiatopapillosa* (syn. *S. cervi*[61]; syn. *S. altaica*[2]) develops in the peritoneal cavity, rarely in other organs in cattle.

***Morphology.***

*S. equina* has a long, filiform, and white body with transversely striated cuticle. The male measures between 50 and 65 mm length and the female is 110-130 mm long.

At the anterior end, the mouth is surrounded by a modified chitinoid peribuccal crown, with the appearance of a ring that contains four projecting lips and 4 hornlike cephalic spines around the lips. The esophagus is divided into a muscular part, anteriorly situated, and posterior glandular part.

The posterior end of the male gradually thins, and the tail ends spiralled. It has two narrow and small caudal alae, two very small caudal appendages near the terminal end of the tail, and papillae around the anal orifice. The spicules are unequal calibrated and dissimilar. The left one is larger (610-640 μm) than the right (280-290 μm) and looks as a tube with a membranous distal portion while the right one is irregularly shaped, stout and short.

The female has the vulvar opening in the cervical region. At the posterior end, it has two very small lateral appendages and the tail ends bluntly. They are viviparous and eliminate sheathed microfilariae, measuring 250 x 7 μm.

*Setaria labiatopapillosa* is similar to the previous species, but it has eight peribuccal papillae, each equipped with one thornlike structure, at the anterior end. The tail of the female contains small caudal papillae, with thorns.

***Life cycle.*** The life cycle is indirect, diheteroxenous. Adult parasites live in their specific habitat. Viviparous females eliminate microfilariae that enter into the bloodstream, circulate through blood vessels and can be found in peripheral blood. Intermediate hosts intervene and ingest microfilariae. The IH for *S. equina* are mosquitoes from *Aedes* genus; other *Setaria* species may be transmitted by other vectors such as *Stomoxis calcitrans* for *S. cervi* of cattle, or *Anopheles* mosquitoes for *S. labiatopapillosa*. These IH ingest the larvae which develop in the thoracic muscles of IH. Microfilariae moult twice in the body of IH, finally resulting infective $L_3$ larval stage. Infective larvae migrate in the mouthparts of mosquitoes and infect a new, healthy animal when mosquitoes feed. The inoculated larvae migrate to their habitat and and mature after 2 moults. The prepatent varies period between 8 and 10 months.

An important biological feature consists in the lack of *Wolbachia* sp. endosymbiont from the structure *Setaria equina* (hypodermal cords or reproductive tissues). This fact suggests that *Setaria* species are not dependent on *Wolbachia* sp. for survival[21].

**Epidemiology**

***Geographical distribution.*** Infection is worldwide spread, wherever intermediate hosts find favorable biotopes to their development, respectively, moisture and heat. Infection is diagnosed in horses in Hungary (9.2%)[69], in Turkish equines (15%)[110], in donkeys from South Africa (71.4%)[93] or in working donkeys of Ethiopia (85.7%)[56].

***Sources of contamination*** are infected horses and cattle, and intermediate hosts which transfer the parasites from diseased to healthy animals.

***Susceptibility.*** All animals, horses or cattle, kept on pasture are exposed to infection. The disease is most commonly diagnosed in adult animals.

***Route of contamination*** is transcutaneous through intermediate hosts bites.

***Resistance*** of parasites is conditioned by the survival of intermediate hosts. This is

influenced by temperature and humidity. These factors also influence the development of larvae into the IH body. At 18.0-25.5°C, the larvae need at least 15 days to become infective. The period will be longer when the temperature is below or above these limits.

**Pathogenesis**, **clinical signs** and **pathology.** *S. equina* is a nonpathogenic worm in the peritoneal cavity location. It may exert a slightly irritative action responsible for fibrinous peritonitis that is rarely observed.

*S. labiatopapillosa* is also nonpathogenic in temperate areas, but in warm regions may invade the spinal canal of small ruminants and cause cerebrospinal meningitis, paralysis and death.

Both species may migrate erratically, intra ocular, in immature stages. The infection occurs when mosquitoes feed around eyes and inoculate the infective larvae there. They migrate in the aqueous humor of the eye. Striated cuticle and movements of the worms act locally, irritative-inflammatory[73]. They cause lacrimation, poor vision, conjunctivitis, photophobia, cloudiness of the cornea and finally, the corneal opacity.

**Diagnosis.** Clinical diagnosis is impractical, due to the asymptomatic parasitism, intra-cavitary location being a surprise of necropsy. Localization into the eye, expressed by photophobia, lacrimation, conjunctival keratoses, and blindness is easily confirmed by observing of the parasites that actively move in aqueous humor.

Microscopic examination of the blood smears allows to identifying of microfilariae, but it is not a common practice, the exam being uncertain.

Mobile parasites on serous surface, without visible lesions, are incidentally revealed at necropsy.

***Differential diagnosis*** includes other bacterial, parasitic, and traumatic ophthalmopathies.

**Treatment.** The treatment is unjustified due to lack of pathogenicities in peritoneal location and difficulty of diagnosis. In ocular form, the surgery, symptomatic and anthelmintic medications are recommended. Ivermectin at a dose rate of 0.5 mg/kg, a single intramuscularly treatment, has induced a reduction of 88% in the number of live worms, and surviving worms have expressed a reduced mobility[78].

**Control.** Control is not attempted due to the non-pathogenicity of the parasites. Insecticidal prophylaxis of all animals kept on pasture during the risk period may have a protective effect against IH invasion.

## 9.3. Filariidae: filariidosis

Family Filariidae includes small to medium-sized subcutaneous parasites of mammals. It is divided into two subfamilies, Filariinae and the Stephanofilariinae. Typical morphological character of the family is the presence of the vulva at the anterior end, facilitating the elimination of eggs or larvae. Members of the family have dipteran intermediate hosts and cause cutaneous lesions. The diseases are generically called filariidosis.

### 9.3.1 Parafilariosis: Summer bleeding in horses

**Definition.** Parafilariosis is a vector-borne nematodosis of horses and cattle expressed, during the summer, by focal hemorrhages on the skin, called also summer bleeding disease, bloody sweat or verminous nodules.

**Etiology.** The disease is caused by parasites belonging to the family Filariidae, subfamily Filariinae, genus *Parafilaria*: *P. multipapillosa*, in subcutaneous and intermuscular connective tissue of horses, and *P. bovicola* in subcutaneous and intramuscular tissues of cattle.

***Morphology.*** *P. multipapillosa*. The parasites are long, thread-like and whitish; male measure approximately 30 mm length and female is 40 to 60 mm long. The anterior end is rounded, and the cuticle of the cervical region has circular protuberances arranged in

13 to 15 rings. Esophagus is undivided. The posterior end of the male is rounded and short, fitted with many papillae that surround the anal opening. Spicules are unequal calibrated and dissimilar. The left one measures 680 to 750 μm length, and the right is accentuated shorter than the right, measuring only 130-140 μm length. Female has the vulva placed near to mouth; posterior end is blunt. Females are ovoviviparous and lay embryonated eggs, oval-shaped, thin shell, measuring 55/30 μm.

*P. bovicola* female is 5 to 6 cm long and 500 μm wide and the male is 2.5 to 3 cm long.

***Life cycle*** is indirect, diheteroxenous. The mammals, horses and cattle, are definitive hosts in which the parasites live into the subcutaneous and inter- and/or intramuscular connective tissues in the regions of thorax, shoulders, withers in horses, donkey, mule, and cattle. The females pierce the skin and create a small hole necessary for eggs releasing. After copulation, the females lay embryonated eggs that are liberated into the drops of blood. The eggs hatch rapidly and the first-larval stages (microfilariae) are released. Intermediate hosts intervene and ingest these microfilariae during their feeding. Many species of licking flies are involved as IH and vectors around the world, depending by the species of *Parafilaria*. Intermediate hosts of *P. multipapillosa* are the horn flies (*Haematobia irritans* and *H. atripalpis*)[2,66]. *P. bovicola* is transmitted by species included in genus *Musca*: *Musca lusoria*, *M. xanthomelas* and *M. nevelli* in Southern Africa and *Musca autumnalis* (the face fly) in Europe. The larvae moult twice, into the intermediate host's body, and will become infective in 11 to 20 days, according to temperature.

Infective larvae ($L_3$) are transmitted to healthy animals during a new feeding episode of IH. The larvae are liberated through mouthparts of flies on wounds or ocular secretions. They migrate under the skin and will develop into adults after 5 to 7 months and two molts. Mature worms produce nodules and copulate inside. The females prick and penetrate the skin creating the "hole of eggs shedding".

The maximum longevity of *P. bovicola* adult parasites may reach 372 days[108].

**Epidemiology**

***Geographical distribution.*** Infections with *Parafilaria* spp. are worldwide spread. *P. multipapillosa* is recorded in various parts of the world, including South America, Africa and Eurasia[2]. *P. bovicola* is spread in Africa, Asia and several European countries respectively, Germany[62], the Netherlands[11], Sweden[89], Italy[47], France and Belgium[18,88].

The disease is characterized by a seasonal evolution. In European temperate climate, the infection evolves in spring and summer while, in tropical warm and moist areas, it is diagnosed preponderantly after the rainy season.

***Sources of contamination*** are infected animals and intermediate hosts. It is estimated that one infected animal will act as a source of infection for many other animals. Chirico[22] showed that approximately 0.6% of *Musca autumnalis* contain *P. bovicola* larvae.

***Susceptibility.*** All horses and large ruminant, members of the subfamily Bovinae (cattle, buffalo), kept on the pastures, are sensitive to infection.

***Route of contamination.*** Intraconjunctival route is typical, when insects feed by licking. This type of prehension, the licking, characteristic to these intermediate hosts, eliminates transcutaneous contamination.

***Resistance.*** The survival of the parasite is conditioned by the intermediate host's resistance. This is influenced by mean annual temperature, rainfall, frost, and altitude. *P. bovicola* larvae may survive in *Musca autumnalis*, which serve as overwintering reservoirs[22].

**Pathogenesis.** Adult gravid females exert a local mechanical action, consisting in the piercing of the intact skin, in order to create a hole to eliminate eggs. The worms act, also, irritative-inflammatory on the tissues inside

the nodules causing rupture of capillaries, hemorrhagic exudates and skin necrosis. Open skin lesions may create sites of penetration for bacterial agents, which complicate the lesions, causing phlegmons.

Preferred areas for location of the parasites are dorsal and lateral aspects of the body where are observed up to 74.4% of bleeding points[107].

**Clinical signs.** Clinical signs are characteristic. Small, painful nodules (1.2 to 1.5 cm diameter and 0.7 cm in depth) develop on the skin before the penetration. After the penetration, the nodules become large (4x1 cm), swollen, and hemorrhagic. Bleeding points at the sites of piercing of females are visible, at the surface of nodules, and a trickle of blood flows on the skin. The hair and skin around the points become matted and streaked with blood, attracting more flies to feed.

The nodules are located preferentially on the neck, withers, and back in horses. In bovines, the sites of infection predominate on the withers, shoulders, thorax and less on the rump and loins.

**Pathology.** In acute evolution, the lesions have an opaque yellow-green appearance and consist in subcutaneous oedema and petechiae, resembling bruises.

Chronically, the lesions reach a gelatinous greenish-yellow and dirty brown appearance. A characteristic metallic, unpleasant odour is felt in chronic evolution.

In severe forms, the underlying muscles can be involved, and the discoloration may extend into the inter- and intramuscular tissues, the lesions being, also, found in mediastinal, sub-pleural, and peri-renal tissues.

The carcasses have to be trimmed in slaughterhouses causing additional economic loss.

**Diagnosis.** Clinically, observation of bleeding points, during the risk period and endemic areas, allow an accurate diagnosis. At slaughtering, the lesions similar of bruises and having a distinct metallic smell are indicative if the worms lack. Microscopically, embryonated eggs or microfilariae may be observed in stained smears or exudates. Serodiagnosis using ELISA technique has high specificity and sensitivity.

***Differential diagnosis*** in live animals includes injuries caused by *Onchocerca* spp., *Habronema* spp., biting insects and ticks, thorns and other sharp objects. In carcasses, the lesions that resemble bruises must be differentiated of trauma.

**Treatment.** Majority of treatments were developed to use in cattle.

- Old treatments in cattle, based on levamisole hydrochloride and nitroxynil (at a dose rate of 20 mg/kg bw, 2 times at 3 day intervals) gave promising results, causing the reduction of lesions and lesion area by 76% by levamisole and by 93% by the latter compound[145].
- Nitroxynil at a dose rate of 20 mg/kg bw administered once, subcutaneous injection, reduced the number of bleeding points by 97.8%[148].
- Ivermectin at 0.2 mg/kg bw, subcutaneous injection caused complete disappearance of symptoms at 7 days post-treatment[97].
- Ivermectin, 0.2 mg/kg bw, subcutaneous injection reduced the lesion area and mean mass of damaged tissue trimmed from the carcasses by 83.3% and 89.9%, respectively[129].

**Control.** Vector control is an important action that may prevent contamination. Insecticides and permethrin–impregnated collar for horses or ear tags in large ruminants are useful to control the fly vector.

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# 10. Thelazioidea

Superfamily Thelazioidea is divided into three families, Thelaziidae, Pneumo-spiruridae and Rhabdochonidae. It contains parasites of birds, mammals, fish and primates, the eye worms included being the most studied members[1].

## 10.1. Thelaziidae: thelaziosis

Family Thelaziidae comprises two subfamilies, Thelaziinae and Oxyspirurinae that number about 7 genera. Genus *Thelazia* is most important, the species which belong to it causing thelaziosis, an important parasitosis, in cattle, horses, canids and, rarely, humans.

**Definition.** It is an endemic biohelminthosis, evolving during the warm season, characterized by conjunctivitis, commonly affecting cattle, horses rarely sheep or other animals. It is caused by nematodes of the genus *Thelazia* which are parasites of the orbits.

**Etiology.** Several species are worldwide distributed, affecting domestic and wild ruminants, horses and canids. Parasites inhabit the orbits, conjunctival sac, under the lids, the lachrymal glands and ducts and nictitating membrane. May be differentiated parasite species only in ruminant, species that affect ruminants and horses, respectively species prevalent in canids, but which can develop in ruminants and other host species.

- *Thelazia gulosa* affects domestic and wild ruminants in Europe, North America, Australia and Asia.
- *Thelazia skrjabini* is found in domestic and wild ruminants originating in Europe, North America, Asia and Australia.
- *Thelazia rhodesi*, parasite of domestic and wild ruminants, and horses, spread in Europe, North and South America, Asia and Africa.
- *Thelazia lacrymalis* is identified in equids, domestic and wild ruminants from Europe and North and South America.
- *Thelazia callipaeda*, or "oriental eyeworm" is the common species of canids and felids, but it is reported also in rodents and humans, being spread in Europe, ex-USSR and Far East countries.
- *Thelazia californiensis*, parasite in dogs, other carnivores and wild ruminants is found in Mexico and United States.

***Morphology*.** General morphology of thelaziids consists in a thin, cylindrical, filiform and whitish body. The length of males varies between 6 and 26 mm and female is 10 to 20 mm long and 0,2-0,4 mm width.

At the anterior end, the cuticle is transversely ringed, showing coarse striations (figure 29).

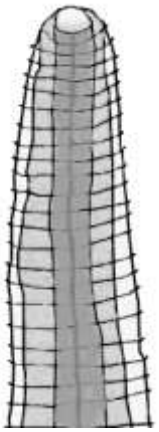

**Figure 29.** *Thelazia* spp.: anterior end - transverse striations

They have a buccal capsule, well-developed but short, thick-walled and unarmed; its anterior edge turns back to the posterior of the body and is cutted in six festoons. The mouth opening is hexagonal and the lips lack.

Posterior end of the male is short, the alae lack, but shows numerous papillae that surround the anal opening; the spicules are unequal. Posterior end of the female is round, blunt and vulva is anterior situated.

***Life cycle*.** The life cycle is indirect, diheteroxenous involving, as intermediate hosts, several species of flies. Adult parasites

inhabit the orbit and their adjacent: nictitating membrane and under the eyelids, conjunctiva and conjunctival sacs, lachrymal glands and excretory ducts. They are secretophagous parasites, consuming lachrymal secretions. The females are viviparous and eliminate first-stage larvae, which move into the lachrymal secretions. Secretophagous non-biting flies feed on secretions and ingest these larvae. Several species of flies intervene as IH for each *Thelazia* spp.[22]:

- *T. gulosa*: *Musca domestica*, *M. autumnalis*, *M. larvipara*, *M. vitripennis*, *M. osiris* and *M. amica*;
- *T. skrjabini*: *M. autumnalis*, *M. herveia*, *M. osiris* and *M. amica*;
- *T. rhodesi*: *M. domestica*, *M. autumnalis*, *M. convexifrons*, *M. larvipara*, *M. crassirostris*, *M. herveia* and *M. sorbens*;
- *T. lacrymalis*: *M. autumnalis* and *M. osiris*;
- *T. callipaeda*: *Amiota okadaia* and *A. variegata*;
- *T. californiensis*: *Fannia benjamini* and *F. canicularis*;

The first-stage larva undergo a development process to the third-stage larvae ($L_3$) through two successive molts, into the intermediate host body, in hemocoel and fat body of the female and the testes of the male where encapsulate. When intermediate hosts feed, the larvae migrate to the labella of flies and are transferred to the definitive hosts in lachrymal secretions. Following inoculation, the worms reach adulthood in the orbit in approximately 1 month.

**Epidemiology**

***Geographical distribution*.** In cattle, it is generally considered that *T. gulosa* and *T. skrjabini* are spread mainly in the New World while *T. rhodesi* is particularly common in the Old World[7]. The disease is reported in the last 10 years, in Dagestan (38%), the species involved being *T. rhodesi*, *T. gulosa*, and *T. skrjabini*[26]. In Italy, *T. gulosa* and *T. skrjabini* have been recently identified in autochthonous cattle in Apulia and Sardinia[7]. In England, thelaziosis of cattle has registered a continuous decline during the last 40 years due to the extensively use of avermectins (ivermectin, doramectin, moxidectin and eprinomectin) as endectocide treatments[24]. These drugs, especially their residues, impair the development of *Musca* spp. in the dung of treated cattle causing the general reduction of flies' population[6]. Consecutively, the prevalence of infections decreases.

In horses, *Thelazia* sp. is rarely reported; in Kentucky, the prevalence was 31.25% (5 of 16)[13]. *T. lacrimalis* was found in 3.1% of horses slaughtered at the Linköping abattoir in central Sweden[9].

*T. callipaeda* is prevalent in dogs, cats, and humans in the former Soviet Union and in countries of the Far East (Japan, China, Korea, Indonesia, India, Myanmar, Thailand, and Taiwan[19]. It was also reported in France and Germany[3,5,8], southern Switzerland[14], Portugal in cats and dogs[23,25], Spain[16], Belgium[2].

***Sources of contamination*.** Two major sources of contamination can be differentiated: infected animals, mainly those kept on pastures and the flies, intermediate hosts. The intensity of parasitism per fly is variable between 115 and 151 larvae[17] and the prevalence of infection in the fly populations is variable between 3.21% in *M. larvipara* and 4.46% in *M. autumnalis*, the species involved being *T. rhodesi* and *T. gulosa*[20]. Regarding *T.* callipaeda, the farm and military dogs are the main reservoir hosts[19].

***Susceptibility*.** Adult animals are more susceptible than calves, foals and puppies. This fact is explainable by the absence of a protective immune response following multiple infections during their life, re-infections and accumulation phenomenon, correlated with the long lifespan of *Thelazia* adults, exceeding one year.

The dogs, rabbits, cats and monkeys are proven their susceptibility as definitive host of *T. callipaeda* in experimental infections while goats and sheep are not responsive.

***Route of contamination*** consists in inoculation of infective larvae ($L_3$) by the intermediate hosts into the orbit area (conjunctival mucosa).

Seasonal evolution during the summer, in temperate regions, is characterized by increasing of morbidity rate from June to September, directly correlated with increasing of activity and density of fly populations. There are multiple ways of transmission under grazing conditions, on pastures near forests, with favorable biotopes (manure, organic matter) for development of fly larvae. Horizontal diffusion of outbreaks is realized through intermediate hosts, which are also vectors and by displacement of infected cattle.

***Resistance*** of larval stages in the environment is reduced; survival does not exceed several hours.

**Pathogenesis.** Aggression of adults and larvae is exercised locally and depends on the intensity and duration of parasitism. The parasites act by complex mechanisms: mechanical, irritative-inflammatory, inoculatory and toxic. Mechanical action is due to movements of worms and is correlated with inflammation caused by transverse coarse striations. Inflammation of the conjunctiva and cornea occurs initially, followed by local bleeding, lachrymal duct obstruction, erosions, even ulcers, parasites being easily visible. Parasites favor the engraftment of bacteria, rickettsiae and other infectious pathogens, complicating inflammatory processes.

