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Eucestoda

Taenia (Genus)

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Phylum Platyhelminthes

Class Cestoda

Subclass Eucestoda

Order Cyclophyllidea

Family Taeniidae

Genus *Taenia*

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Chapter 18

Taenia (Genus)

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Introduction

The genus *Taenia* Linnaeus, 1758 belongs to the family **Taeniidae** Ludwig 1886, in the order **Cyclophyllidea** van Beneden in Braun, 1900. The name **taenia** means **band** or **ribbon**, derived from Greek (Maggenti et al., 2017). Carolus Linnaeus established the genus *Taenia* in 1758, in the 10th edition of Systema Naturae to include the species that were known at that time as parasites of humans and dogs, namely *Taenia solium, T. vulgaris, T. lata*, and *T. canina*. Pork tapeworm *T. solium* is a nominal type species, *T. vulgaris* is now recognized as a synonym of the pork tapeworm (*T. solium*) and the remaining 2 species do not belong to the genus. It was shown later that *T. lata* is a synonym for the broad fish tapeworm *Diphyllobothrium latum* Linnaeus, 1757 (now called *Dibothriocephalus latus*) and *T. canina* is a synonym of the common dog tapeworm also called the flea tapeworm *Dipylidium caninum* (Linnaeus, 1758). Up to that time, the genus *Taenia* was one of the first helminth genera along with the species recognized along with species of *Fasciola* and *Ascaris*.

All species of *Taenia* require 2 mammalian hosts (definitive and intermediate) to complete the life cycle via a predator-prey relationship. Interestingly, except for the 3 human taeniid parasites (*T. solium*, *T. saginata*, and *T. asiatica*), all other *Taenia* species, in the adult stage, inhabit the alimentary tract of terrestrial carnivores and in the larval stage (also called the **metacestode** stage) they occur in various herbivorous mammals. Many species are of medical and veterinary importance, and besides the 3 *Taenia* that are found only in humans as definitive hosts, several other species may infect humans.

Highlights for *Taenia*

- **First cestode genus.** It is the first genus established for cestodes
- **Most studied.** It is one of the most studied genera, but its taxonomy, systematics, and species diversity still remain controversial and conflicting
- **Many species infect humans.** Almost one-fourth of *Taenia* species may infect humans, 3 of them are specific to humans and referred as human-*Taenia* that infect millions of people around the globe annually
- **Economically important.** Besides the zoonotic species, a number of species infect millions of livestock and other important animals worldwide resulting in enormous economic damage
- **Carnivore-herbivore life history.** Species of *Taenia* have a unique life cycle that requires 2 obligate mammalian hosts, an intermediate herbivore and a definitive predator host
- **Many reproduce asexually.** One-fourth of all the species may multiply asexually at the metacestode stage
- **Some species can hybridize.** Hybridization between closely related species may occur in areas where they are geographically sympatric, such as *T. saginata* and *T. asiatica*
- **Large tapeworms of humans.** The *Taenia* species are some of the largest of the tapeworms of humans and may reach a length of several meters
- **Long life span.** *Taenia* may live as long as their hosts
- **Cosmopolitan distribution.** *Taenia* species with anthropogenic associations are mostly cosmopolitan, although endemic species are known from each zoogeographic region.

Morphology of *Taenia* Species

The strobila or body is ribbon-like with many proglottids. The immature and mature proglottids are wider than they are long, with relative length increasing posteriad in the strobila. The rostellum usually has 2 rows of hooks of typical shape; the hooks of the anterior row are larger, alternating with those of the second row. The rostellum rarely has just 1 row of hooks, or hooks may be absent as in adults of *Taenia saginata*. There is a single set of reproductive organs in each proglottid. The genital pores alternate irregularly. The female genital organs are situated posteriorly in the segment. The ovary is bi-lobed and is situated at the median. The vitelline gland is simple, situated posterior to the ovary. The testes are abundant, mostly anterior and lateral to the female organs. The uterus arises as a median, longitudinal tube. The gravid uterus has lateral branches and is often secondarily branched.

Figure 1. Rostellar hooks of *Taenia taeniaeformis*. Source: S. Ganzorig and S. L. Gardner. License: CC BY.

The eggs are spherical, each with a thick-walled embryophore, and composed of thick walls (this description comes from that provided by Rausch, 1994).

Asexual Reproduction of Metacestodes

The phenomenon of asexual multiplication in the larval stage is common in trematodes, but not in cyclophyllid cestodes as only fewer than 1% of all cestodes have proliferative or asexually reproducing larvae (Mackiewicz, 1988). However, a large number of *Taenia* species (about one-fourth) have been reported to be able to multiply asexually at the metacestode stage (*Taenia multiceps, T. serialis, T. endothoracicus, T. krepkogorski, T. parva, T. selousi, T. twitchelli, T. crassiceps*, *T. polyacantha*, and *Versteria mustelae*) (See Moore and Brooks, 1987). *Taenia retracta* also was found to multiply at the metacestode stage (Karpenko and Konyaev, 2012). Species of *Echinococcus* (another taeniid genus) also multiplies asexually at the larval stage, while only a few other cestodes are capable of producing asexually proliferative larvae, including 1 mesocestoidid, *Mesocestoides vogeae*; a dilepidid (family Dilepididae) *Paricterotaenia paradoxa*; and 3 species of hymenolepidids, *Staphylocystis pistillum*, *S. scalaris*, and *Pseudodiorchis prolifer* (Mackiewicz, 1988; Galan