**Clinical signs.** Incubation period lasts 3 to 5 days. Clinical evolution debuts with epiphora, photophobia, congestion, local swelling, ocular secretions and pruritus around the eye. Eye discharge becomes purulent after 1 or 2 weeks and corneal ulcers occur, with unilateral ophthalmia, even panophthalmia. Local signs are accompanied by general symptoms, decreased appetite, weight loss, decreased milk production and slow movements of animals with severe forms.

**Pathology.** Lesions develop gradually. Initially, catarrhal and petechial conjunctivitis occurs followed by keratitis, chronic follicular conjunctivitis, ulcers and corneal opacity. Relation between high morbidity of thelaziosis and incidence of ocular epithelioma in cattle must be verified.

**Diagnosis.** Clinical diagnosis is easy during patent phase. It is based on symptoms and with the slightly visualization of adult parasites in the conjunctival sac. Collecting of lachrymal secretion and its microscopic examination to observe the larvae is necessary in the early stages of the disease.

***Differential diagnosis*** includes bovine keratitis by *Moraxella bovis* (pinkeye), traumatic lesions, setariosis.

**Treatment.** Thelaziosis is the only nematodosis that benefits from topical treatment due to the parasites locations, at the external part of eye in contact with air.

Therapy is based on the combined use of specific drugs with antibiotics, anti-inflammatory and cicatrizants. Applications are made in the form of eye washes or ointments. Useful substances are in table 17

**Control.** An integrated protocol is needed to control eyeworm disease in animals. This involves control of the fly vector and periodical deworming of animals. Control of the vectors is based on the use of ear tags, preventive collars or periodical spraying of animals. Ointments with pour-on application may be used for a prolonged efficacy. Periodical deworming of animals, better quarterly, aims to protect animals against adults development; avermectins are useful.

**Table 17.** Active substances used in the treatment of thelaziosis

| species | active substance | dose rate (mg/kg bw) | efficacy (%) | author |
|---|---|---|---|---|
| dog | milbemycin oxime/praziquantel | 0.5/5 | 96.8 | Motta et al., 2012 |
| cat | milbemycin oxime/praziquantel | 0.2/5 | 80.0 | |
| cattle | tetramisole | 15 | 100 | Čorba et al., 1969 |
| | levamisole | 10% sol, 6-10 drops | 100 | Salifu et al., 1990 |
| | doramectin | 0.5 pour-on | 95.3 | Marley et al., 1999 |
| | | 0.2 sc | 100 | Kannedy and Phillips, 1993 |
| | ivermectin | 0.5 pour-on | 100 | Kennedy et al., 1994 |
| | | 0.2 sc | 100 | Kennedy, 1992 |

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# 11. Spiruroidea

Superfamily Spiruroidea contains four families (Gongylonematidae, Spiruridae, Spirocercidae and Hartertiidae) with 21 genera, parasites predominantly in birds and mammals[2]. Spiruroids are, generally, parasites of the upper digestive tract, and preponderantly affect the stomach and esophagus. They are biohelminths, arthropods being involved in their life cycle.

## 11.1. Gongylonematidae: gongylonemosis in animals

Family comprises about 34 species included in a single genus, *Gongylonema* that has some synonymy: *Gongylomene*, *Gongylonemoides*, *Misonunus*, *Myzomimus* or *Progongylonema*. The worms are characterized by large verruciform thickenings that cover the cuticle, especially to the anterior end of the body. These are arranged in several longitudinal and parallel rows and continuously are reduced in thickness toward the posterior end.

Members of the family are parasites of the mucosa into the anterior segments of digestive duct (esophagus). The disease caused is called gongylonemosis.

**Definition.** *Gongylonema* spp. infection evolves chronic, asymptomatic, dallying usual as a parasitism condition, not as a disease. The parasites occupy the esophagus and other anterior segments of digestive ducts in herbivorous, swine and poultry. Infection is a surprise of necropsy or slaughter, being diagnosed only after the death of animals.

**Etiology.** Several species are important in domestic animals:

*Gongylonema pulchrum* is a common species of anterior segments of digestive system (tongue, esophagus, stomach and rarely rumen) in a large variety of animal hosts: cattle, horses, sheep, goats, camels, cervids, pigs, bears, squirrels, rabbits, and and primates, including humans, worldwide.

*Gongylonema verrucosum* develops in the mucosa and submucosa of rumen in sheep, goats, cattle and zebu, in India, USA and South Africa.

*Gongylonema ingluvicola* inhabit in the crop, esophagus, and proventriculus of gallinaceous birds (chickens, turkeys, pheasants, partridges and quail), worldwide.

*Gongylonema neoplasticum* is found in esophagus and stomach in rodents and lagomorphs, worldwide.

***Morphology.*** *G. pulchrum* has a cylindrical body, whitish, slender, and equal calibrated. The length of male reach up to 62 mm and female is up to 145 mm (figure 30).

The anterior end is rounded and slightly tapered. The mouth opening is delimited by small, inconspicuous lips. The cuticle shows several distinctive, longitudinal and irregular rows of large, round or oval, verruciform thickenings called also cuticular bosses. Cuticular cervical alae, well-developed, are present.

At the posterior end, the male has two unequal caudal alae which determine an asymmetric appearance to the tail. The spicules are also unequal, the right one being longer (84 μm to 180 μm long) than the left one (4 μm to 23 μm long). A variable number of pedunculate papillae surround the anal orifice, being pre- or post-anal situated. Vulva is opened towards the tail of the female. The eggs are embryonated when are laid and measure 50-70x25-35 μm.

The male of *G. ingluvicola* measures 17 to 20 mm long by 224 to 250 μmwidth and the female is 32 to 55 mm long by 320 to 490 μm width.

At the anterior end present a shield-like markings region and two cervical alae. The markings are scattered near the head but posteriorly are arranged in numerous longitudinal, almost parallel rows. The thickness of markings is continuous reduced to posterior.

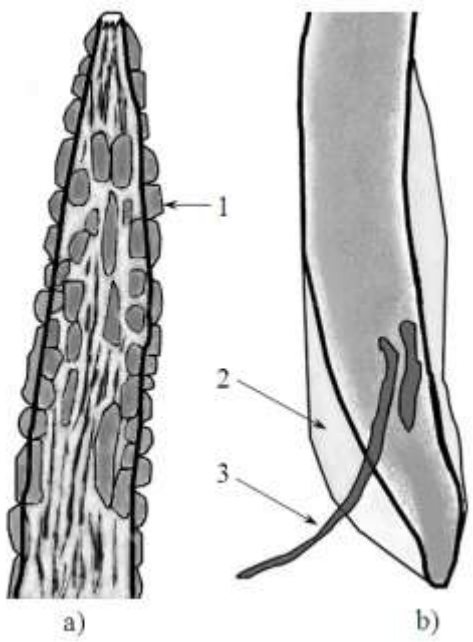


**Figure 30.** *Gongylonema* spp.:
a) anterior end; b) posterior end (male);
1. verruciform thickenings; 2. caudal alae;
3. spicules

At the posterior end, the male has two asymmetric, and narrow caudal alae, a variable number of papillae and two unequal spicules: the left one is long almost as the body, measuring 17–19 mm length and 7-9 µm width and the right one is 10–12 mm long and 15–20 µm wide. Vulvar opening is situated posterior. The eggs measure 58x35 µm.

***Life cycle*.** is indirect, diheteroxenous. Adult parasites reside in their habitat. After copulation, ovoviviparous females lay embryonated eggs that contain first-stage larva. The eggs are passed through feces in the environment. They are ingested by intermediate hosts represented by coprophagous beetles (dung beetle) or cockroaches. Genera *Aphodius*, *Onthophagus*, *Blatella* and other intervene in the biology of *G. pulchrum* and small cockroach *Blatella germanica* or the beetle *Copris minutus* in development of *G. ingluvicola*. *G. neoplasticum* has a diversified group of intermediate hosts, comprising cockroaches, mealworms, and fleas. In their body, the eggs hatch and first-stage larvae undergo an evolution process, reaching infective-stage $L_3$ after two successive molts. Definitive hosts become infected by ingestion of intermediate hosts that contain the third-stage larvae. It is not very well-known the route by what the larvae reach the wall of the esophagus. They are probably released from intermediate hosts in the stomach, penetrate blood vessel and back to the esophagus through circulation. Another possibility consists in the crawl back into the esophagus.

**Epidemiology**

***Geographical distribution*.** *Gongylonema* spp. infection is spread across the globe. *G. pulchrum* was identified in wildlife throughout the world. The infection was found in jackals (*Canis aureus*, 4%) from Serbia[11], wild boars (*Sus scrofa*) from Turkey (11%)[61], Sherman's fox squirrel (*Sciurus niger shermani*) in Florida (2%)[12], black bears (*Ursus americanus*) from Pennsylvania (33.1%)[26], cottontail rabbits (*Sylvilagus floridanus*) in the Southeastern United States (1%)[4] and many other species in the world.

It was found in large and small ruminants and pigs. In cattle, its prevalence varied depending by the altitude: 45% in plains, 22% in submontane, and 10% in mountain zone from Dagestan[66]; in Japan was 18.4% between December 1986 and June 1987[30]. In hair goats from the Sanliurfa region, Turkey, the prevalence was 32.53%[1]. In ruminants kept in captivity, in India, the prevalence was 11.76% in nilgai and 20.2% in giraffe[10]. *G. pulchrum* was found in 60% of axis deer (*Axis axis*) and 100% of feral swine (*Sus scrofa*) examined in Hawaii[38]. Feral swine represents a high sensitive category all around the world, the prevalence of infection being 77% in Cumberland Island[53].

*G. ingluvicola* was the most spread nematode in free-range chickens from South Africa, the prevalence varying between 43.3 and 86.7%[43].

In free-range chickens in Zimbabwe the species was the most prevalent in young (28%) and adult (56%) birds[54]. In young scavenging chickens in Ghana the prevalence recorded was 62%[57]. In Tanzania, prevalence was influenced by season, being 6.3% during the wet season and 17.7% in the dry season[55]. The species was discovered in northern bobwhites (*Colinus virginianus*) in northern Florida, United States, the prevalence being 1.3%[13].

*G. neoplasticum* was recovered from black rat (*Rattus rattus*) in Kuala Lumpur, Malaysia registering different prevalence, between 0.7% and 17.5%[41,52]. In Central Taiwan, the prevalence in the same species was 14.3%[65].

***Sources of contamination*** are the infected animals with asymptomatic parasitism. These pollute the environment with eggs. Intermediate hosts are the second source that contaminates healthy animals. The level of infection in dung beetle populations is variable, but it seems to be lower due to the complexity of *Gongylonema* spp. life cycle. In *Copris lunaris* beetles the infection rate was 2.2% in Iran[42].

***Susceptibility*.** Ruminants appear to be more susceptible than other domestic species. This may be due to grazing which favors contact of definitive hosts with beetles and cockroaches.

***Route of contamination*** is oral by consumption of infected intermediate hosts.

***Resistance*.** The eggs survive minimum 4 months at temperatures between 6.6°C and 37.7°C and 37% of the entire period of exposure consisted in cold and freezing temperature; at room temperature, 22° to 24°C, all eggs survived and remained infective at least 4 months. The third-stage larva survives in water for over 30 days when emerges accidentally from intermediate hosts[30].

**Pathogenesis and pathology.** *Gongylonema* spp. is not highly pathogenic nematodes. *G. pulchrum* is embedded into the esophageal mucosa, in a spiralled shape. This aspect represents an adaptation to the esophageal peristalsis needed to prevent the rupture of the parasite when the food bolus passes. Then, the parasite elongates becoming straight due to the enlargement of esophagus.

The development of larvae and adult rarely causes micro-haemorrhages, and esophageal and crop mucosal edema due to the irritative-inflammatory action exerted. Migration of the adult female during egg laying may be expressed by mechanical damage. Esophagitis is associated with the presence of the "stitch worm" on the mucosa, being a pathognomonic lesion. *G. neoplasticum* in domestic rats is reported to induce neoplastic tumors.

**Clinical signs.** *Gongylonema* spp. infection does not develop symptoms. In heavy infections may evolve dysphagia, especially esophageal dysphagia, and sensitivity of esophageal region.

**Diagnosis.** Usually, the disease is evidenced at necropsy. The eggs may be confused with those of *Strongyloides* spp., strongyls (embryonic phase) or spirurids, in pigs.

***Differential diagnosis*** in severe infections includes esophageal dysphagia with another etiology.

**Treatment.** There is no specific treatment. Benzimidazole derivatives are less effective, or totally ineffective. Levamisole as a single dose of 8 mg/kg, mebendazole at 70 mg/kg for 3 days, subcutaneously injected ivermectin as a single dose of 0.2 mg/kg and thiabendazole at 100 mg/kg for 3 days demonstrated a moderate or low efficacy of 63.2%, 22.8% and 25.8%, respectively while thiabendazole did not express any efficacy[29].

**Control.** Prevention of infection is difficult due to the intermediate hosts, beetles and cockroaches, which are highly mobile arthropods, spreading the infection at the long distances.

## 11.2. Spirocercidae: spirocercidosis in dogs

The Spirocercidae comprises three subfamilies: Spirocercinae, Ascaropsinae and Mastophorinae. The family is characterized by hexagonal mouth opening and buccal cavity armed with teeth. Subfamily Spirocercinae has lips weakly developed and contains genus *Spirocerca* that comprises parasites of carnivores[2].

Members of the family cause diseases called generically spirocercidosis, while members of the genus produce spirocercosis.

**Definition.** Spirocercosis is a chronic biohelminthosis caused by the nematode from Spirocerca genus that affect mammals but is typical in canids, expressed by a variety of clinical forms: digestive, respiratory and cardiovascular.

**Etiology.** The disease is caused by *Spirocerca lupi*, parasitizing in canids, preponderantly dog, fox and wolf. The specific habitat is the wall of the esophagus, stomach and thoracic aorta where they live embedded in nodules.

***Morphology.*** *Spirocerca lupi* has a stout, cylindrical and coiled body, bright pink to red colored. The male measures 3 to 5.4 cm length and the female is 5.4 to 8 cm long. At the anterior end has a short buccal capsule, well-developed, expanded anteriorly, thick-walled and the mouth opening is delimited by six rudimentary lips (or two, trilobed).

Posterior end of male shows two lateral narrow alae, six pairs of pre- and post-cloacal papillae and several unpaired, and two unequal spicules; the left measures 2.45-2.8 mm length and the right is 0.47-0.75 mm.

The vulvar orifice is situated in the anterior region of the body. The eggs are embryonated when are laid, cylindrical-shaped, thick shell, and measure 30-37x11-15 μm.

***Life cycle.*** Life cycle is indirect, diheteroxenous, involving intermediate and paratenic hosts. The adults live entwined within the esophageal or gastric nodules and feed on blood. After copulation, the females lay embryonated eggs that are passed through the gastrointestinal tract in the environment. The eggs may be eliminated in the vomitus. Coprophagous beetles (genera *Akis*, *Copris*, *Geotrupes*, *Gymnopleurus*, *Scarabaeus*, *Atenchus*, and others) intervene as intermediate hosts. After ingestion, the eggs hatch and release the first-stage larvae ($L_1$) that encyst within the tissues (mainly on the tracheal tube) and molt twice, becoming the third-stage larvae, $L_3$, which is infective stage.

Paratenic hosts may intervene, consuming the intermediate hosts. In their body, larval stages re-encyst again especially in the esophagus, stomach, mesentery, subcutis, wall of the crop, thoracic muscles or other organs. Numerous species of amphibians, reptiles, birds, even small mammals (rodents, hedgehogs, rabbits) are involved. The larvae may also be transferred from one paratenic host to another, the larvae being re-encysted each time.

The final host becomes infected by ingestion of an intermediate or paratenic host that contains infective larvae. The third-stage larva is released in the stomach, penetrates its wall and migrates through the wall of coronary, gastric, gastro-epiploic and celiac arteries to the aorta. Here pass through the connective tissue to the wall of the esophagus where adults become. During all these migrations, the larvae molt twice before reaching the adult stage.

Erratically migrations in the lung, trachea, kidney and urinary bladder or subcutaneous tissue may develop. The prepatent period varies between five and six months.

Recently, a new bacterial symbiont, *Comamonas* sp. (Brukholderiales: Comamonadaceae) was found in the larval-stage of the *S. lupi*, localized in the gut epithelial cells of the nematode larvae. It is not yet clarified its role in nematode biology, but its existence may open modern approaches in the control of disease[21].

**Epidemiology**

***Geographical distribution.*** *Spirocerca lupi* is a nematode with a worldwide distribution in warm climates where intermediate hosts benefit of optimal climatic conditions for their development. The infection is reported in Europe, Asia, Africa, and North and South America.

In Europe, the disease is reported in foxes from Sicily the prevalence recorded being 9.16%[18], in the raccoon (*Procyon lotor*) (8.8%) and wolves (11.5%) from Poland[56,63] and in dogs from Greece (10% and 0.4%)[22,47].

In Africa, the disease was diagnosed in stray dogs from Durban and Coast (5.4%) and Free State Province (13%) South Africa[40,44], Gabon (25.3%)[14], Ethiopia (7%)[67], Morocco (54.5%)[51], Sierra Leone (3.5%)[23], Kenya (78%)[8] and Ghana (18%)[5].

In North America, infection is reported in stray dogs from Mexico (4.5%)[9], but old reports have confirmed evolution of *S. lupi* in United State[15].

In Central and South America, the disease was found in dogs, in Brazil (1.9%)[49] and Jamaica (6%)[59].

In Asia, *S. lupi* was identified in dogs from Iraq (15%)[64], Iran (19.04% and 6%)[20,50] and Thailand (17.8%)[24].

All these presented reports demonstrate the cosmopolitan spreading of *S. lupi*. It is not excluded the presence of infection in other countries or regions than those mentioned.

***Sources of contamination*** are the definitive, intermediate and paratenic hosts which intervene in different ways, in the circuit of parasite in nature.

Definitive hosts act as environmental pollutants through the eggs scattered in faeces. The lifespan of adults may reach 2 years, and the prolificacy of the female is up to 3 million eggs per day[6], the intensity of parasitism being 2100 epg[60]. Intermediate hosts are sources of infection for the final hosts. Paratenic hosts are important in the dissemination of the parasites in nature; they maintain the viability and infectivity of larvae for a long period.

The prevalence of infection with larval stages in intermediate hosts is variable and is influenced by a variety of factors. The origin of dung beetles, rural or urban, determine a higher prevalence in arthropods collected from urban areas (13.5%) than in rural areas (2.3%); all the infected dung beetles exhibited a preference for omnivore (pig and dog) dung[17]. Sizes of the dung beetles, and consequently, the mouth size influence the ability of the arthropods to serve as intermediate hosts for *S. lupi*. The prerequisite is the size of the mouth which needs to allow the passage of food particle larger than the average size of eggs[16].

***Susceptibility.*** Canids show the higher sensitivity. Among canids, dog and wolf are most susceptible to infection. The breed influences the sensitivity, being higher in trace hunting dogs (21%), than in scent hunting dogs (5%) and household pets (0%)[47]. Large breeds are more sensitive to infection than small dogs; age, sex or season, do not influence the susceptibility[35].

***Route of contamination*** is oral, ingesting infected intermediate or paratenic hosts.

***Resistance*** of the eggs in ambient conditions is incomplete known because they are consumed by intermediate hosts; further exogenous evolution depends by the survival rate of the dung beetles.

**Pathogenesis and pathology.** Pathogenic mechanisms are complex and incompletely understood. Parasites act locally, irritative-inflammatory and mechanic. They cause sites of the bacterial superinfection of the lesions caused by parasites. Toxins resulted from parasites metabolism or death act locally and generally aggravating the disease. Parasites are responsible for neoplastic transformation of different tissues. The lesions are polymorphic and divided into two groups: lesions caused by larval migration and

damage produced by adults in their specific habitat.

Larvae cause inflammations (endocarditis, interstitial nephritis, mediastinitis, pleuritis, pneumomediastinitis, peripheral lymphadenopathy, diskospondylitis and spondylosis of the thoracic vertebrae, septic polyarthritis), aortic lesions (elastic degeneration and muscle fibrosis or mineralization resulting permanent scars and aneurysms in the thoracic aorta, local thrombosis, metaplastic ossification of the aorta), necrosis (salivary gland necrosis, sialoadenosis, hind limb muscular necrosis), hypertrophic osteopathy, haemorrhages and other secondary lesions (pyothorax, hemothorax, hemopericardium, secondary megaoesophagus, pleural effusion, lung lobes atelectasis).

Adults cause produce nodules disseminated in esophagus, stomach, intestine, mediastinum, lumbar fascia, rectum, trachea, interdigital tissue, lung, thymus, diaphragm, heart, kidney, urinary bladder and subcutis. These nodules measure from <1 to >4 cm in diameter and contain usually between three and six worms. Tumor lesions occurring in spirocercosis (cauliflower-like esophageal sarcoma, osteosarcoma, fibrosarcoma) are caused by adults. Gastro-oesophageal intussusception and oesophageal obstruction or perforations are reported following the development of these tumors in the esophagus.

**Clinical signs.** The clinical picture os spirocercosis is highly polymorphic, but several symptoms are the most common, recording significant percentages; regurgitation (20 - 94%), lethargy and depression (59%), vomiting (46%), pyrexia and decreased appetite or anorexia (41% each), weight loss (27 - 35%), melena, submandibular swelling and pale mucous membranes (29% each), hypersalivation (24%), coughing (18 - 21%), neurological signs (paraparesis, paraplegia, hyporeflexia) and hematemesis (18% each)[19,27,35,37,39,45].

The other symptoms that accompany the evolution of spirocercosis are classifiable in digestive (repeated attempts to swallow - odynophagia), respiratory (dyspnea, retching, abnormal respiratory sounds - muffled breathing sounds), neurological (seizures, areflexia of the limbs, bilateral rotary nystagmus, mydriatic pupils), musculoskeletal (lameness, abnormal gait, ataxia), cardiovascular and lymphatic disorders (hemopericardium, congestive heart failure, anterior vena cava syndrome, swollen distal limbs, generalised lymphadenopathy) and other signs (subcutaneous nodules, fever, abdominal distension and dehydration).

Clinical pathology consists in leukocytosis (82%) and microcytic hypochromic anemia (30%) that are the most common hematological abnormalities. Normocytic, normochromic or hypochromic and non regenerative anemia, thrombocytopenia, hyperproteinemia, and increased alkaline phosphatase and creatine kinase activities are other signs.

**Diagnosis.** The useful methods in spirocercosis diagnosis are:

- Faecal flotation reveals the eggs passed through feces. The sugar flotation technique is more sensitive in than are the dilution methods[36].
- Clinical pathology reveals mild anaemia that is present in about 50% of cases.
- Serology - Indirect immunofluorescent assay has 100% sensitivity and 80% specificity.
- Diagnostic imaging by radiography, computed tomography and ultrasonography reveal the presence of tumor in esophagus or in other organs.
- Endoscopy (esophagoscopy) is more sensitive than radiography and allows to perform biopsies from esophageal masses.

Endoscopy is the most sensitive diagnostic method, its efficacy being 100%, followed by fecal flotation (80%), radiography (53%) and clinical pathology (53% anemia, 54% elevated creatine kinase activity)[37].

***Differential diagnosis*** includes heartworm, esophageal or gastric neoplasms, angiostrongylosis, filaroidosis and various cardiopathies.

**Treatment.** The treatment involves medical treatment, and surgical and chemotherapeutic treatment. Medical treatment consists in the use of modern and highly efficient drugs. Good results are obtained using avermectins:

- milbemycin oxime at a dose rate of 0.5 mg/kg PO on days 0, 7 and 28 and then monthly (a total of 6 times) has caused a remarkable reduction in granulomas[48].
- milbemycin oxime, a single dose of 0.5 mg/kg bw is 79.8% effective in preventing the development of *S. lupi* in the esophagus. The efficacy increase at 100% when the doses were repeated at 14- or 28-day intervals[28].
- milbemycin oxime, 11.5mg/kg bw on days 0, 7 and 28 and then monthly stopped shedding *S. lupi* eggs after 3-44 days[25].
- doramectin, 0.5 mg/kg bw, administered orally once daily for 42 days is effective in the elimination of *S. lupi*, the nodules disappearing totally in 65% of dogs at 42 days after treatment[34].
- doramectin, 0.4 mg/kg bw subcutaneously, at 2 weeks intervals, followed by monthly injections until the disappearance of the esophageal granulomas has produced completely disappearance of the nodules in six of the seven (85.7%) dogs between day 35 and day 544 post-initial treatment[32].
- doramectin at a dosage of 0.2 mg/kg bw sc at 14-day intervals, three treatments, has induced disappearance of symptoms in 6 weeks after treatment in 85.7% of dogs and the esophageal nodules had completely resolved in 57.1% of dogs. Repeating the treatment with 0.5 mg/kg bw po daily for an additional 6 weeks has caused complete resolution of the nodules in all dogs[7].
- ivermectin at a dose rate of 0.6 mg/kg bw, subcutaneously, twice, 14 days apart and oral prednisolone, 0.5mg/kg bw, every 12h, for a total of 3 weeks, has caused complete resolution of the clinical signs and nodular regression in 50% and 62.5% of animals, and total negative results of fecal examination in all dogs (8/8), at 2 months from the beginning of the treatment[46].

Chemotherapeutic treatment refers to anti-neoplastic therapy. Doxorubicin was prescribed as adjuvant, but no conclusions were reached regarding the efficacy. Carboplatin and doxorubicin, mono- or combined therapies, have improved survival in dogs. Osteosarcoma respond well to treatment whereas fibrosarcomas are resistant[58,62].

**Control.** Sanitation measures in the paddock and shelters, disposal of faeces, bio-thermal inactivation of manure and residues to prevent contamination of IH, combating the stray dogs and preventing dogs from hunting, scavenging and eating uncooked viscera, performing periodic rodents control and sanitary and parasitological control of canine populations can reduce the incidence of disease. Control of coprophagous beetles or paratenic hosts is not feasible due to the variety and ubiquity of these hosts in an endemic area.

Chemoprophylaxis may be applied with:

Monthly spot-on administration of a combination of imidacloprid 10%/moxidectin 2.5% (2.5 mg moxidectin/kg bw) (Advocate® for dogs) in puppies starting at the age of 2 to 4 months. This protocol has expressed a preventive efficacy of 94.7%[33].

Doramectin at a dose rate of 0.4 mg/kg bw on 3 occasions, 30 days apart did not entirely prevent spirocercosis in dog. It causes the reduction of the clinical signs, delaying and reducing egg output[31].

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# 12. Oxyuroidea

The Oxyuroidea superfamily is the only lower taxon contained by the order Oxyurida. It contains round worms called oxyurids or pinworms which are normally parasites in the large intestine (cecum and colon) of vertebrates and, rarely, in invertebrates. The superfamily is divided into three families: Pharyngodonidae, Heteroxynematidae, and Oxyuridae.

## 12.1. Oxyuridae: oxyuridosis

The Oxyuridae family is the most important one to veterinary medicine because it contains two genera, *Oxyuris* and *Pasalurus*, responsible for important diseases in domestic animals, namely oxyurosis, in horses, and passalurosis in rabbits. The species *Enterobius vermicularis*, which is included in the genus *Enterobius*, causes enterobiosis in humans.

The members of the family are characterized by a cylindrical body, slightly or prominently unequally calibrated, with variable sizes. It is equipped with non-pedunculate amphids at the anterior end, an enlargement of the posterior pharynx, a genital cone without sclerotized supporting structures and irregular in shape at the posterior end of males. The family comprises parasites of mammals, sometimes of birds[1].

Biologically, the members of Oxyuroidea superfamily are geohelminths with a strictly monoxenous life cycle. The gravid females have the capacity to migrate to the anus of the hosts, in order to lay and deposit the eggs in the perianal region, where they are embedded in a substance that hardens on contact with air, to form crusts.

### 12.1.1. Oxyuriosis in horses

**Definition.** It is an intestinal, chronic, and benign nematodosis that affects equines caused by nematodes of the family Oxyuridae, expressed by anal itching and depilations at the base of the tail. It is a cosmopolitan disease, evolving in horses of all ages, throughout the year.

**Etiology.** The disease is caused by *Oxyuris equi*, which is called the equine pinworm, of the *Oxyuris* genus.

***Morphology.*** Adult worms have a stout, cylindrical body, whitish, unequally calibrated, thickened at the anterior end and thinned at the tail. They exhibit a pronounced sexual dimorphism, the female being much larger than the male. The male size varies between 1 and 3 cm in length, and the female is 5 to 15 cm long, the tail being long, thread- or whiplike, measuring approximately two-thirds of the body length. At the anterior end, they have a relatively short and broad stoma and a hexagonal mouth opening delimited by two lateral lips. On each lip, two suckerlike papillae are present. The rudimentary buccal capsule is short and armed with three bristles-like teeth at the bottom. The esophagus is expanded anteriorly and posteriorly and has a posterior bulb equipped with a valvular apparatus. At the posterior end, the male has two short caudal alae, supported by two large pair of papillae, situated preanally and postanally. It has a single, needlelike, long spicule, measuring more than 120 microns, and the gubernaculum is absent. The female has the vulvar opening placed on the anterior part of the body, at a distance of 7 to 10 mm from the anterior end.

The eggs are unembryonated when laid and the shell is double and thin. Their sizes vary between 85 to 95 μm in length and 40 to 45 μm wide. The eggs are asymmetric, having a slight "D" shape, and present a pseudo-operculum at the sharpened pole.

***Life cycle.*** The life cycle is monoxenous, direct. It consists in the alternation of the enteral-parasitical and exogenous phases. Adult parasites live free, unattached, in the large intestine (colon, cecum) in equines (horse, mule, donkey, zebra) and feed on intestinal content and microorganisms (ciliates)[3]. After copulation, the gravid

females move down to the anus of the definitive host. They lay eggs in clumps enclosed in a grey gelatinous substance, a sticky film similar to dried egg albumin that hardens on contact with air, on the perineal skin. After they lay all the eggs, the females are eliminated through the anus and die. Some of the clumps fall on the ground where the eggs embryonate. The process consists in the development of the first-larval stage that remains inside the egg and follows two molts, resulting in the infective element that is the embryonated egg which contains the $L_3$ larval stage. Contamination is done by ingestion of embryonated eggs on contaminated litter or forage. The eggs hatch in the gut and $L_3$ larvae migrate to the large intestine and burrow into the lining. Here, they molt to the $L_4$ larval stage, which finally moult to immature adults. The prepatent period is variable, between 4 and 5 months.

**Epidemiology**

***Geographical distribution***. Oxyuriosis is a worldwide prevalent disease that records a variable prevalence throughout the world, in different equine species. In Europe, the prevalence was 1.2% in the Netherlands[40], 0.7% in Germany between 1984 and 1991[19] and 36% in working horses in Poland[25]. In North and South America, the disease recorded a prevalence of 78% immature and 40% mature *O. equi* in Kentucky over a 28-year period[48], 90% in equines, in the Paraíba Valley, State of São Paulo, Brazil[42] it was also found in horses from the biosphere reserve La Sierra Madre de Chiapas", México[28].

The infection with *O. equi* was identified in 26% of horses in northern Queensland and 7% in Victoria, Australia[39,10]. In Africa, oxyuriosis affected 2% of donkeys in Ethiopia[27], 6.2% of working horses in Lesotho[49] and 16.94% of horses in Cameroon[35]. In Asia, it was recorded in 22.6% of the working horses in Iran[47].

***Sources of contamination.*** Infected equines are the sources of soil pollution. Pollutant potential is not well defined, but approximately 8.000 to 60.000 eggs were found around the anus of an animal[7].

***Susceptibility*.** Receptivity of hosts is not well known, but epidemiological observations reveal that parasitism is more common in adult animals. Other different opinions sustain that younger horses are generally more susceptible than adult horses. Susceptibility is influenced by the keeping system of horses. The horses kept on farms had a lower prevalence of *O. equi* infection and, generally, many other helminth species, compared to horses kept in silvopasture conditions. Silvopasturing exposes the horses to contaminated grasslands, to the lack of quality fodders and control of their health status[22].

***Route of contamination*** is oral, by ingestion of infective eggs through fodder and water.

***Resistance*.** Eggs have a variable resistance, between 9 and 10 weeks to 6 months depending on ambient conditions, dry habitats being more favorable.

**Pathogenesis.** Pinworm action is moderate, sometimes barely perceptible. The fourth-stage larva, burrowed in the lining of the large intestine, pricks the mucosa to feed, exerting a reduced irritative-inflammatory action, expressed by mucosal erosions. The adult females cause a double, i.e., mechanical and irritating, action, due to their up and down movements in the bowel in order to lay eggs. This causes an inflammation and irritation in the perianal region, expressed by depilation areas, erythema, itching, and crusts. Toxins released by the death of females may intensify the local pruritus. The perianal area, rubbed as a consequence of local pruritus, may be inoculated by bacteria, which complicates the lesions.

**Clinical signs.** Oxyuriosis is expressed by several typical symptoms, which give a high indicative value to the clinical exam. Rubbing the base of the tail against solid objects, the

presence of a whitish crust that surrounds the anus, continuous and moderate itching in the posterior area of the body, a dull hair coat, depilation, broken hair over the tail head, and unsightly areas of broken hairs are the characteristic clinical signs of the disease. Several general symptoms are associated, such as restlessness, interrupted feeding and loss of condition,.

**Pathology.** Intense itching causes erythematous and hemorrhagic dermatitis and wounds in the perianal region. The movement of females in the bowel can cause catarrhal colitis and proctitis, which becomes hyperplastic in its chronic form. White females, 10-15 cm long, can be seen on the rectal mucosa during defecation, due to the prolapse of the rectum.

**Diagnosis.** Clinical signs have an increased indicative value. Hair bristles and erythematous areas that surround the base of the tail and perianal crusts are typical for oxyuriosis. Confirmation is obtained by the so-called "scotch tape test". The eggs are rarely eliminated through feces into environment. Because of this reason, flotation tests are useless. A piece of clear adhesive tape that touches the skin surrounding the anal area is used. Next, this piece is taped to a microscope slide and examined, the eggs being easily observed through the tape.

***Differential diagnosis*** includes a large number of diseases of varied natures: mange (chorioptic, sarcoptic and psoroptic), lice (chewing and sucking), ringworm (dermatophytosis, especially microsporosis), onchocercosis, insect hypersensitivity (*Culicoides*, horse-fly-Tabanidae, mosquito), food hypersensitivity, atopy, equine coital exanthema and trauma.

**Treatment.** Current therapy is based on broad-spectrum anthelmintic, benzimidazole and avermectin derivatives, which act better in the state of polyparasitism. The drugs tested, which showed a high efficacy, are shown in table 18.

**Control.** A full program of surveillance and control of pinworm infection involves three major objectives: hygiene, chemoprophylaxis and biological control. Hygiene refers to frequent change of litter and keeping it clean, keeping the floor of the shelter dry, food and water uncontaminated with eggs and even body hygiene by daily grooming.

**Table 18.** Active substances used in therapy of the pinworm infection in horses

| group | active substance | dose rate (mg/kg bw) | efficacy/author |
|---|---|---|---|
| organophosphate | trichlorfon | 40 - 100.0 | 96-100.0[12] |
| nicotinic agonists | pyrantel pamoate | 13.2 paste | 91.2[43] |
| benzimidazole derivatives | thiabendazole | 44.0 - 88.0 | 100.0[38] |
| | cambendazole | 10.0 - 20.0 po | 100.0[13] |
| | parbendazole | 2.5 | 100.0[37] |
| | oxibendazole | 5, 10, or 15.0 | 100.0[33] |
| | mebendazole | 8.8 | 100.0 adults 95.0-100.0 L4 [11] |
| | fenbendazole | 5.0 | |
| | albendazole | 2.5 - 5.0 | |
| | oxfendazole | 10.0 - 50.0 | 100.0[15] |
| avermectines | ivermectin | 0.2 mg/kg bw paste | 96.0[43] |
| | | 0.2, 0.3 and 0.5 im | >97.0[34] |
| | moxidectin | 0.2, 0.3 or 0.4 gel io | 91.0-100.0[36] |

Chemoprophylaxis targets periodical deworming, which has the highest protective efficacy if done quarterly. The same medications described under therapy can be used. Biological control involves the use of nematophagous fungi, which affect the viability of eggs. They destroy the eggs during the passage through the digestive tract, due to the development of their morphological elements in feces, surrounding the eggs. Several species of fungi have been tested (*Duddingtonia flagrans*, *Monacrosporium thaumasium*)[8], but the best results were demonstrated by Pochonia chlamydosporia, whose mycelial mass causes destruction of the eggs[9].

## 12.1.2. Passalurosis in rabbits

**Definition.** It is a common intestinal geohelminthosis occurring in the family Leporidae (rabbits and hares), evolving as a state of unapparent parasitism or benign clinical manifestations.

**Etiology.** The disease is caused by *Passalurus ambiguus*, genus *Passalurus*, family Oxyuridae.

***Morphology*.** Parasites are characterized by a cylindrical body, unequally calibrated, thickened anterior and thinned posterior, measuring 3.8 to 5 mm in length x 200 to 460 μm wide, the male, and 5.3 to 11 mm length x 410 to 590 μm wide, the female. At the anterior end, the lips are not apparent, and the pharinx contains three small denticles. The esophagus has two dilatations, a prebulbar swelling and a distinct bulb. At the posterior end, the male has a tapered tail that ends in a long spike, and two caudal alae, posteriorly extended to the origin of the spicule. The alae are supported by a pair of papillae. Additionally, there are four pairs of papillae that surround the cloaca and a short spicule. The posterior end in females is more elongated and has prominent annular thickenings. The vulvar opening is situated anteriorly, post-esophagus. Eggs are asymmetrical, "D"-shaped due to a flat side, measure 95-103x43 μm and are pseudo operculated at the thinned pole and unembryonated when laid. The eggs undergo a fast initial development through the intestinal transit, so that they are embryonated when they pass in the environment through feces.

***Life cycle*.** The parasites inhabit the cecum and colon of lagomorphs, especially those included in the Leporidae family. European hares (*Lepus europaeus*), snowshoe hares (*Lepus americanus*), jackrabbits (*Lepus* spp.) and European rabbits or common rabbits (*Oryctolagus cuniculus*) are the most common hosts for pinworms. After copulation, the oviparous females lay unembryonated eggs which develop rapidly in the posterior part of the large intestine and rectum, thus appearing in feces as embryonated eggs, in the gastrula stage[26]. According to another opinion, females are ovoviviparous and lay embryonated eggs that contain the first-larval stage. The first-larval stage molts twice inside the egg and thus infective eggs result[6]. Regardless of their stage of development when laid and of the habitat where they become infective, it is generally accepted that the eggs are already infected when they are disposed through the feces.

The animals become contaminated by ingestion of infective eggs or by autoinfection. The third larval stage burrows and develops into the mucous layer and glandular crypts in the mucosa of the small intestine, colon and cecum. The larvae molt twice and develop immature adults, which become adults following a new molt. The prepatent period varies between 56 and 64 days.

**Epidemiology**

***Geographical distribution*.** The disease is distributed worldwide, being common in many rabbitries and hunted rabbits. The prevalence has recorded different values in the United States, namely 17% in the southeast[2] and 11.7% in the northeast[50], in cottontail

rabbits (*Sylvilagus floridanus*). In continental Europe, the disease was diagnosed in 13.11% of feral rabbits from the Leipzig region[29] and 4.8%, between 1998 and 2002, in wild rabbit (*Oryctolagus cuniculus*) in Germany[18], 71.8% in wild rabbit in Dunas de Mira, Portugal[17] and 12.16 % in European brown hare (*Lepus europaeus*) in southwestern Slovakia[14]. In insular Europe, infection was found in 51.3% of wild rabbits in the Azores, 43.9% in the Canaries and 83.3% in the Madeira Islands, Macaronesia archipelago, 47% on Tenerife, Canary Islands[20,21], 14.2% in wild rabbit in eastern Scotland[4], 0.5% in mountain hare (*Lepus timidus*) and 54% in wild rabbit in Aberdeenshire, Scotland[5]. In Asia, the disease is evidenced in 10% of wild rabbit in East-Azerbaijan Province, Iran[24].

***Sources of contamination*** are represented by the fodders polluted with infective eggs and feces that contain these eggs when they are eliminated. The coprophagy habit contributes to contamination, realizing a self-contamination.

Infected animals pollute the environment; the rate of pollution depends on the season and host age, but there were no differences between sexes. Adult rabbits during non-breeding season pollute the environment in the highest degree[31].

***Susceptibility*.** Young rabbits are, generally, more receptive than adults. The rearing conditions, such as mothers with their offspring on deep litter, in boxes cleaned weekly or on slatted floor, weaned youth in cages with slatted floor, do not influence the susceptibility and spreading of infection, the prevalence varying between 14.1% and 27.5%, depending on the farm[41].

Sex does not influence susceptibility, either: infection showed relatively equal values in females (74.6%) and males (70.0%)[17].

***Route of contamination*** is oral, by ingestion of infective eggs, by food or feces (coprophagy).

***Resistance*.** The eggs have an increased resistance to dehydration during their development.

**Pathogenesis, clinical signs and lesions.** Pathogenicity of *P. ambiguus* is reduced; adverse effects on the host are not recorded even in infections with thousands of individuals[32]. Larvae which penetrate the mucosa can carry bacteria, exerting an inoculation action. Loss of condition and poor reproduction are described as clinical signs of infection[16]. Granulomatous appendicitis and lymphadenitis are reported in the literature[23].

**Diagnosis.** Clinically, diagnosis is impossible due to its asymptomatic evolution, more as a state of parasitism than as a disease. Necropsy allows the identification of reduced lesions and the observation of parasites in the large intestine, free in the lumen. Copromicroscopic exam using flotation test is a diagnosis of certainty. The FLOTAC technique is one of the best copromicroscopic methods for identifying *P. ambiguus* in feces[45].

***Differential diagnosis*** includes trichuriosis and trichostrongylidosis.

**Treatment.** The following substances are used, with good results:

Fenbendazole, 50 ppm in the food for 5 days, eliminated all immature and adult pinworms[16].

The use of ivermectin is questionable; Richardson[44] recommended it, at a dose rate of 0.4 mg/kg bw, as an efficient drug against round worms in rabbits while Sovell and Holmes[46] considered that ivermectin had no effect on numbers of *Passalurus* sp.

Piperazine adipate, at a dose rate of 200 mg/kg po, repeated in 14 days, is highly effective against *P. ambiguus*[30].

**Control.** Removal of the eggs directly in the infective stage induces a high transmissibility to passalurosis. The best control is accomplished by the use of farming systems that strictly prevent the introduction of the parasite into the colony. These husbandry practices are associated with the hygiene measures of the shelters, kennels and

paddocks. It is required to keep the floors dry and to collect and store the feces on a daily basis. Disinfection will be performed periodically.

In contaminated units, in order to remove the infection it is required to deworm the entire herd and, at the same time, to decontaminate the environment extremely thoroughly.

Raising rabbits in the industrial system, in cages, is an efficient prevention method. Once contamination has been produced (through food or with the influx of infected rabbits), the disease develops due to autoinfection opportunities and the coprophagous behavior of rabbits.

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# 13. Gnathostomatoidea

Gnathostomatoids are nematodes characterized by well-developed pseudolabia and enlarged and spinous anterior end. The superfamily comprises one family, Gnathostomatidae, divided into two subfamilies: Spiroxinae and Gnathostomatinae. Only one genus occurs in mammals, the others containing parasites of lower vertebrates[1,2].

## 13.1. Gnathostomatidae: gnathostomosis in pigs

Family Gnathostomatidae contains genus *Gnathostoma* that includes nematodes from stomachs of carnivorous mammals. Its members are characterized by the presence of two well-developed lateral lips and an inflated head, separated from the rest of the body by a constriction. Species of the genus Gnathostoma are widespread.

### 13.1.1. Gastric spiruridoses of pigs (gnathostomosis, ascaropsosis, physocephalosis, simondsiosis)

Generically called gastric spiruridosis, this disease involves a group of species belonging to suborder Spirurina, but from diverse families. Thus, the individually, the diseases are ascaropsosis, physocephalosis, simondsiosis, gnathostomosis.

**Definition.** Regardless of the name used, they are biohelminthoses with chronic evolution in swine, expressed by digestive and general disorders. The disease occurs in pigs raised in household system.

**Etiology.** The disease is caused by the worms belonging to suborder Spirurina. Two families are involved: Spirocercidae and Gnathostomatidae, and four genera, *Ascarops*, *Physocephalus*, *Simondsia* belonging to the first, and *Gnathostoma*, from the second family. The species are:

- *Ascarops strongylina*, inhabits the stomach in pigs and wild boar.
- *Physocephalus sexalatus* parasitizes on the epithelium of gastric mucosa in pigs, rarely in ruminants and rabbit.
- *Simondsia paradoxa* develops on gastric mucosa in swine. Females penetrate the mucosa and channels of gastric glands and produce nodules.
- *Gnathostoma hispidum* infects gastric mucosa of pig, boar, sheep and many other vertebrate animals including humans. Larvae can migrate to the liver and other organs.

***Morphology*.** Nematodes belonging to both families are characterized by an equally calibrated body, moderate sizes, ranging between 6 and 45 mm length. At the anterior end, the worms have the mouth opening delimited by lips. At the posterior end, the males present two cuticular dilations with several papillae and two unequal spicules. The female is ovoviviparous. The eggs are ellipsoidal and possess a thin and bilayered shell. The sizes of the eggs are variable, between 28-74/12-42 μm and they are embryonated.

*Ascarops strongylina*'s mouth vestibule has two small lips and transversely striated cuticle. The male is 10 to 15 mm long, and the female has 15-22 mm long and 0.4 mm width. The posterior end of the male is curved and has two asymmetrical caudal alae, the right being about twice wider than the left one. The male has four caudal, pedunculate and long pairs of papillae; three pairs are situated preanal and the fourth is adanal. The spicules are unequal; the left is longer and thinner, slender and the right one is short, thick and blunt. The vulvar opening is placed at the middle of the body; posterior the female has caudal alae but less developed comparing to male. The eggs have thick shell and measure 34-40/18-20 μm.

The male of *Physocephalus sexalatus* measures 6-13/0.3 mm and the female is 13-22 long and 0.4 mm wide. The cuticle has a slight dilation near the pharynx. At the posterior end, the male has two caudal alae and two long and unequal spicules. The eggs measure 31-39/15-17 μm.

*Simondsia paradoxa*: the male is 12-15 mm long, and the female has 15 mm length. At the anterior end, the mouth is armed with two teeth, one of them situated dorsally, and the other is placed ventrally. The posterior end is coiled in male and saccular in female. Elliptical eggs measure 20 to 29 μm.

*Gnathostoma hispidum* has the body covered with spines and is red in the anterior half of the body and yellowish-gray to posterior. The male measures between 20 and 25 mm length and 1 to 2 mm wide and the female is 20 to 45 mm long and 2.5 mm wide. At the anterior end has a bulb armed with 9-12 rows of hooks. The male has two long, unequal spicules; the female's vulva is situated in the middle of the body. Eggs have thick shell, a protrusion to a pole, and measure 70-75/39-42 μm.

***Life cycle.*** Life cycle is diheteroxenous; coprophagous beetles intervene as intermediate hosts. Adults live in their habitat and eliminate embryonated eggs that reach the soil and water through faeces. The eggs of spirocercids (*Ascarops*, *Physocephalus*, and *Simondsia*) are ingested by their intermediate hosts, *Aphodius*, *Ontophagus*, *Geotrupes*, *Gymnopleurus* and *Scarabaeus* beetles. The eggs hatch and the larvae molt twice becoming infective $L_3$ larvae.

The eggs of *Gnathostoma hispidum* develop in the aquatic environment and hatch in about a week, depending by the temperature. The first-stage larvae are ingested by intermediate hosts, cyclopoid copepods (*Cyclops*). In their body, the larvae molt twice becoming infective. Paratenic hosts, such as fish, amphibians, and rodents may intervene. They ingest the copepods and the larvae re-encyst in muscle, liver, in their body. Definitive hosts become infected through ingestion of intermediate or paratenic hosts. The larvae are released into the stomach and migrate to the liver, arterial walls, gastric wall and then reach the gastric mucosa. The larvae molt twice during these migrations, and finally mature. Prepatent period varies between 30 and 50 days and the patency is over a year[7,21].

**Epidemiology**

***Geographical distribution.*** Gastric spiruridoses of pigs are worldwide spread, but there are few data on their prevalence in domestic pigs, all species being frequently reported in wild boar. The species *A. strongylina*, *P. sexalatus* and *G. hispidum* are reported in domestic pigs, in India[4,22], Kenia (*A. strongylina*, 1.7% and *P. sexalatus*, 0.9%)[13], Ghana (*A. strongylina*, 8.1%)[15] and South Africa (*A. strongylina*, 11.5%)[10]. In Australia, *S. paradoxa* is reported in feral pigs (7.84%)[20].

In wild boars these spirurids are identified in Romania (*A. strongylina*, 6% and *P. sexalatus*, 2%)[6], Spain (*A. strongylina*, 11.1 and 87%, *P. sexalatus*, 6 and 22.2%, and *S. paradoxa*, 22.2%)[9,12], France (*A. strongylina* and *P. sexalatus* in 97% of the animals)[11], Croatia (*P. sexalatus*, 25.5-40% and *A. strongylina*, 40-57.5%)[16,17], Germany (*P. sexalatus*)[3]. The infections are identified in United State: *P. sexalatus* (8-10%) in Texas[5,18] and *P. sexalatus* (13 %) and *A. strongylina* (6 %) in Georgia[14]. In Asia, *A. strongylina* and *P. sexalatus* (each 56%) were found in Iran[8], Japan[19].

***Sources of contamination.*** The infected pigs and their droppings scattered in areas with specific biotopes, as marshes, where intermediate hosts are spread, are the sources of environmental pollution. The fecal eggs count is not known. Fertile period of the females extends over several months. Dispersal of eggs in various biotopes is possible by transporting of manure on grassland, by wastewater used to irrigate lands for forage. The sources of contamination of the animal are intermediate and paratenic hosts.

***Susceptibility.*** Young animals are the most vulnerable. Pigs are contaminated by ingestion of intermediate hosts, specific to each parasite. Mice and rats may intervene as

paratenic hosts, transmitting the disease in pigs. Adult parasites are found over 4 months of age, the number of parasites increasing with the age of the animals. Wild boars are more susceptible to infection even than backyard pigs due to their increased opportunities to consume intermediate or paratenic hosts.

***Route of contamination*** is oral, through consumption of food and water that contain intermediate or paratenic hosts.

***Resistance*** of the eggs in the environment is unknown; they are consumed by intermediate hosts, and survival of larval forms depends on the resistance of their hosts.

**Pathogenesis.** Migratory larvae through the hepatic artery lumen, the vascular walls in liver parenchyma exert an irritative-inflammatory action. They cause microlesions, micro-hemorrhages and sinuous necrotic tracts in the liver and other organs. Inoculation effect consists in secondary superinfection. Microbleeds, sero-hemorrhagic and nodular inflammations in traumatized gastric mucosa are produced. Toxic, spoliatory and allergic actions are significant.

**Clinical signs.** The disease evolves subclinical in low infections, but in massive infections the animals show inappetence, vomiting, excessive thirst, adynamia, sensitivity in the abdomen, constipation alternating with diarrhea, growth retardation, animals lose their weight and become anemic even death.

**Pathology.** The larvae into the blood vessels and liver parenchyma initially cause parenchymal and necrotic hepatitis and nodular cirrhosis when the disease becomes chronic. Adults in the stomach determine catarrhal, hemorrhagic or nodular gastritis (nodules, the size of a hemp seed). The mucosa in the fundus region is reddened and swollen or covered with easily removable pseudo-membranes. Underneath pseudo-membranes, the tissues are intense reddened and ulcerated. The nodules contain parasites, and open usually into the stomach or sometimes in the abdominal cavity. Purulent peritonitis and death occur in this situation. Hyperplastic gastritis with the presence of parasites in the stomach lumen develops in chronic form. Free worms or embedded in mucosa are easily evidenced in stomach. Histologically, areas of necrosis of the mucosa are bounded by eosinophils.

**Diagnosis** can be done corroborating epidemiological data, clinical signs and is confirmed by the identification of eggs in the feces. Clinical exam is indicative, the symptoms being common with other gastrointestinal helminthoses. Positive diagnosis consists in revealing of the eggs in feces using flotation methods.

The necropsy allows to observe catarrhal, hemorrhagic, nodular or proliferative gastritis, and of the nematodes into the stomach. Sometimes, the nodules ulcerate and gastric mucosa is edematous. Nodules contain a greenish-yellowish or purulent mass and parasites in different developmental stages.

***Differential diagnosis*** includes ascariosis, hyostrongylosis (may develop associated), specific or toxic gastritis.

**Treatment.** Benzimidazoles, imidazo-thiazoles and avermectins derivatives are useful. Good results are obtained with:

- Ivermectin at a dose rate of 2.4 ppm in food, ad libitum 7 days, had a 100% efficacy against *A. strongylina*, *P. sexalatus* and *S. paradoxa*[9].
- Doramectin, 0.3 mg/kg bw given intramuscularly has expressed a 99.5% efficacy against *A. strongylina*[23].

Benzimidazole derivatives have high efficacy in swine nematodoses, without a special testing against gastric spiruridoses. It is likely to have the same efficacy as high as in other nematodosis (ascariosis).

**Control.** The control of the diseases aims prophylactic treatment of pigs in endemic areas, destruction of intermediate hosts (coprophagous beetles), avoidance of feeding

the pigs with uncooked fish, preventing of access of the pigs in areas around fisheries stations. The animals will be maintained in sanitized shelters; the diet will be balanced regarding the quantity and quality of fodders. The weak animals will be removed from the flock. Two chemoprophylactic treatments must be applied per year, in all animals, in the spring and autumn, in endemic areas. In young animals, first treatment must be applied immediately after weaning, and in adult pigs kept at pasture, autumn, after entering in stabulation. Periodically disinfection must be done after mechanical cleaning of the shelters.

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# 14. Trichinelloidea

The Trichinelloidea superfamily is included in the Enoplea class, Trichinellida order. It is divided into three families and five subfamilies, but some of these taxa were elevated in rank. Thus, it is currently accepted that this superfamily contains five families: Capillariidae, Cystoopsidae, Trichinellidae, Trichosomoididae, and Trichuridae. The Trichinellidae, responsible for trichinellosis in animals and humans, Capillariidae, which causes capillariosis, and Trichuridae, which causes trichocephalosis, are the main families important to veterinary medicine.

## 14.1. Trichinellidae: trichinellosis in animals

The Trichinellidae family is characterized from a morphological point of view by a very small body, ranging between 1 and 4 mm in length, slightly unequally calibrated, the posterior end being a bit wider than the anterior end. The females are viviparous and the life cycle is special, so-called autoxenous, when all stages of its life cycle occur in the same host individual. The family comprises a single genus, *Trichinella*. The disease caused by the members of this family is called trichinellosis.

**Definition.** Trichinellosis is a cosmopolitan parasitic zoonosis that affects humans and over 100 species of domestic and wild mammals, and some bird species. It is caused by nematodes of the family Trichinellidae which affect animals of all ages. It is characterized by a symptomatic evolution in animals and severe clinical expression, sometimes fatal to humans. In humans, the serious clinical forms are caused by intestinal development of parasites and migratory larval forms. Infection with *Trichinella* spp. has several essential features, namely:

- zooantroponotic character, or transmissibility of disease from animals to humans by ingestion of infected meat;
- wide geographical spread;
- large number, between 100 and 300 species affected, heterothermic animals, warm-blooded mammals, reptiles, fish and birds;
- severe clinical expression, even fatal to humans, in conditions of natural and asymptomatic evolution in animals;

**Etiology**

A new structure of the genus *Trichinella* is proposed based on biological, biochemical and molecular characters[140,160,161,159,154,108,102]. Within it, 12 gene pools are delimited. They are numbered from T1 to T12 or without this encoding, corresponding to well-defined Trichinella species or genotypes of uncertain taxonomic status: T1 - *Trichinella spiralis* sensu strictu Owen, 1835; T2 - *Trichinella nativa* Britov and Boev, 1972; T3 - *Trichinella britovi* Pozio et al., 1992; T4 - *Trichinella pseudospiralis* Garkavi, 1972; T5 - *Trichinella murrelli* Pozio et al., 2000; T6 - genotype with uncertain status; T7 - *Trichinella nelsoni* Britov and Boev, 1972; T8 - genotype with uncertain status; T9 - genotype with uncertain status; T10 - *Trichinella papuae* Pozio et al., 1999; T11 - *Trichinella zimbabwensis* Pozio et al., 2002 and T12 - *Trichinella patagoniensis* Krivokapich et al., 2012.

- *T. spiralis* is characterized by a cosmopolitan distribution in temperate regions of the northern hemisphere. The domestic pig has the highest sensitivity related to this species[87]. It may also affect other mammals: dog, cat, fox, wolf, coyote, wild boar, bear, mouse, rat, including man[8,88,140,141].
- *T. pseudospiralis* has a cosmopolitan distribution in wild birds and mammals, but apparently its host is normally the spelled raccoon (*Procyon lotor*)[66]. It was identified in the U.S., Europe, Africa, Australia (Tasmania) and in equatorial Asia. It was extended to the northern hemisphere from southern Asia by migratory birds[44,219,220].

- *T. nelsoni* is widespread in Europe and Africa, below the parallel of 40° north latitude[186,187,188]. Wild canids (foxes in Europe, jackals in Africa), hyenas and wild cats are reservoirs of parasites[158]. Wild pigs (warthog) can be parasitized. It is resistant to high temperatures, compared to other genotypes, as a result of adaptation to the tropical climate.
- *T. nativa*[66] is characterized by a Holarctic distribution, in the entire northern hemisphere, above of 60° latitude. The southern boundary is represented by the average January isotherm of - 5°C[186,187,188,157,156]. Wild mammals are the natural hosts of this species: canids (wolves, foxes), bears (polar bear), and mustelids. Pinnipeds (fin-footed mammals: walrus, seal) are also hosts for this species. Cetaceans may be parasitized. It is more resistant to freezing than other species, surviving for at least 72 hours.
- *T. britovi* is relatively common in wild carnivores, being identified in a wide variety of hosts, namely in sylvatic canids and cats, bear, boar, horse, domestic swine and humans. In Romania it is diagnosed in wolf (*Canis lupus*), Euriasian lynx (*Lynx lynx*), and European wild cat (*Felis silvestris*)[17]. It has low infectivity to rats and moderate in pigs. Geographical spread is similar to *T. spiralis*, it being a species of temperate regions.
- *T. murrelli* is widespread in the temperate Neartic region of the U.S. (Connecticut, Georgia, Illinois, Indiana and Pennsylvania). The northern boundary of the area of distribution is represented by the isothermal average of January - 6°C, while the southern boundary is not determined. It is diagnosed in black bear (*Ursus americanus*), common raccoon (*Procyon lotor*), coyote (*Canis latrans*), fox (*Vulpes vulpes*), other wild carnivores (*Mustela vison*, *Felis rufus*) and horse[160].
- *T. papuae* was found in wild boar in an isolated region of Papua New Guinea. Its geographic distribution is still unknown. The larvae do not form cysts in the muscles, being similar to *T. pseudospiralis*[155].
- *T. zimbabwensis* was detected in farm crocodiles (*Crocodilus niloticus*) in Zimbabwe and Ethiopia, in wild crocodiles in Mozambique, and monitor lizards in Zimbabwe. The larvae do not form cysts in the muscles parasitized[153].
- *T. patagoiensis* was recently identified. From a biological point of view, it is more similar to *T. britovi* and *T. murrelli*. It is widespread in the Neotropical region[102].

The species are grouped in two clades: the encapsulated clade containing six species and three genotypes of undetermined taxonomic status and the non-encapsulated clade, three species belonging to this clade (*T. pseudospiralis*, *T. papuae* and *T. zimbabwensis*).

***Morphology*.** The parasites present a pronounced sexual dimorphism. The male measures 1 to 1.6 mm in length / 30-40 μm wide and the female 2 to 4 mm / 60 to 70 μm. At the anterior end, both sexes have the mouth opening, which is punctiform, equipped with a retractile buccal stylet. At the posterior end, the male lacks spicules and spicular sheaths, but presents two lateral alae and two finger-like copulatory appendages between the alae. The cloacal opening is placed between the appendages, being transversely opened. It also has two pairs of papillae, the ventral being hemispherical, and a dorsal cone. The female is slightly thickened at the posterior end. The vulvar orifice is situated on the ventral side, in the anterior fifth of the body, toward the middle of the esophagus, with an oval and cleft appearance.

The final stage of endogenous development in the encapsulated species is represented by the perilarval and adventitial cystic reaction. The cyst is a complex structure that houses the coiled muscular larva within the cyst. Three components are distinguished, structurally, in *Trichinella* cyst: nurse cell, the capsule and pericystic vasculature network. The classic

form of *T. spiralis* cyst is fusiform, with two knobs of fat at both poles that give them the appearance of a lemon. The length of the cysts ranges from 300 to 850 μm, with a mean of 730 μm and a width of 200 to 380 μm, and an average of 295 μm. The average length / width ratio is 2.47, demonstrating the fusiform appearance of the cyst. The sizes and shapes of the cysts, however, depend on the anatomical region of origin of the muscle parasitized and host animal species.

**Life cycle**

The biology of the parasites of the genus Trichinella is complex and involves successive stages completed entirely in the parasitized hosts. This feature gives the biological cycle an autoxenous character. The first-larval stage ($L_1$) is localized in the nurse cell, which is a modified myocyte; adult parasites live in the columnar epithelium, in the small intestine; the newborn larva or embryo is a free stage migrating through lymphatic-hematogenous circulation[49].

The cycle starts with the ingestion of contamination sources that contain *Trichinella* larvae or cysts. It is followed by a short gastric phase in which these fragments are digested, liberating the larvae. Released larvae move to the intestine. Endogenous biology in *Trichinella* spp. is initiated, following the penetration of larvae into the small intestine. Two phases are distinguished: the enteral phase, which occurs within the small intestine, and the parenteral phase, which includes larval migration and development in the muscle niche.

The enteral phase starts with the penetration of the mucosal cells by the larvae, without the destruction of the epithelial cells. The larvae mature into adults, and the females lay larvae after copulation.

The larval migration phase consists in the dissemination of the larvae through circulation throughout the body. The larvae that reach the muscles will encyst. Those which reach untypical biotopes, to which they are not adapted, will die.

The muscle encystation phase initially consists in the transformation of the myocyte into a nurse cell that has an altered structure, and, subsequently, in the development of the cyst around the larva in about 6-7 weeks.

The chronobiology of the extra-intestinal stages is characterized by the presence of larvae in the bloodstream in 7 to 12 days pi. Their access to the muscle masses happens in 8 to 12 days pi and the curving process of the larvae at 18-20 days pi. Then the larvae also gain the ability to infect new hosts. The development and encystation of larvae happens between 21 and 45 days pi. The process of calcification of cysts is initiated at 5-6 months pi and lasts 15 to 16 months.

**Epidemiology.**

***Geographical distribution***. Trichinella infection is referenced to a variable number, between 150-300, species of mammals, birds and reptiles.

Infection is diagnosed in Europe mainly in sylvatic fauna in countries such as France, in fox[194]; Lithuania in wild boar[9]; Netherlands in wild boar and fox[96]; Slovakia in wild boar and fox[54]; Sweden in fox[36] and Bulgaria in fox, badger, wild cat, wolf, bear, jackal, wild boar and mustelids[105]. Infection in pigs is absent in the Czech Republic and Slovakia[54], Belgium[62], Austria, Denmark and the Netherlands[96].

In Africa, trichinosis is diagnosed in Egypt in pigs (1.691%), stray dogs and rodents (20.9% - 41.9%)[116,129,138], in South Africa in the Nile crocodile (38.5%, *Crocodylus niloticus*)[107], in Zimbabwe and Mozambique in the Nile monitor lizards (*Varanus niloticus* - 17.6%) and crocodile, respectively (20%)[152].

In North America, the infection is diagnosed in the U.S. in pigs, the maximum prevalence of 0.33% being revealed in 1970[223]. Sylvatic trichinosis is the main focus of the North American continent. In Canada, *Trichinella* spp is prevalent in terrestrial and aquatic

mammals, where the identified species were *T. nativa*, *T. murrelli* and the genotype *Trichinella* T6[7,8]. In Mexico, the prevalence of trichinellosis in pigs ranged between 0 and 6% in 1986 to 1999[145].

The infection is diagnosed in South America in synanthropic and wild animals in Argentina[8], in Chile, where the infection rate of pigs decreased from 0.017% in 1991 to 0004% between 1998 and 2000[179], and in Bolivia, where antibodies were detected in the sera of domestic pigs in different regions[25].

In Asia, the infestation is widespread in Afghanistan[104], China[114], rare in India[178], Iran, in sylvatic fauna[77], in Japan in fox, dog raccoon, bear and dog[86], in South Korea, Laos, Malaysia, Syria, Thailand, Vietnam, Uzbekistan and Turkey[151].

***Sources of contamination*** are represented, on the one hand, by synanthropic animals such as the pig, rat, dog, cat, coypu and, recently, equines, and, on the other hand, by the sylvatic foci, where foxes, badgers, boars, and bears play an essential role. The consumption of viscera, slaughterhouse products or corpses that contain *Trichinella* cysts or infective larvae is another source of contamination. Pigs become infected by eating various sources of parasites: live or dead rodents, protein soups and slaughterhouse waste unsterilized by heat, and as a result of cannibalism (consumption of tails and ears). Contamination in ruminants is possible through the consumption of infected meat. These species accept meat in their diet in cases of malnutrition and pica syndrome as demonstrated in ruminants[44]. Sources of contamination in horses are the crushed grains and vegetable flours contaminated with ground rodent bodies[59].

Two foci are defined in the epidemiology of the disease: synanthropic, in which the sources of parasites are the domestic animals (pig, rat, dog, cat, and coypu) and sylvatic, in which the fox, badger, boar and bear are important. Dissemination of the infection between the two foci is possible through rats that determine the perennial feature of the disease, by cannibalism. The consumption of game meat also intervenes in the transfer of infection between the two foci. Coprophagous and necrophagous beetles are important because the larvae remain viable about 5 to 8 days in their body. They are sources for carnivores, rodents and insectivorous animals[43,44,59,128].

***Susceptibility*** is influenced by multiple risk factors. They are systematized in intrinsic (species, the health of the individual) and extrinsic factors (breeding system, nutritional behavior, infective dose, animal behavior in experimental infestations).

The carnivores (dog, cat, fox, wolf, mustelids, white bear, seal, and walrus), omnivores (pig, wild boar, and bear), rodents, and humans are naturally susceptible. The infection is achievable, under experimental conditions, in species with native receptivity, but also in those considered unresponsive. In the second category are included the herbivores (horse, ruminants), rodents (guinea pig, hamster, rabbit), fish and birds.

Another issue recorded in recent years is the expansion of natural receptivity in species considered until recently free from trichinosis. The horse, a species among whose members were detected infected individuals in Belgium (0.9%) and Poland (0.53%) by ELISA, is representative in this sense[18,221].

***Route of contamination***: The ussual route of contamination is oral, by ingestion of *Trichinella* cysts through the above mentioned sources. Transplacental and transmammary routes are possible due to the small size of the migrating larvae[40,43]. Experimental infection can be achieved parenterally, intraperitoneally and intravenously in mice, rectally, nasally or intratracheally in rabbit[118,124].

***Resistance*** of parasites depends on the evolutionary stage of the parasite and the environmental conditions related to the action of destructive factors.

Adults in the intestine have a variable resistance, dependent on sex. The males die and are lysed immediately after fertilization, and the females survive 5 to 6 weeks fixed in intestinal crypts[44].

The larvae encysted in muscles have a resistance of up to 50 years in live animals. The larvae retain their infectivity for up to 3 weeks in bodies kept in putrefaction at room temperature. The larvae removed through recently infected animals remain viable for up to 15 days and in the body of arthropod insects, they survive for 5-8 days[128]. *T. spiralis* larvae encapsulated in muscles do not survive for more than 48 hours in freezing conditions, at -32 ° C[192]. The influence of physical (heat, cold, X-rays, ultraviolet and gamma radiation) and chemical agents (sodium chloride solution, sucrose, glucose, glycerol, alcohol) depends on the size of the pieces of meat, and the intensity and duration of their action.

**Pathogenesis.** Pathogenic mechanisms are well known in human and laboratory animal infections, but to a lesser extent in natural trichinosis, in animals in which the evolution is subclinical[15,24,58].

Pathogenicity of *Trichinella* spp. is exercised differently under natural conditions, depending on the evolutionary stage of the parasite. The adults cause a bowel syndrome because of their enterotropism. Migratory or encysted larvae produce a muscular syndrome, following the previous one, due to their muscle tropism[60]. Three phases are distinguished in trichinellosis pathogenesis, correlated with parasite life cycle phases[58,117]: the intestinal phase; the larval migration phase; and the muscle location phase.

During the ***intestinal phase,*** the adults exert mechanical-irritating, toxic, inoculation, and immunogenic effects in the small intestine[44,60]. The *mechanical-irritating effect* is expressed by mucosal inflammation, villous fusion and destruction of a large area of absorption. As a result, malabsorption occurs, the activity of intestinal enzymes decreases, glucose absorption diminishes, and the ratio of blood - fatty acids changes, in the sense that the unsaturated ones increase while the saturated ones decrease[201,34]. *Toxins* produced by adult parasites are eliminated through the kidneys, causing glomerulonephritis, tubular nephritis with hyaline cylinders in the tubular lumen, a decrease of the filtration capacity of the kidney, and the initial increase in serum levels of urea and creatinine[166]. The *inoculation effect* is discreet due to the penetration of mucosal lymphoid formations - Peyer plates, Lieberkuhn glands, and lymphoid follicles - where the defense against infectious pathogens is well organized[60]. The *immunogenic effect* induces an immediate response consisting in the rapid or gradual expulsion of adult parasites from the gut as a consequence of the host's immune response[91].

The ***larval migration phase*** is accompanied by prominent irritating-inflammatory, toxic and immunogenic effects[60]. *Irritating-inflammatory action* is exerted on the lymphatic and blood capillaries, causing vascular injury, injury of myocytes (muscle injury) and internal organs (organ damage)[117,163]. Vascular lesions are reflected in the physiology of capillaries and the biochemical and haematological composition of blood. In the capillaries, a capillaropathy expressed by spasm of vessels and stasis, is evidenced[31]. Biochemical, hypoproteinemia, hypoglycemia, increased ascorbinaemia, decreased serum cholinesterase activity, changes in fatty acid and haematological changes, leukocytosis, eosinocytosis, decreased hemoglobin, hematocrit and mean corpuscular volume are the changes that accompany this phase[46,47,171,203]. The lesions during the migration through muscle tissue consist of myolysis and focal lymphocytes and eosinophilic granulocyte infiltration in guinea pigs and rats. Among organs, the liver, kidneys, brain, lungs, adrenals, and other organs are affected[204]. The *toxic effect* is

interrelated with the irritating-inflammatory action. The migration of the larvae determines exo-and endo-toxin dissemination throughout the body. This will cause hepatic steatosis and lipid dystrophy of the kidney accompanied by glomerular, tubular and interstitial nephritis[147].

The *immune response* induced by the larvae during migration consists in stimulation of B and T cells from the mesenteric lymph nodes. They induce degranulation of mast cells, increasing the eosinophils number and the secretion of IgE and IgG. These immunoglobulins will intervene in the antibody-dependent cell-mediated cytotoxicity phenomenon[27].

The ***muscle location phase*** consists in multiple pathogenic actions exert by encysted larvae: irritating-inflammatory, toxic and antigenic60. *Irritating action* is responsible for inflammation of the muscle fiber. It causes muscle mass hypertrophy, myorexis (muscle rupture) and myolysis, granular degeneration of the fibers, lymphocyte and histiocyte infiltration, loss of the transverse striations of the fibers, disappearance of myofilaments, the sarcoplasm becomes granular, the size of the nucleus and nucleoli of myocytes increases but that of the mitochondria decreases, and the rough endoplasmic reticulum prolife-rates[61,65,84,106,110,195]. *Toxic action* manifests itself locally and generally. Local, exo and endotoxins of *Trichinella* spp. are responsible for muscle fiber degeneration and intracellular metabolic disorders with delayed stimulation of the activity of adenosine mono-tri-phosphatase (MATP) and a decrease of the respiratory control index[216]. Generally, it is responsible for hyperthermia and edemas that accompany the disease reactions[60].

The antigenic effect is not surprising considering the intimacy of the relationship between parasite and host. It is believed that the immune response of the hosts in this phase is reduced in intensity because encysted larvae are protected from the host's immune defense[44,50].

Besides the pathogenic mechanisms exerted by the evolutionary stages of the parasite during the invasion, a number of side effects of *Trichinella* spp. are experimentally demonstrated. Although *T. spiralis* is a parasite that exhibits an oncogenic effect[26,112], the role of *T. spiralis* and *T. pseudospiralis* as an inhibitor of tumor growth has also been demonstrated[197]. It also occurs in the rejection of skin allografts[4].

**Immunity.** The antigenic complexity of *Trichinella* spp induces varied immune responses in parasitized organisms, but a natural immunity also occurs.

*Natural or innate immunity* - *Trichinella* spp. parasitize diverse hosts, mostly warm-blooded mammals. The Poikilothermic species are considered to have an innate resistance to Trichinella invasion, although it succeeds in experimental conditions[117].

*Non-specific immunity* - Ancylostomidae infections in hamster cause cross reaction with *Trichinella* spp. It consists in the delay and reduction of physical and fecundity development of females. Rapid expulsion of adults in the gut is also delayed[14]. *Eimeria* spp. infection in mice does not prevent infection with *Trichinella* spp.[175].

*Acquired immunity* can be active or passive.

Active immunity can be post-infectious or post-vaccination. It is induced on the first infection, and it is not subsequent to a state of premunition. Repeated reinfection provides a better protection against *Trichinella* spp. Post-vaccination immunity is demonstrated by numerous studies in pig, rat, mouse, using as vaccine $L_3$ larvae of *T. nativa* or excretory-secretory antigens (ES)[22,73,191222].

Passive immunity is proven by transmammary transfer from an infected mother to the newborn. The level and duration of immunity depends on multiple factors, some of them exerting a suppressor effect - corticosteroids, malnutrition, stressors[53,55].

Immunity in trichinellosis is humoral- or cell mediated.

*Humoral immunity*

During the development of trichinellosis, IgG and IgM levels are high and have an increased avidity to the somatic antigens of *T. spiralis* while the level of IgE is lower[91,207].

*Cellular immunity*

The cells directly involved in damaging the parasites are neutrophil granulocytes and eosinophils. The latter have an important role in the immunopathology of trichinellosis. They act on larvae through the Ig and a complement system. The C36 fragment of the complement binds to the parasite and subsequently to the eosinophils. The eosinophils will increase their production of oxygen radicals and release eosinophilic cationic protein (ECP), major basic protein (MBP) and peroxidase which will damage the parasite. Binding of eosinophils can be done via IgE and IgM. Eosinophils intervene, likewise, locall, at the intestinal level in rapid or gradual expulsion of adult parasites through an antibody-dependent cell-mediated cytotoxicity (ADCC) mechanism. Eosinophils are fixed on parasites covered by IgG that are generated by the B lymphocytes under the influence of parasite antigens. Once fixed, PBM that adversely affect adult parasites will be released[198].

Two elements, antibodies (Ab) and antigens (Ag), are involved into the immune mechanisms.

*Antibodies* are serum proteins. They are synthesized by B-lymphocytes. Biochemically, they are gamma globulin and are divided into five classes: IgA, IgM, IgE, IgG and IgD. They form the Ag-Ab complex binding to the Ag. IgA occurs in the gut, being involved in the phenomenon of rapid expulsion of adult parasites from the gut. IgM and IgE are responsible for cytopathological modifications with alteration of somatic and germ cells of adult parasites, prior to expulsion[44].

Trichinella *antigens* are of two types: somatic antigens, present in the tissue extract of parasites and excretory secretory or metabolic antigens (ES). The somatic Ag serve as complement activation, with a maximum capacity of Ag originating from newborn larvae. ES Ag secretion is achieved by stichocytes that contain secretory granules. Common Ag of *Trichinella* and other helminths are identified (*T. spiralis* and *Fasciola hepatica*)[174]. This phenomenon may play an essential role in interspecific protection.

**Clinical signs.** Natural infections in animals are not expressed clinically. This requires the assessment of the presence of larvae in the body as "Trichinella infection" rather than "trichinellosis"[72].

Two clinical forms evolve in experimental infections in pigs after several days of incubation: intestinal and muscular. Symptoms include diarrhea, prostration, loss of appetite, abdominal pain, abdominal wall contracted, painful on palpation followed by general symptoms, contractions and muscle pain, bruxism, difficult mastication, impaired locomotion, slow and stiff movement, feverish state, polydipsia.

Dogs develop nonspecific symptoms: vomiting, diarrhea, anorexia, fever, agitation, neuromuscular symptoms and lethargy[143,167].

Humans are more dramatically affected, the infection being characterized by abdominal pain, diarrhea or constipation, vomiting, malaise, fever, diffuse myalgia, periorbital and / or facial edema, conjunctivitis, headache, rash, difficulty in swallowing or opening the mouth, insomnia, weight loss, coryza, hoarseness, bronchitis, haemorrhages at the base of fingernails and / or retina, visual disturbances and paralysis of the eye's muscles[33].

**Pathology.** The lesions do not reach in animals the level of severity that the changes in humans reach. They refer to the effect of larvae in intestine and muscular stages.

Intestinal lesions consist in acute catarrhal enteritis, intestinal mucosal edema, petechiae and the presence of *Trichinella* adults. In

muscles are evidenced acute myositis affecting the highly active muscle mass.

Histologically, the intestinal form is characterized by the metamorphosis of cylindrical cells in goblet cells, epithelial cell desquamation in rows, microbleeds and superficial necrosis of villi, glandular structure destruction and dilation of lymphatic spaces.

In muscle location, dissolved muscle myofibers, mononuclear and polymorphonuclear infiltrations, angiogenesis, hypertrophy of myonuclei, myotube formation, mitosis, muscle bundles rounded and separated from other bundles, the disappearance of A, I and Z bands of the sarcomeres, an increase of the endoplasmic reticulum and Golgi complex, decreased glycogen and mitochondria relocation have been described[98].

Oncogenic action of *Trichinella* spp consists in the involvement in various tumor diseases: squamous cell carcinoma of the mouth[26], lingual carcinoma[35], cancer of the larynx[190].

**Diagnosis.**

Current methods of diagnosis are very diverse and can be classified depending on the moment of their practicing in diagnostic methods applied intra-vitam and post-mortem, respectively. Intra-vitam methods include clinical and experimental diagnosis. In animals, it is almost impossible to diagnose trichinellosis based on symptoms. Experimental diagnosis is achieved in the laboratory by indirect methods (haematological examination, reactions of precipitation, flocculation, agglutination, immunofluorescence, complement fixation, agar-gel double diffusion - Ouchterlony, ELISA and intradermal reaction) and direct exams (coprology, observation of migrating larvae, biopsy).

Post-mortem diagnostic aims to detect *Trichinella* infection after slaughter of the animals. It is achieved by direct and indirect methods. Direct methods include trichineloscopy and artificial gastric digestion. Identification of *Trichinella* cysts and larvae is achieved from fragments of muscles sampled after slaughter. Two important factors that influence the sensitivity of these methods are: sample size and predilection sites (table 19). Indirect methods (precipitation reaction with extracts of muscle, xenodiagnosis) have limited application, being used mostly for experimental purposes, but in some circumstances they can complete the trichineloscopy.

**Table 19**. Predilection sites of *Trichinella* spp. larvae in animals[87,142]

| Species | Site of choice |
|---|---|
| Domestic pig | diaphragm, tongue, masseter |
| Horse | tongue, masseter, diaphragm |
| Wild boar | tongue, diaphragm |
| Bear | tongue, masseter, diaphragm |
| Walrus | tongue |
| Fox | tongue, eye muscles, forelimb muscles |
| Raccoon dog | diaphragm, forelimb muscles |
| Sheep | tongue, masseter, diaphragm |

***Differential diagnosis*** includes muscle cysticercosis caused by larval forms of *Taenia solium* in humans, sarcocystiosis, toxoplasmosis, echinococcosis localized in the muscles and other migratory larvae of parasitic nematodes (*Ascaris suum*, *Strongyloides ransomi*) or saprophytic and distomum musculorum suis (DMS), mesocercaria of *Alaria alata*, parasitic trematode in domestic and wild carnivores. *Trichinella* cysts are partially or fully calcified, will be decalcified.

**Treatment.**

The therapy of trichinellosis in animals and humans is based on the use of broad-spectrum anthelmintics associated with symptomatic therapy, especially in human medicine. Three important elements influence their use: the high effectiveness against adults of *Trichinella*, which cannot be detected by the intra-vitam diagnosis, high efficiency against larval migration phase, which is difficult to diagnose, and efficacy decreases when larvae are encysted in the muscle, in chronic the form. The

effectiveness depends on the chemical nature of the drug, dosage, repeatability and association with immunomodulatory medications or capsule lithic compounds. Three groups of active substances stand out: benzimidazole derivatives, imidazothiazole and avermectins.

Among the benzimidazole derivatives, albendazole, at a dose rate of 10-15 mg/kg bw, 3 doses, showed an efficiency between 94.2 to 98.6% in pigs[130]. Mebendazole, 6.25 mg/kg bw administered two hours pi removes between 95 to 100% of adult parasites; at a dose rate of 50 mg/kg bw for 5 consecutive days during the invasive phase, it reduced by 96% the number of larvae recovered at 45 days pi[126]. Flubendazole at a dose rate of 20 mg/kg bw/day, 10 doses at intervals of 48 hours, associated with hyaluronidase induced maximum efficiency[71]. At a dose of 8 mg/kg bw administered in the feed, for 8 consecutive days, it had an efficacy rate of 100% against the adult stage of *T. spiralis* in pigs. At a dose rate of 31 mg/kg bw administered for 14 days, the efficacy was 72.35%. Higher doses of 62 mg/kg bw induced a high efficiency of 87.77% against the larvae[122]. Oxfendazole and oxibendazole are also used, but they need high doses to show good effectiveness[90].

Of the imidazothiazole derivatives, levamisole was less effective than benzimidazoles and avermectins against *Trichinella* spp. The dose of 7.5 mg/kg bw had an efficiency of 4.83% and 3.57% against parasite adults and larvae respectively, during migration[193].

Ivermectin, at a dose rate of 0.2 mg/kg bw, showed an efficiency of 94.99% and 83.85% against the adults and larvae on migration in experimental trichinellosis in rats[193]. Doramectin at a dose of 0.3 mg / kg i.m. is 100% effective against the adult parasites in the gut, or 66.6% against the larvae in migration and causes a 30% reduction in the number of viable larvae[68].

**Control.** In many European countries, trichinellosis was declared a disease that requires monitoring and for European Union member states, it is mandatory under EU Zoonoses Directive, 2003/99/EC. Legislation in Europe and other countries around the world requires the accurate diagnosis of trichinellosis by direct methods, namely trichineloscopy and artificial gastric digestion.

In case of detection of infected carcasses, the legislation requires complete confiscation and inactivation. In intensive pig units, slaughterhouses, meat processing units, and rendering plants, a control of rodents will be conducted periodically, associated with collection and destruction of corpses. Stray dogs and cats, species that are connecting elements between wildlife and domestic animals, must be controlled.

Prevention of *Trichinella* infection in humans is based on three main approaches: (i) consumer education about the risk posed by consumption of raw or undercooked meat and meat products, regardless of its origin (domestic: pig, horse; or wild: wild boar, bear, walrus, crocodile), if it was not properly tested for the presence of *Trichinella* larvae, (ii) raising of the pigs (the most important source of contamination for humans) in the industrial system, with modern shelters, under strict veterinary control, and use of certified feed (iii) control of all susceptible animals (domestic and wild) by a standardized method of gastric digestion at slaughter or after hunting[72].

Chemoprevention and immunoprophylaxis, although they have demonstrated good results that support their applicability, are only experimental.

## 14.2. Capillariidae: capillariosis

The systematics of capillarid nematodes has been the subject of multiple classifications and reorganisations. They were originally classified as subfamily Capillarinae, part of the family Trichuridae. Roberts and Janovy[173] refer to capillarids as family Capillaridae. Anderson[6] considers it as a subfamily included in the family Trichuridae. Thus, two main directions are differentiated in the

systematics of capilarids: the subfamily Capillarinae, part of the family Trichuridae or the family Capillaridae, included in the superfamily Trichocephalloidea. The structure of this group (whether subfamily or family) has changed, in turn, extensively, the number of genera included varying around 24. There are about 300 species of capillarids, their classification being one of the most difficult in the Nematoda. Regardless of the accepted classification and the number of genera or species existing in capillarids, they are parasites in a wide range of hosts, from fishes to mammals and birds. The species are highly diverse morphologically, widely distributed; almost all are oviparous and have a mono or heteroxenous life cycle.

The members of this taxon are responsible for various diseases in animals and humans, caused by different localisations of parasites in the digestive tract and accessory glands, in the respiratory or excretory system. From a medical veterinary point of view, several entities are important, namely:

- Digestive capillariosis in birds with two different locations, crop and esophageal, and intestinal, respectively.
- Bladder and urinary capillariosis in carnivores.
- Tracheobronchial capillariosis in carnivores.

## 14.2.1. Capillariosis in birds

Capillarids or hairworms are nematode parasitic worms of Galliformes, Anseriformes, Passeriformes and many other species of domestic, wild and game birds belonging to a large number of taxa.

### *14.2.1.1. Crop and esophageal capillariosis*

The disease is caused by the members of the *Capillaria* genus that has many synonyms, as follows: *Trichosoma* Rudolphi, 1819; *Trichosomum* Creplin, 1839; *Calodium* Dujardin, 1845; *Liniscus* Dujardin, 1845; *Hepaticola* Hall, 1916; *Eucoleus* Dujardin, 1845 and *Thominx* Dujardin, 1845. The last two names are the most common in current etiology.

**Definition.** It is a nematodosis produced by species localized in the crop and esophagus with chronic evolution which manifests itself through dilated crops, fluid from the mouth and mouth lesions, emaciation and possible death.

**Etiology.** The disease is caused by two species, *Capillaria annulata* and *C. contorta*. Both species are reported in the mucosa and submucosa of the oropharynx, esophagus and crop of chickens, grouse, guinea fowl, partridges, pheasants, quail, turkeys and ducks.

The classic and recognized names can now be replaced by other synonyms, such as *Eucoleus annulatus* and *E. contortus* or *Thominx annulata* and *T. contorta*. We still use traditional names, with the *Capillaria* name of the genus, due to many taxonomic difficulties and multiple names assigned for the same species.

***Morphology.*** *C. annulata* (figure 31) has a cylindrical, threadlike, slender body. The male measures 10 to 26 mm in length by 52 to 74 μm wide and the female is 25 to 60 mm in length by 77 to 120 μm wide. At the anterior end, both sexes present a cuticular bulbous swelling and an unadorned mouth. The males possess avery long spicule, measuring 1.12 mm to 1.63 mm, which slides through a cuticular sheath, at the posterior end.

The vulva is placed opposite the terminal end of the esophagus. Eggs are oval-shaped, measure 55 to 65 by 26 to 28 μm and have characteristic opercula at both poles.

*C. contorta* has a slender, filiform, progressively thicker posteriorly and spirally rolled body. The males vary from 8 to 17 mm long by 60 to 70 wide and the females measure between 15 and 60 mm long by 140 to 180 wide.

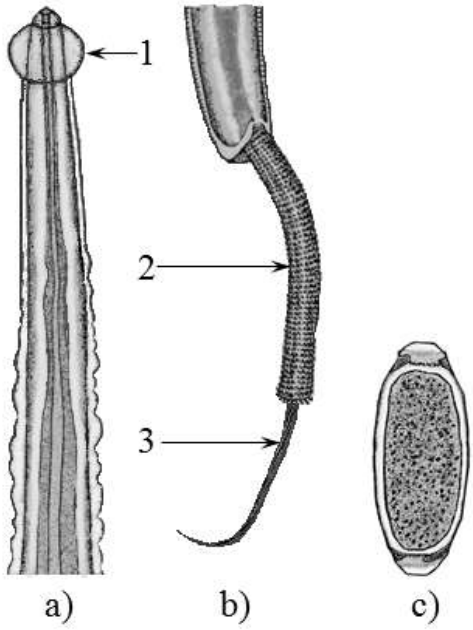


**Figure 31.** *Capillaria annulata* morphology: a) anterior end; b) posterior end; c) egg; 1. cuticular bulbous; 2. spicular sheath; 3. spicule

The dorsal cephalic cuticular swelling found in previous species is absent in *C. contorta*. At the posterior end, the males have two terminal laterodorsal prominences. The spicule is slender, transparent, measures about 800 μm in length, being shorter than the *C. annulata* spicule, not more than one-tenth of the body length. The spicule sheath is unarmed and nonstriated, but it has numerous fine, hairlike processes on its surface.

***Life cycle*.** Adult parasites are localized in the mucosa of the anterior segments of the digestive tract, mouth, pharynx, esophagus and crop. Oviparous females lay unembryonated eggs. These are eliminated through the feces in the external environment. Exogenous evolution is direct in *C. contorta* and indirect in *C. annulata*. The direct cycle consists in embryogenesis and molting of the first-larval stage inside the egg, resulting in an infective egg that contains the $L_2$ larva. The indirect evolution consists in the intervention of the intermediate hosts, earthworms (*Eisenia*, *Lumbricus*, *Allolobophora*), which ingest the eggs. The eggs develop in their body into infective eggs that contain $L_2$. The contamination of the birds is done by ingestion of eggs or earthworms containing infective eggs. After ingestion by the birds, the larvae penetrate the mucosa of a typical biotope and mature into adults following two molts. The prepatent period varies between 45 and 54 days in *C. contorta* and 16-25 days in *C. annulata*.

**Epidemiology**

***Geographical distribution*.** The disease is distributed worldwide and records different values or prevalence, depending on various factors. *C. annulata* was found in 2.0 and 4.3% of rural scavenging poultry in Tanzania during wet and dry season, respectively, while *C. contorta* recorded 9.0% and 1.0%. No correlation was found between season and prevalence[150]. In free-range chickens from the KwaZulu-Natal province of South Africa, no significant difference was observed in the sex distribution for *C. annulata* and *C. contorta*, but a significant difference was identified in the intensity of infection of both males and females. In the case of *C. obsignata* and *C. annulata*, the prevalence rate and number were higher in females than in males[139]. *C. contorta* was more prevalent (64.7%) than *C. annulata* (17.6%) in pheasants in Samsun, Turkey[76]. *Capillaria* spp. infections are also diagnosed in Romania in pheasant (43.75%)[67] and capercaille (60%) (personal unpublished data).

***Sources of contamination*** are represented by various species of birds, including some of the wildlife. On the other hand, earthworms directly intervene in the food web of the birds, contributing to the perennial character of outbreaks.

***Susceptibility*.** The chickens (*Gallus gallus domesticus*), especially young birds, have a higher degree of vulnerability. However, infection with *C. annulata* is more prevalent

in adults (10%) compared to growers (1%) in free-range chickens in Tanzania[120].

The technological purpose of the birds, laying hens or broilers, associated with the breeding system are important factors in their susceptibility to infection. With reard to egg-laying chickens, the free-range and yarding systems are the most suitable for contamination compared with battery and furnished cage systems. In meat-producing chickens, the indoor system offers a high level of protection to broilers, compared to free-range and organic farms.

***Route of contamination*** is oral by ingestion of embryonated eggs or infected earthworms.

***Resistance*** of the eggs lasts up to a year in common environmental conditions. The eggs survive at temperature as low as - 15oC during the winter. Direct sunlight, the dryness and freeze / thaw alternation, destroy the eggs in a range varying from several days to several weeks. Eggs survive for several months in feces and irrigated pastures[100].

**Pathogenesis.** Parasites exercise a remarkable inflammatory action in their characteristic biotope. It consists of a thickening of the wall of the crop, an enlargement of the glands and, in heavy infections; the mucosal surface can be sloughing. The action of inoculation, although of low intensity, can be expressed by a maceration of the crop lining, which becomes rough.

**Clinical signs.** The general condition of infected birds is severely affected, especially in young birds up to 4 months of age. Diminished appetite, repeated and painful swallowing, neck extension, lethargy, anemia, weakness and emaciation may develop. The crop is empty, full of gas or indigestion may set in as a result of an overloading of the crop. In this case, only the crop is impaired, without affecting the esophagus. Birds show torticollis, frequent movements of the head. Gradually anemia, weakness and low-lying occur. Evolution can be fatal, the mortality rate being high (often in pheasant and partridge).

**Pathology.** The crop wall is thickened and the mucosa exfoliated, covered by a flocculent exudate. The parasites cause catarrhal esophagitis and ingluviitis, which become pseudomembranous, hemorrhagic or necrotic in their severe forms. Parasites penetrate into the submucosa where they form sinuous galleries. The crop often contains a viscous and hemorrhagic liquid, with a fetid odor. In the chronic form, the esophageal and proventriculus mucosa are thickened, rough, folded lengthwise, with areas of necrosis where the parasites can be seen. *C. contorta* often evolves severely causing diphtheritic membranes in the oral cavity and esophagus of blue jays (*Cyanocitta cristata*)[79].

**Diagnosis.** The positivity of the coproscopic examination correlated with the symptoms is of certainty in live birds. Scraping the lining of the esophagus or stomach during necropsy is required in order to observe the adult parasites.

***Differential diagnosis*** includes pharyngeal trichomonosis, crop indigestion by other causes, hypovitaminosis B1.

**Treatment.** Benzimidazoles and imidazothiazole derivatives or avermectins are used.

- Levamisole at a dose rate of 2 mg/100 g bw administered subcutaneously or tetramisole, 3 g/10 liters drinking water, were effective against pheasant and quail capillariosis[144].
- Mebendazole at a dose rate of 120 mg/kg bw in the feed for 14 days was higly effective against *Capillaria* spp.[148].
- Ivermectin, 0.2 mg/kg bw, intramuscular, caused the disappearance of capillarid eggs and a complete clinical recovery in captive falcons[205].

**Control.** Measures are intended to ensure proper hygienic, nutritional and sheltering conditions, cleaning and storage of litter and manure for bio-thermal-sterilization in all

breeding systems. Control depends on the life cycle of the species and management of the units. In species with a direct life cycle, contaminated litter must be removed and destroyed. For control of a species with an indirect cycle, earthworms should be destroyed, and birds should be moved to clean ground. Chemoprophylaxis can be applied; Hygromycin-B, mixed in food, at an approximate rate of 48 g/100 kg of feed, controls the disease[83].

### *14.2.1.2. Intestinal capillariosis*

**Definition.** It is an enteritis and typhlitis affecting chickens, web-footed birds, pigeons, and other groups, determined by the location of the *Capillaria* species in the small intestine and cecum. It manifests itself by digestive disorders, malnutrition and anemia.

**Etiology.** Several species are involved in this form of capillariosis:

*Capillaria obsignata* (syn. *Baruscapillaria obsignata*, *C. columbae*) is common in the small intestine in chickens, turkeys, pigeons, guinea fowl, quail and geese.

*C. caudinflata* (syn. *Aonchotheca caudinflata*) affects chickens, turkeys, pheasants, partridges, guinea fowl, grouse, pigeons, quail, ducks and geese. It is located in the mucosa of the small intestine.

*C. bursata* is found in the mucosa of the small intestine in chicken, turkey, goose, and pheasant.

*C. anatis* is a parasite of the cecum, sometimes located in the small intestine.

***Morphology.***

The sizes of the 4 species localized in the intestine, namely the length of the males and their spicules and the length of females and size of their eggs and other morphological features are shown in table 20.

*C. obsignata* has a fine, threadlike and slender body. At the posterior end of males, the cloacal opening is placed almost terminally and two very small bursal lobes interconnected by a membrane are present. The vulva is situated near the esophagus-intestine junction and is prominent. *C. caudinflata* male has a small caudal bursa supported by two T-shaped processes at the posterior end. *C. bursata* is the largest intestinal species; the caudal bursa is round, supported by 4 projections.

*C. anatis* has a filiform body; the posterior end of the male has two lobes but no caudal alae.

***Life cycle.*** Life cycle is direct in *C. obsignata* infection, indirect in *C. caudinflata* and *C. bursata,* and unknown in *C. anatis*. The direct

**Table 20.** Morphometry of *Capillaria* spp. of birds

| Characteristic | C. obsignata | C. bursata | C. caudinflata | C. anatis |
|---|---|---|---|---|
| **Males** | | | | |
| ➢ Size | | | | |
| • Length (mm) | 7–13 | 9–18 | 11–20 | 8–15 |
| • Spicules (mm) | 1.1–1.5 | 0.7–1.2 | 1.1–1.6 | 0.7–1.9 |
| ➢ Lateral caudal alae | - | + | + | - |
| ➢ Spicule sheath | Spines | No spines | Minute spines | No spine |
| **Females** | | | | |
| ➢ Size | | | | |
| • Length (mm) | 10–18 | 12–25 | 16–35 | 11–28 |
| • Eggs (μm) | 44–46/22–29 | 47–58/20–24 | 51–62/22–24 | 46–67/22–29 |
| ➢ Vulvar appendage | None | Semicircular | Pronounced | None |

cycle consists in the environmental embryogenesis of eggs, in 3 days at 35°C, extended to 13 days at 20°C, with ingestion of embryonated eggs as the way of contamination, the hatching and maturation of larvae in the intestine following a local penetration of the lining. The indirect cycle involves earthworms (*Allolobophora caliginosa* or *Eisenia foetida*), intermediate hosts. The infective eggs develop in their body and contamination of the birds is achieved through consumption of the earthworms. The larvae liberated from their body burrow in the intestinal mucosa and mature following successive molts (the third and fourth molts). The prepatent period ranges from 20 to 24 days in both types of cycles.

**Epidemiology**

***Geographical distribution*** is worldwide, in all intestinal species. Both major intestinal capilarid species (*C. caudinflata* and *C. obsignata*) were identified in broiler geese in former Czechoslovakia, recording a prevalence of 0.2%, and 7.7%, respectively[30]. The intestinal species have recorded high prevalence rates in pheasants, in Turkey: *C. bursata* (35.3%), *C. caudinflata* (23.5%) and *C. obsignata* (5.9%)[76]. The prevalence of these species in the free-range/organic and backyard systems in Denmark was high: *C. obsignata* (53.6% and 50.0%), *C. anatis* (31.9% and 56.3%) and *C. caudinflata* (1.5%, and 6.3%). In the deep-litter and the broiler/parent systems only *C. obsignata* (51.6% and 1.6%) was found, while in battery cages capillarid infections were absent[149]. In local scavenging chickens, in northern Jordan, *C. obsignata* recorded a 0.5% prevalence[1].

The data presented above demonstrates a high prevalence of infections with monoxenous species of *Capillaria* in chickens in intensive breeding systems, as compared to scavenging chickens. This is due to the high density of chickens in their houses and heavily contaminated litter. Both reasons contribute to an accentuated contamination of the birds in industrial systems.

***Sources of contamination*** include infective eggs in monoxenous species and earthworms in species that have an indirect cycle.

***Susceptibility*.** Laying hens and young chickens over 30 - 40 days of age are the most susceptible. Susceptibility does not seem to be influenced by the breeding technology in monoxenous capillarids. *C. obsignata* was identified the following types of geese farming systems: in halls with deep litter without a run, and in the case of grass runs adjacent to a body of water, respectively[10].

***Route of contamination***. Contamination occurs orally by means of feed and water that contain infective eggs, or by ingestion of intermediate hosts.

***Resistance*.** The rate of development of *C. obsignata* eggs is influenced mainly by *temperature*. At 4°C, no development occurred, while at 20°C, embryogenesis is complete in 13 days. Up to 35°C, the eggs embryonate in 5 to 72 hours, but above 37°C, the eggs are aborted at the morula stage. At - 8°C, all unembryonated eggs are destroyed in 10 days, and their upper lethal temperature varies between 35° and 41°C. Embryonated eggs were killed at - 3.5°C after 7 days, survive a short period when exposed to 45°C and are inactivated at 50°C in 10 minutes. At room temperature, unembryonated eggs will normally develop in an atmosphere of 100% *relative humidity*. 75% R.H. is not suitable to complete embryogenesis and the viability of eggs declines to 50% R.H and they are inactivated in 10 days. Both unembryonated and embryonated eggs are rapidly destroyed in *ultra violet light* in the case of a water layer whose depth is 90 cm, after a 5 minute-exposure to irradiation. A 15-minutes exposure inactivates more than 95% of the eggs[215].

**Pathogenesis.** The parasites act locally exerting an *inflammatory action*, which consists in a thickening of the wall of the

small intestine and cecum, catarrh of the mucosa and local haemorrhages. *C. obsignata*, and, probably, all *Capillaria* species, are thigmokinetic nematodes that exert a *mechanical action* upon the intestinal mucosa. The touch stimuli, represented by the bowel peristalsis, cause a change in the velocity of linear or angular movement of *Capillaria*, resulting in a considerable villar detachment. The *toxic action* consists in wing and leg pseudoparalysis and astasia.

**Clinical signs.** Birds infected with intestinal capillarids tend to huddle, may be emaciated, develop diarrhea with watery and brownish feces that contain mucus and mucous portions, loss of appetite or capricious appetite, even anorexia, polydipsia, low feed efficiency, decreased egg production and sometimes death.

The disease signs of the disease in pigeons are a low flight performance and a disrupted mating and laying rate, weakness and anemia. The strong infestation is fatal after 6 to 10 days.

**Pathology.** The lesions consist in catarrhal and hemorrhagic (ecchymosis, linear hemorrhages) enteritis and typhlitis, exudate in the upper intestine, a thickening and swelling of the the intestinal wall, necrotic foci scattered on the intestinal mucosa, anemic mucosae and emaciated dead bodies.

**Diagnosis** is based on microscopic examination of feces in order to identify eggs of Capillaria spp. The necropsy allows observation of adult worms in the lumen of the small intestine or cecum and the lesions caused by them. The clinical examination of birds is valueless.

***Differential diagnosis*** includes histomonosis, trichomonosis, eimeriosis, spirochaetosis and other intestinal helminthosis or other enteritis.

**Treatment.** Fenbendazole at a dose rate of 30 or 60 ppm resulted in an efficacy rate of almost 100% against natural *C. obsignata*[94]. The therapies described for thre crop-esophageal form may be used in intestinal capillariosis.

**Control.** Preventive measures are the same as in esophageal capillariosis.

## 14.2.2. Capillariosis in carnivores

Capillariosis in carnivores is rarely reported and is more prevalent in wild animals. The disease has a sporadical evolution expressed by two entities: bladder and urinary syndrome or tracheobronchial capillariosis.

### *14.2.2.1. Bladder and urinary capillariosis*

**Definition.** It is a disease caused by the development of a nematode in the urinary system of domestic and wild carnivores, and is expressed by difficult, painful and frequent urination. Although the disease only occurs sporadically in domestic animals, infection is cosmopolitan in distribution, the most susceptible domestic animal being the hunting dog.

**Etiology.** The disease is produced by:

- *Capillaria plica* (syn. *Pearsonema plica*), which is located in the urinary bladder of canids, felids and mustelids.
- *Capillaria* (syn. *Pearsonema*) *feliscati* is a parasite of the urinary bladder of the cat.

***Morphology*.** (figure 32) The adults have a long, slender, thin, whitish and transversely striated body. The male measures 1.3 to 3 cm long, and the female is 3 to 6 cm in length. At the posterior end, the male has a long spicule and the spicular sheath is smooth, lacking spines. The egg is oval-shaped, has bipolar plugs and measures 60 / 30 μm.

***Life cycle*.** *C. plica* is a bio-helminth that has a heteroxenous, indirect life cycle. Adults live embedded within the mucosa of the urinary bladder in canids (dogs, foxes, wolves, diverse mustelids, raccoon dogs and raccoon) and felids (domestic and wild cats). The females lay eggs that pass through urine in the environment. The eggs are ingested by earthworms, intermediate hosts (*Lumbricus*

*terrestris* and *L. rubellus*), hatch in their intestine and the larvae burrow through the wall of the intestine into the connective tissue. The definitive hosts are contaminated by ingestion of earthworms. The larvae liberated from earthworms burrow in the mucosa of the intestine of carnivores and molt twice. The third larval stage penetrates the capillaries of the intestinal wall and migrates through the portal circulation, to the liver, heart, and lung, and is disseminated via the general circulation to the kidney. They penetrate the renal glomeruli, tubules, pelvis, and ureter and mature in the bladder. The prepatent period varies from 58 to 63 days.

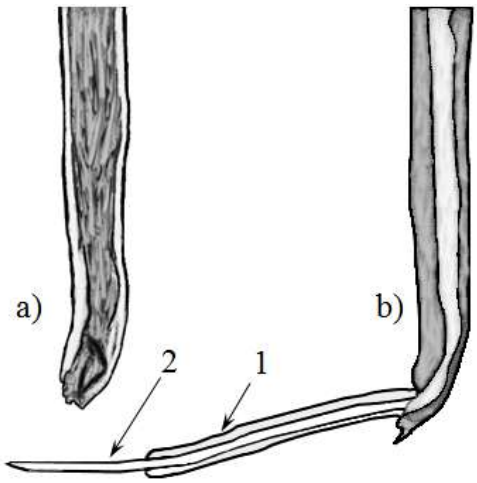


**Figure 32.** *Capillaria plica* morphology:
a) posterior end, female; b) posterior end, male; 1, spicular sheath; 2, spicule;

**Epidemiology**

***Geographical distribution.*** The disease has a worldwide distribution, and wild animals are considered the primary hosts. High rates of prevalence are reported globally: 93.3% and 11.3% in foxes and raccoon dogs, respectively, in Lithuania[28], 23.5% in wild foxes in the Netherlands[19], 64% in raccoon (*Procyon lotor*) in Western Kentucky and 43% in North-Central Arkansas[37,169], 53% in red foxes in Norway[48], 78% in Southern Germany[20], 80.5% in Denmark in the same species[176], 52% in red foxes in Hungary[199] and 13,3% in wolf, 28% in wildcats in Romania (personal unpublished data). The disease is also diagnosed in domestic and wild cats in Germany, Japan[64,183,184] and in the stone martens (*Martes foina*) of Tyrol[214]. These data demonstrates that the disease is most prevalent in foxes, worldwide

***Sources of contamination*** are infected carnivores that pollute the environment and earthworms (IH) that induce disease in carnivores (DH).

***Susceptibility.*** Receptivity is high in wild canids (fox, raccoon), compared to felids or domestic carnivores. This is explainable by the accidental or non-accidental presence of earthworms in the diet of these species. Breed, sex or age, do not exert any influence in terms of susceptibility, even if older carnivores are considered more infected carriers[185].

***Route of contamination*** is oral, through ingestion of earthworms that contain infective eggs.

***Resistance*** of the eggs in the environment is conditioned by the survival of the earthworms (IH).

**Pathogenesis.** The evolution of urinary capillariosis is accompanied by low pathogenic effects. This is due to the superficial location of the parasites, at the mucosal surface, where they move freely within the urine in the bladder[218]. Other sources say that adults live embedded in the mucosal epithelium where they exercise an inflammatory action and that they can spread to the ureters and renal pelvis[32].

In heavy infections, parasites can exert an obstructive mechanical action that consists in the blockage of the ureteral lumen and clinically in the post-renal syndrome. The inflammatory action consists in the dilation of blood vessels in the bladder wall, bladder mucosa discoloration and cystitis.

**Clinical signs.** The disease progresses insidiously, subclinically, but it is aggravated

by bacterial superinfection. Urinary disturbances, dysuria, haematuria, pain in the kidney area can occur.

**Pathology.** Adults of *Capillaria plica* are identified in the bladder, and catarrhal cystitis with a slight effusion on the mucosal surface is visible.

**Diagnosis.** Diagnosis is done by the examination of urine sediment where the eggs are observed. They must be differentiated, in dogs, from the eggs of *Dioctophyme renale*, which are embryonated when laid, and whose shell has a sculptured appearance. Symptoms are indicative and necropsy reveals lesions and adults parasites.

***Differential diagnosis*** includes dioctophymosis, kidney stone and other diseases that affect the kidney in carnivores.

**Treatment.** The drugs used, with good results, are:

- Ivermectin 0.2 mg/kg, subcutaneous injection, one dose, repeat if needed, determines complete parasitologic and clinical cure.
- Fenbendazole 25 mg/kg bw or 50 mg/kg be, per os, for 12 to 14 days is effective against *C. plica* causing the disappearance of symptoms and removal of eggs in urine[213].

**Control.** Keeping the animals away from soil surfaces and earthworms, prohibiting contact with areas frequented by wild animals, sanitation, exclusion of intermediate hosts and keeping the animals (especially foxes) on wire mesh floors, are applicable measures which have shown good results[32].

### *14.2.2.2. Tracheobronchial capillariosis*

**Definition.** It is a sporadic nematodosis affecting domestic and wild carnivores, and it manifests itself through a nasal and pharyngeal syndrome.

**Etiology.** The disease is caused by *Capillaria aerophila*, also called *Trichosoma aerophilus*, *Thominx aerophila*, or *Eucoleus aerophilus*, which is a name that's been recently accepted and is being currently used.

***Morphology*.** The adults have a long, thin, whitish, filamentous and slightly spiral body. The male measures between 1.5 and 2.5 cm in length and females are 2 to 4 cm long. At the posterior end, the male has a rudimentary caudal bursa consisting of two lateral caudal lobes. The spicule slides through a spiny sheath. The vulva, in the female, is located near the posterior end of the esophagus. The eggs are barrel-shaped, 60-70 μm long x 30-40 μm wide and have asymmetric plugs at both poles. The shell is granular and striated, having net-like ornamentations that consist in a network of anastomosing ridges and bridges, and slightly green.

***Life cycle*.** The life cycle is direct. Adults inhabit the epithelium of the bronchioles, bronchi, and trachea, sometimes in the nasal cavity and frontal sinus. At these locations, their body is threaded through the epithelial surface. Eggs are eliminated in the environment through feces or sputum. In the proper biotope with adequate moisture and temperature values, the eggs embryonate in 20 to 40 days, resulting in the second larval stage, $L_2$, which remains in the egg.

Contamination is done by ingestion of infective eggs through contaminated food and water. Larvae migrate hematogenously from the intestine and reach the lung parenchyma where they penetrate the wall of the alveoli and move up to the air passages. The prepatent period is between 3 to 5 weeks.

**Epidemiology**

***Geographical distribution*.** Generally, the disease is distributed throughout the world, recording different values of prevalence. The red fox (*Vulpes vulpes*) seems to be the most affected species. *Eucoleus aerophilus* was found in foxes, in the Netherlands, (46.8%)[19], United Kingdom (0.2%)[168], Hungary (66%)[199], Norway (88%)[48], Denmark (74.1%)[176] and Romania (46%)[70].

Other domestic and wild carnivores are also sensitive to *E. aerophilus* infection. The prevalence in stray cats was 1.4%, in northern

Italy[196], 5.8% in dogs and 3.1% in household cats in Romania[134,135], 4% in coyotes from the southwestern United States[137] and 43% in raccoons (*Procyon lotor*) from north-central Arkansas[169]. The infection with *E. aerophilus* is found in hedgehog, the prevalence varying between 15.1% and 40.7% in wild hedgehogs and hedgehogs in human care in Germany[12].

***Sources of contamination*** are represented, on the one hand, by the diseased animals as environmental pollution sources, with unembryonated eggs, and, on the other hand, by the feed and water that contain embryonated eggs, as sources of animal infection.

***Susceptibility*.** The red fox (*Vulpes vulpes*) is the most responsive species, and young animals are the most vulnerable within the species. Dozens of other species of canids, felids and mustelids, are susceptible. Wild species are more exposed to risk factors (environmental pollution, consumption of food from the ground, water contaminated with eggs) than domestic species.

***Route of contamination*** is oral by consumption of food and water with embryonated eggs.

***Resistance*** and embryogenesis of eggs are both influenced mainly by temperature and humidity. The maturation of the eggs does not occur after more than 15 days at a temperature of 20 ± 1 °C and 80 – 85 % relative humidity[212].

**Pathogenesis.** Adult parasites exert in their habitat an inflammatory action that consists in rhinotracheitis and bronchitis. Inoculation action is caused by secondary bacterial infections. Severe broncho-pneumonia is developed through a combination of the two actions.

**Clinical signs.** The disease evolves after an incubation of about 10 days, with a chronic respiratory syndrome, aggravated in young carnivores, until the age of 18-24 months. Nasal discharge, snoring, coughing, wheezing, a whistling noise, severe dyspnea with open-mouthed breathing, loss of appetite and sometimes feverish states, adynamia and loss weight may be observed. The animal becomes emaciated, anemic and has a rough, dirty coat.

**Pathology.** The lesions caused by adult parasites are catarrhal tracheobronchitis, pulmonary edema, hemorrhages on tracheal mucosa and lung parenchyma, broncho-pneumonia. All stages, larvae, adults, and eggs, may be observed in histologic sections of affected tissues.

**Diagnosis.** Diagnosis is done intra-vitam by coproscopic examination, using flotation methods, or rhinoscopy, identifying characteristic eggs. Necropsy allows the observation of lesions (necrotic and catarrhal rhinotracheitis and bronchitis). Parasites may be observed by scraping the mucosa, suspending the scraped material in a saline solution, in the Petri dish, and doing a microscopic examination against a black background.

***Differential diagnosis*** includes crenosomosis and filaroidosis.

**Treatment.** Several modern therapies demonstrated a good rate of efficacy against *E. aerophilus* infection.

- Imidacloprid 10% and moxidectin 1% spot-on combination (Advocate®, Bayer Animal Health) administered once showed a 99.79% reduction of fecal egg counts[211].
- Fenbendazole at a dose rate of 50 mg/kg bw, per os, every 24 hours, for 10 days, resolved clinical signs of *E. aerophilus* infection[29].

**Control.** Sanitation measures represent the best choice in the prevention of this geo-helminthosis. Catteries, kennels, shelters, pens, runs, and any other shelter for carnivores must be kept clean. Shaded soil and poorly drained areas where eggs develop very well must be avoided by the animals. Cages with wire mesh floor should be used in farms for fur foxes r. Periodic deworming of animals ensures their protection against lung nematodes.

## 14.3. Trichuridae: trichuriosis in animals

The Trichuridae family, part of Trichinelloidea superfamily, includes the subfamily Trichurinae, which contains one genus, *Trichuris*. The popular name "whipworm" is derived from the shape of the parasites that have an unequally calibrated body, being thinner at the anterior half and thicker at the posterior, simulating a whip handle. The current name of the genus is *Trichuris*, and it is the first name assigned to the genus by Roederer, in 1761. Therefore, this is the validated and accepted name. An inadvertence is found by comparing the name assigned and recognized with the morphology of the parasite.

"*Tricho*" is a prefix designating hair, derived from the Greek thrix, trichos, meaning hair. "*Oura*" is a suffix that originated from ancient Greek, signifying "tail." "*Cephalus*" is a suffix meaning head, and its etymology derives from Greek, kephale, head. In other words, "*Trichuris*" means thin as the hair shaft, at the tail (posterior end, "hair tail"). Actually, the inequality of the body of the parasites included in this genus consists in a thinned anterior end and a much thickened posterior end. Lack of good microscopes has allowed the assignation of a misnomer that reflects the morphology of parasites incorrectly. From this point of view, Trichocephalus ("hair head") is the correct name.

**Definition.** The disease is a chronic geo-helminthosis that affects different species of mammals, commonly with a subclinical evolution, caused by nematodes of the genus *Trichocephalus*. This genus comprises several species of nematodes, commonly known as whipworms, which species parasitize many domestic animals including ruminants, carnivores and swine.

**Etiology.** The genus *Trichocephalus* includes more than 60 to 70 species, which infect the large intestine of their host. The most common species in veterinary parasitology are:

- *Trichocephalus discolor* parasitize in cattle;
- *T. ovis* infect the caecum of wild and small domestic ruminants (sheep, cattle, camels, cervids, giraffes, antelope and porcupines);
- *T. suis* is a parasite of swine, but infections can be established in humans[13,101];
- *T. vulpis* located within the cecum and the colon in domestic and wild carnivores;
- *T. campanula* parasitize the cecum and colon in felids;
- *T. myocastoris* in the large intestine of coypu;
- *T. leporis* in domestic and wild rabbits;

***Morphology*.** The anterior part of the body is long (about 2/3 of the body), slender and thin, while the posterior end is blunt and rounded in both sexes. The posterior thickened part of the male's body is curled dorsally. The spicule slides through a protrusible sheath that has a smooth or spiny external surface. The vulva is located in the posterior part of the body, near the junction with the esophageal portion. The eggs are elongated, lemon-shaped, with a thick shell and bi-polar opercula (figure 33). The sizes of several species are showed in table 21.

**Figure 33.** *Trichocephalus* spp.: egg

**Table 21.** Morphometry of several *Trichocephalus* spp.

| species / particulars | | *T. discolor* (Knight, 1971) | *T. ovis* (Kuchai et al., 2013) | *T. suis* | *T. vulpis* | *T. leporis* | *T. myocastoris* (Baruš et al., 1975) |
|---|---|---|---|---|---|---|---|
| Total length | male | 55-74 | 46-80 | 50 | | 19-21 | 27.8-39.7 |
| | female | 51-65 | 35-78 | 60-80 | | 17.4-20.9 | 30.2-45.2 |
| Max. Width (post) (♂+♀) | | 0.50-1.01 | 0.55 | 0.65 | | | |
| Min. Width (ant) (♂+♀) | | 0.12-0.19 | | 0.5 | | | 0.19-0.31 |
| Spicule | | 1.7-2.3 | 4-6.9 | | | 1.6-3.2 | 2.9-4.5 |
| Egg Size (µm) | | 55-67x26-36 | 70-80x30-45 | 60x25 | 90x40 | 60-65x29 | 50-65x24-30 |

***Life cycle***. The cycle is monoxenous, direct. Adult parasites are localized in the large intestine, mainly in the cecum. They penetrate, with their cephalic end, deep into the lining and submucosa of the cecum and colon. They induce, in this habitat, the formation of a syncytium of epithelial origin and feed on blood obtained from the syncitium. The females lay unembryonated eggs after copulation. The eggs are eliminated in the environment, through the feces. Under favorable temperature conditions varying between 28 and 32$^{o}$C, at a relative humidity of 100%, in aerated and shady soils, the process of embryogenesis takes place, covering a period of around 10 days, and the larvae remain inside the egg. Below this temperature, up to 10°C, ontogenesis expands, reaching 3 to 4 months or even a year. No larval molting process is recorded inside the eggs.

Contamination occurs by ingestion of infective eggs, with feed or water. The eggs hatch in the small intestine and the larvae penetrate the mucosa where they develop for about 10 days. The molting of larvae during this period is controversial. Miller[131] argues "*no moulting of the larvae was observed from the first to the 10th day of development*," while more recent studies show that four successive molts are performed in the course of the adults' development[6]. Regardless of the existence of the molting processes, the larvae emerge, after 10 days, from the lining of the small intestine and migrate to the large intestine, where the adults will develop. The initial development of larvae in the small intestine is contradicted by recent studies, which argue that hatched larvae migrate quickly to the large intestine where they invade the mucosal epithelium and, through four successive molts, develop into adults[6].

The prepatent period varies greatly, between 41 and 135 days, depending on the species. Life span of adults does not exceed 6 months.

**Epidemiology**

***Geographical distribution.*** The infections with *Trichocephalus* spp. in animals have a cosmopolitan distribution, with different rates of prevalence. *T. discolor* is less prevalent and abundant among helminths of the gastrointestinal tract of young cattle in northwest Germany[95]. Infection recorded a high prevalence (73.3%) in 12-month-old bulls from Schleswig-Holstein Land[164]. *T. ovis* was diagnosed in 1.8% of sheep and 3.6% of goats from Papua New Guinea[99] and 5.8% of sheep in the northern region of Nile Delta, Egypt[92]. The prevalence was 21.6% in small ruminants in southern Ethiopia[2] and 19.0% in goats from the Kashmir valley, India[206]. The infection is evidenced in many other African and Asian countries, demonstrating the lack of a disease control program. *T. suis* occurs in 7% of free range pigs from Busia District, Kenya[85] and 10.13% in pigs in Chongqing, China[109]. In Danish industrialized sow farms,

*T. suis* was rarely diagnosed, only in a very few instances[78]. The infection registered a relative high prevalence (24.8%) in pigs slaughtered in Osaka, Japan [125]. The infection was found only in household and semi-intensive farms in Romania, in adult pigs, breeding sows and boars, during the autumn and winter. The prevalence varied between 20 and 60%[45]. Regarding infections with *T. vulpis*, the literature comprises numerous papers that reveal the global distribution of the disease and its level of prevalence. The prevalence was 8.0% in stray dogs captured in Osaka Prefecture, Japan[93], and 26.19% in dogs from rural areas in the Lobos District, Buenos Aires province, Argentina[51] and 3.3% in owned dogs from central Italy[170].

***Sources of contamination*.** The reservoir of infection is composed of diseased or carrier animals that eliminate unembryonated eggs through feces. The amount of pollution can be high in some species. The prevalence may reach 25% of the flock in pig farms, and the fecal egg count exceeds 200 to 300 EPG. Such situations are also possible in kennels, where the daily average of egg output reaches a mean of 2035 EPG. The ratio of males to females in *T. vulpis* infection is 1:2 and the fecal egg output is greater in lighter than in more intense infections[133].

***Susceptibility*.** Canids and pigs are more vulnerable than ruminants. Young animals, before and after weaning, are, generally, more sensitive within the species, but there is no evidence of age resistance to *T. vulpis* in adult dogs [132]. Undernourished populations, maintained in unsanitary housing, in an immunosuppressed and parasitical state, have an increased sensitivity. Recently, it has been demonstrated that deep-litter may not be a risk factor for *T. suis* transmission within the pens[127].

***Route of contamination*** is oral, through food and water polluted with infective eggs.

***Resistance*.** Temperature and humidity are factors that greatly influence the resistance of eggs in the environment. Soil type, particularly its salinity, and direct sunlight also influence in some degree the eggs' survival. High temperatures accelerate the rate of the embryogenesis of eggs while low temperatures delay and inhibit their development. Embryogenesis of *T. suis* eggs runs optimally in 11 days at temperatures between 30 and 34°C. The development of the eggs requires about two months between 22 and 24°C, and at temperatures ranging between 6 and 24°C, only 10% of eggs embryonate, in about 7 months[3]. Eggs of *T. suis*, in shaded areas with high humidity, at thermal changes between 6 and 20°C, remain viable 5 to 6 years[80]. They survive freezing at -20°C for several months. Eggs of *T. vulpis* and *T. suis* are not destroyed by the mesothermic aerobic sludge digestion, but about 11% of the eggs are destroyed by the anaerobic digestion[16]. Regarding the effect of ionizing radiation, a dose of 480 kRad destroyed about 97% of the undeveloped eggs of *T. suis*[57].

**Pathogenesis.** Parasites exert a mechanical and inflammatory action, due to continuous pricking of the mucosa. As a result, small necrotic areas of the cecum and anterior third of the large intestine will develop. The toxic action, caused by the by-products of the parasite, consists in interference with haemoglobin production, or erythrocyte destruction and, subsequently, anemia. Secondary bacterial infections (inoculation action) will cause the transformation of necroses into abscesses and the development of ulcers. Spoliation due to hematophagous nutrition action is questionable. Lee and Wright[111] have demonstrated that *T. muris* penetrate the mucosa of the large intestine with the anterior end and induce the formation of a syncytium of epithelial cells. This syncytium is used as a food source. It is likely that this observation is applicable to all species of the genus so it can be said that nutrition in the *Trichocephalus* genus is

histiophagous. In this context, anemia caused by *Trichocephalus* spp. is due to the toxic action and not to thed spoliation effect.

**Clinical signs.** The clinical picture, insidious and uncharacteristic, is expressed in young animals, in massive infestations, by digestive disorders. There are symptoms common to all affected species, while some particularities are species-dependent. General symptoms are loss of weight, growth retardation, watery hemorrhagic diarrhea, but more frequently constipation is present, anemia, emaciation, nausea, vomiting, and anorexia. Particularly, *T. suis* induces dehydration, incoordination and convulsions (hysterical and epileptiform). *T. ovis* is considered less pathogenic in cattle, and it is rarely considered as a severe pathogen of sheep; in heavy infections of lambs it causes diarrhea and, occasionally, flecks of blood may appear in the feces. In calves infected with *T. discolor* recumbency and oral ulceration are described[63]. *T. vulpis* is responsible for unthriftiness, abdominal pain and dysentery.

**Pathology.** The general lesional picture consists in catarrhal to hemorrhagic typhlitis and colitis, or hyperplastic in the case of a chronic evolution. In heavy infections with *T. discolor*, in calves, subcutaneous edema, diffuse edema of the colon with hundreds of adult Trichuris discolor in the cecum and colon are described. *T. suis* causes catarrhal to mucohemorrhagic enteritis (dysentery), anemia, hemorrhagic necrosis and edema of the cecal mucosa, ulceration of the intestinal mucosal lining and the development of fibrinonecrotic membranes. In *T. vulpis* infection, typical hyperplastic typhlitis is produced. Histology consists in enterocyte destruction, capillary erosion and multifocal necrotizing colitis.

**Diagnosis**, clinically is impossible. Coproscopic methods are used to identify the presence of characteristic eggs. Typhlitis and colitis can be observed at necropsy, accompanied by numerous parasites fixed in the mucosa or free in the intestinal lumen.

***Differential diagnosis*** in pigs includes salmonellosis, hemorrhagic bowel syndrome, swine dysentery (*Brachyspira hyodysenteriae*), porcine proliferative enteropathy (*Lawsonia intracellularis*), intestinal parasites including *Eimeria* spp., trichomonosis, *A. suum*, *O. dentatum*, and other causes of colitis (eg, *Brachyspira pilisicoli*). In the other species of *Trichocephalus* will be made by other intestinal helminthosis, hypothrepsic syndrome and anemia due to other causes.

**Treatment.** Therapy is based on the use of an active substance included in benzimidazole derivatives or avermectins groups or associations between different anthelmintics substances and insecticides. Effective therapies against infections with Trichocephalus spp are shown in table 22.

**Control.** Control of *Trichocephalus* spp. infection is achieved through a general program that differs from one species to another. Several directions may be defined, available for all species, namely: increasing of farm animals species in systems that protect them against contamination, implementation of common measures of hygiene and regular chemoprophylaxis. Because of the high resistance of eggs on pasture, reaching up to 6 years, the animals may have to be moved to biologically unpolluted pastures in order to avoid their contamination. The floor into the stables, winter stables, kennels, shelters, pens, runs must be kept dry because the eggs are susceptible to desiccation. Allowing the direct action of sunlight on surfaces and a good drainage of floor are the best options. Wire mesh floors are useful to prevent contamination of the piglets, calves and lambs. A quarterly deworming program, during a year, will ensure a complete protection of animals.

**Table 22.** Active substances used in trichurosis therapy in animals

| species<br>substances | dose rate<br>mg/kg bw | *T. discolor* | *T. ovis* | *T. suis* | *T. vulpis* |
|---|---|---|---|---|---|
| trichlorfon | 48.5 po | 100[115] | | | |
| dichlorvos | 43 | | | 99.9[121] | |
| febantel | 5 (cattle) po;<br>6 and 12 (lamb)<br>15 (dog) | 69[41] | 0[119] | | 100[39] |
| mebendazole | 22x3 days | | | | 100[75] |
| oxfendazole | 2.25, 4.5, 6.75; 30 (pig) | | ≥ 99.4[42] | 100[5] | |
| oxibendazole | 15 | | | | 95.7[146] |
| albendazole | 7.5 | | poor efficacy[189] | | |
| flubendazole | 1.5x5 days (pig)<br>220x3 days (dog) | | | 100[23] | 100[162] |
| fenbendazole | 5 (ruminants)<br>3x3 days (pig)<br>50x3 (dog) | | > 92[210] | 99.8[121] | 98-100[172] |
| ivermectin | 1.6/day, 100 days; 0.3 (pig) | | ≥ 99[165] | 100[136] | |
| abamectin | 0.2, sc | > 99[89] | | | |
| moxidectin | 0.2, sc (ruminants)<br>0.75, sc (pig)<br>0.17 (dog) | 100[217] | 83[38] | 93.5[200] | 67.5[21] |
| doramectin | 0.2, sc; 0.3 (pig) | 92.3[56] | 100[52] | > 99[177] | |
| eprinomectin | 1.0 ERI | ≥94[82] | | | |
| derquantel/<br>abamectin | 2<br>0.2 | | ≥ 97[113] | | |
| moxidectin /<br>triclabendazole | 0.2<br>10 | | ≥95[123] | | |
| milbemycin oxime | 0.5<br>1.0 | | | | 96 [81]<br>98.6 |
| milbemycin oxime<br>/ spinosad | 0.5 - 1<br>30 - 60 | | | | 100[182] |
| milbemycin oxime/<br>lufenuron | 0.5<br>10 | | | | 99.6[21] |
| pyrantel /<br>oxantel /<br>praziquantel | 5 / 20 / 5 | | | | 99.3[181]<br>98.4[74] |
| emodepside /<br>praziquantel | 1 / 5 | | | | >99[180] |

po - per os; sc - injected subcutaneously; ERI - extended-release injection

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# 15. Dioctophymatoidea

Superfamily Dioctophymatoidea is part of the order Dioctophymatida, class Enoplea.

It is characterized by a modified tail of male, that is transformed into a ventral sucker, cylindrical well-developed oesophagus without stichosome and a single female genital tract (monodelphic)[1].

Based on molecular analysis it is demonstrated that superfamily Dioctophymatoidea is monophyletic and includes two families: Soboliphymatidae and Dioctophymatidae. Family Soboliphymatidae contains one genus, *Soboliphyme* that is composed of 9 species. The Dioctophymatidae is divided into two subfamilies, Dioctophymatinae and Eustrongylinae. The Dioctophymatinae includes the monotypic genus *Dioctophyme* which contains the species *D. renale*. The second subfamily, Eustrongylinae is divided into two genera, *Eustrongylides* that is composed of 11 species and *Hystrichis* which consists of at least 6 species[2,18].

## 15.1. Dioctophymatidae: dioctophymatidosis of carnivores

Family Dioctophymatidae is, morphologically characterized by the absence of muscular cephalic sucker, vulvar opening placed in anterior third part of the body, near oesophagus. It contains one species, *D. renale*, a very large nematode, parasite of kidney and peritoneal cavity in carnivores, especially families Mustelidae, Canidae, Procyonidae, and Felidae. It can affect also organisms belonging to other groups of animals. The disease caused by *D. renale* is called dioctophymosis.

**Definition.** It is a parasitic zoonosis that evolves sporadically caused by the development of the parasites in the renal pelvis, ureters, possibly in the liver, and in the peritoneal and pleural cavity.

**Etiology.** The pathogenic agent is *D. renale*, genus *Dioctophyme*, family Dioctophymatidae.

***Morphology.*** *D. renale* is one of the largest nematode important for veterinary parasitology of domestic animals. It is called also the giant kidney worm due to the length of females which reach 100-103 cm and 6 to 12 mm wide, while the male is much lower, just around 35 cm long and 3 to 5 mm wide. The sizes are variable, depending by the hosts being smaller in mustelids, only 28 to 60 cm length for females and 11 to 30 cm for males.

They have a cylindrical body, equal calibrated, bright red and spiralled with thin and ridged cuticle. At the anterior end, the mouth is hexagonal and its opening is lacked by lips but is surrounded by 12 papillae arranged in two circles, an inner and an outer circle. At the posterior end, the male has a muscular, bell-shaped copulatory bursa without rays, and a single spicule. The tail of the female is tapered and blunt at terminal end, and the vulvar opening is situated near the terminal end of oesophagus, posteriorly.

The egg is oval-shaped, elliptical, yellowish, unembryonated when is laid but containing two blastomeres, and has a thick, pitted and brownish shell containing mucoid cap knobs to each pole. The surface of the shell is covered by funnel-shaped pits, except at the ends. It measures about 74 μm long by 47 μm wide.

***Life cycle.*** *D. renale* is a bio-helminth with a di-heteroxenous life cycle. The adults are located into the renal pelvis (right kidney), but may extend to the ureters and urethra, and feed on blood and dead cells. The secondary and more rarely locations are represented by the kidney parenchyma, subcutaneous and/or abdominal cavity. In these habitats, the male copulate the female which lays eggs. They are eliminated in the environment through urine. The eggs embryonate in soft, warm, well-oxygenated water and are ingested by intermediate hosts, aquatic oligochaetes. First-

stage larva ($L_1$) hatches from the egg in the foregut of annelids, penetrates into the body tissues and molts into the second-larval stage. These oligochaetes are ingested by fish that are considered secondary intermediate hosts[5,25]. Other authors consider the fish as paratenic host[21]. Paratenic hosts as frogs and salamander may be also involved[29,12]. The studies of Woodhead[39] have demonstrated unequivocally that fish are intermediate hosts. In their mesenteries, the second-larval stage encysts and molts into the third-larval stage, meaning an evolution process that happens only in intermediate hosts. The $L_3$ larva molts, within a cocoon into the fourth-larval stage which is infective to definitive hosts.

It is certain that the definitive hosts become infected through consumption of fish that contains $L_4$. The larvae pass through the intestine and reach the kidney. In renal pelvis, the larvae moult and become adults. The cycle lasts about one year, the prepatent period being 4 months.

**Epidemiology**

***Geographical distribution*.** The infection is worldwide prevalent, but the most numerous epidemiological data regarding the spread of disease in carnivores originating in Brazil. It is very likely that richness in aquatic biotopes of Amazon basin favors the particular dissemination of infection in this country. The prevalence recorded was 3.57% in dogs from Municipality of Cachoeiro do Itapemirim in the State of Espírito Santo[30] and was identified also in the states of Parana[28], São Paulo[10] and Rio de Janeiro[37]. In the same country, the disease is diagnosed in definitive hosts as cats[36], capuchin monkey[16], crab-eating fox[32], ring-tailed coatis[27], maned wolf[7] and toads (*Chaunus ictericus*), as paratenic hosts[29]. Infection in dog is also reported in Turkey[11]. Family Mustelidae is another important group of definitive hosts. The infection is reported in mink from Manitoba (1.21%)[6], Minnesota (27%)[26], New York (3.8%)[22] and in marten from Ontario (2.0%)[33].

***Sources of contamination*.** The primary sources are infected carnivores, which passed the eggs through urine, polluting the aquatic environment. Secondary sources are intermediate and paratenic hosts (aquatic annelids, fish, and amphibians) that contaminate the carnivores.

***Susceptibility*.** All the animals that consume infected sources are susceptible to infection, regardless of gender or their age. Definitive host species in which the infection is reported, are shown in table 23.

***Route of contamination*** is oral by ingestion of infected intermediate or paratenic hosts.

***Resistance*.** Data on egg survival in the environment are not known because they are consumed by intermediate hosts.

**Pathogenesis.** Adult parasites located in specific habitats exert pathogenic complex action, mechanic, inflammation, spoliation and inoculation, due to their size, erratically migrations erratic and nutrition. Mechanic action is due to the length of parasites that reach 100 cm. It consists in compression atrophy of the renal tissues, medulla and cortex, which continuously thins out until a thin capsular foil remains. In severe cases can lead to the complete disappearance of the kidney. Erratically migrations in the abdominal cavity associated with the eggs laying act irritative-inflammatory upon the organs from cavity. Hepatic and phrenic serositis, mononuclear cell infiltration, edema and haemorrhages, are caused. Haematophagous nutrition and increased need for food correlated with the size of the parasite induce anemia. Migrations of larvae from the intestine into the kidney and subsequent peritoneal cavity may carry pathogenic bacteria that worsen the processes.

**Table 23.** Definitive hosts of *D. renale*

| order | family | species | author |
|---|---|---|---|
| Carnivora | Canidae | *Canis lupus familiaris* | McNeill et al., 1984 |
| | | *Canis lupus* | McNeill et al., 1984 |
| | | *Chrysocyon brachyurus* | Kumar et al., 1972; |
| | | *Cerdocyon thous* | Duarte et al., 2013 |
| | | *Urocyon cinereoargenteus* | Lamina and Brack, 1966 |
| | | *Vulpes fulva* | Ribeiro et al., 2009 |
| | | *Speothos venaticus* | Hernández-Camacho et al., 2011 |
| | | | Karmanova, 1968 |
| | | | Mace, 1976 |
| | Ursidae | unidentified | Hutyra, 1946 |
| | Mustelidae | *Mustela vison*, *Martes americana*, | Mech and Tracy, 2001; |
| | | *Galictis cuja*, *Lutra* spp., | Seville and Addison, 1995; |
| | | *Martes* spp., *Mustela itatsi* | Barros et al., 1990 |
| | | | Karmanova, 1968 |
| | | | Mace, 1976 |
| | Felidae | *Felis catus* | Verocai et al., 2009 |
| | Procyonidae | *Procyon lotor*, *Nasua nasua* | Milanelo et al., 2009 |
| | Phocidae | *Phoca vitulina*; | Hoffman et al., 2004 |
| | | *P. caspica* | Popov and Taikov, 1985 |
| Primates | Cebidae | *Cebus apella* | Ishizaki et al., 2010 |
| Rodentia | Muridae | *Rattus norvegicus* | Tokiwa et al., 2011 |

**Clinical signs.**

Clinical manifestations are typical of a kidney suffering. Numerous studies reveal the evolution of states of prostration, fever, hematuria, abdominal discomfort on palpation, pain in the kidney area and reduced body condition score. The urine is characterized by a cloudy reddish appearance, an alkaline pH of 8.0, specific gravity of 1.040 and increased proteinuria and hematuria. Urinary sediment is abundant and contains many rod-shaped bacterial cells, leukocytes, struvite crystals, erythrocyte and other structures. Clinical haematology has evidenced neutrophilia, toxic granulation in neutrophils and lymphopenia, suggesting acute inflammations[10,37].

**Pathology.** The kidney is enlarged, irregular in shape, reduced in volume, atrophied. Cortex and medulla are destroyed, appearing in transverse section as a thinned foil (renal capsule only remains), until to totally disappearance of kidney. The worms are frequent located in the renal pelvis, spiralled, bright red.

In erratically migration, in the abdominal cavity, a chronic peritonitis is developed. The cavity contains a dirty brown-greenish, odorless, fibrinous exudate. The omentum is matted and adhered to liver, spleen, pancreas or intestine. The mesenteric lymph nodes are enlarged and pigmented. Fibrous scars are developed on spleen and liver[38]. Edema, congestion, hemorrhage, atelectasis, emphysema, and thromboembolism are identified in the lung. Hepatic and phrenic serositis, mononucleated cell infiltrates in the lung and the presence of the eggs inside the center-lobular veins, auricular cavities, and superficial venous bed of the heart are revealed at histopathological exam[21].

**Diagnosis.** Clinic examination is indicative. Various disturbances occur, hematuria, dysuria, sensitivity of kidney area to palpation, behavioral alterations and seizures. Microscopic examination of urine sediment

allows identification of eggs but only in the presence of females in the kidney ducts. Irregular surface of the kidney, thickened and fibrous capsule, destroyed parenchyma that appears as vesicles and the presence of the coiled parasites, migrated into the ureters are relevant for diagnosis.

***Differential diagnosis*** includes nephrosis and chronic nephritis with another etiology amd bladder capillariosis, caused by *Capillaria plica*. Microscopic examination of urine reveals the eggs that differ, having knobs as caps at poles.

**Treatment.** There is no medication. Surgery consists into the removal of the affected kidney, usually the right.

**Control.** It is forbidden to feed animals with raw or improperly cooked intermediate and/or paratenic hosts (fish, amphibians). Consumption of water containing crayfish or infected annelids is dangerous and must be avoided.

## 15.2. Histrichiosis and eustrongylidosis of the web-footed birds

**Definition.** Members of the family Dioctophymatidae affect domestic and sylvatic web-footed birds. The disease evolves as proventriculitis expressed by digestive and general symptoms, chronically or asymptomatically sometimes. It is caused by nematodes of the genera *Histrichis* and *Eustrongylides*.

**Etiology.** Species of family Dioctophymidae have a cylindrical body. Males are equipped at the posterior end with a cup-shaped copulatory bursa, without rays and a spicule. Females are oviparous and monodelphic. Species involved are *Histrichis tricolor*, which parasitize proventriculus, (glandular stomach), sometimes gizzard and esophagus and *Eustrongylides tubifex* localized in the small intestine, both in domestic and wild palmipeds, especially in ducks.

***Morphology.*** *H. tricolor* has a tricolor appearance: the cuticle is white; the digestive tract is dark reddish and other tissues are red. At the anterior end, the mouth opening is bounded by six papillae. The cuticle is transversely striated and has thorns that can sometimes cover the whole body. The male measures 25 mm length and the female is 40 length and 0.8 mm wide. Eggs are oval, elongated and truncated to pole, with a thick crust, and small knobs, unembryonated when are laid, measuring 85-90/40-46 μm.

*E. tubifex* measure 56.6 to 86.8 mm length and 0.97 to 1.07 mm width the male, and 65.0 to 120.0 mm length with a maximum width of 1.65 to 4.3mm, the female. It is a large nematode, with rose beige, spindle-shaped body gradually widening to middle part. The cuticle is semi-transparent, thicker to the posterior end, transverse striated at the anterior end and smooth in the middle of the body. At the anterior end, the mouth opening is triangular, hexagonal or round shaped, lacking lips, but bounded by 12 cephalic circumoral papillae arranged in two concentric circles. At the posterior end, the male has a bell-shaped copulatory bursa, lacking rays, long spicule, about 9.2 mm and thick walled[9]. Eggs are similar to those of previous species, but a bit smaller than H. tricolor eggs, measuring 65-75/45 μm.

***Life cycle.*** Life cycle is diheteroxenous. Females lay eggs that are passed in the feces. The eggs embryonate in 20 to 30 days, in optimal conditions of temperature and humidity, and the first-larval stage remains inside the eggs. Eggs are ingested by IH which differ depending the species: earthworms from Oligochaeta class (*Allolobophora* and *Criodrilis* genera) for *H. tricolor*, and aquatic annelids (*Limnodrilus*, *Tubifex tubifex*) for *E. tubifex*. In their body, infective larvae are developed. Paratenic hosts such as fish may intervene, in their body, the larvae being re-encysted. Transmission between hosts involves predatorism[1].

Contamination is done by ingestion of IH or paratenic hosts that contain infective larvae. Larvae are released in the stomach and develop in 1-2 months, becoming adults. The longevity of adults reaches 40 to 60 days.

**Epidemiology**

***Geographical distribution.*** The infections evolve during the summer, in areas bordering lakes and deltas. The disease is widespread, but the prevalence is less studied. The prevalence of *H. tricolor* was 58% in shorebirds from the Chihuahua desert in Texas and Mexico[4]. The prevalence of *E. tubifex* varied between 41.7% in male great cormorants (*Phalacrocorax carbo*) and 50% in female cormorants from Lake Biwa, Japan[8]. The occurrence of *E. tubifex* is reported in double-crested cormorant (*P. auritus*), black-crowned night heron (*Nycticorax nycticorax*), mallard (*A. platyrhynchos*), ring-necked pheasant (*P. colchicus*) and herring gull (*Larus argentatus*) collected in the western-basin region of Lake Erie, United State[1].

***Sources of contamination*** are wild and domestic waterfowl, diseased or with inapparent forms, fish and oligochaetes as paratenic of intermediate hosts.

***Susceptibility*** of birds is not well known, but the ducks seem to be more responsive.

***Route of contamination*** is oral, ingesting infected paratenic or intermediate hosts.

***Resistance*** of the eggs in suitable biotypes can reach 2 years.

**Pathogenesis and Pathology.** Larvae and adult worms penetrate the lining of proventriculus and gizzard, exerting an inflammation. They penetrate the mucosa, causing its perforations, and pull out, in the lumen, their anterior end in another area of mucosa. Thus, the worms are positioned with both ends outside the lining, and the middle part of the body is deepened in the mucosa. They cause nodular proventriculitis, thickening and fibrosis of the wall and necrosis. Hyperplastic processes lead to the narrowing of the gastric lumen. Histologically, giant cell, histiocytes and fibroblasts are adjacent to parasites.

**Clinical signs.** Infection is expressed by digestive disorders, loss of appetite, ingluvial indigestion, weight loss, adynamia, maldigestion and diarrhea. In *Eustrongylides* spp. infections of wild waterfowls, pale mucous membranes, ataxia, depression, emaciation, and lethargy may evolve[34]. The eggs laying is decreased, and cachexia is developed in adult birds. The mortality of young birds is high. Infestations of adult birds evolve inapparently or asymptomatically.

**Diagnosis.** Eggs of parasites are detected by coproscopic examination of feces (eggtester, flotation methods) in live poultry. The necropsy is commonly used as diagnosis method in geese and ducks because allows identifying of the parasites in the gizzard and of the nodular lesions caused.

***Differential diagnosis*** includes amido-stomosis and other digestive helminths.

**Treatment.** As the disease is usually diagnosed post-mortem after die-offs in wild birds the treatment is not done, lacking the information on the efficacy of modern anthelminthic. It is considered useful to experience the treatment of amidostomosis. On the other hand, mortality of large numbers of nematodes within the host might do more harm than good[34].

**Control.** The set of measures in domestic flocks of geese and ducks concern: sanitization in shelters and paddocks and manure collection and storage for sterilization. Destruction method of paratenic and intermediate hosts are inapplicable.

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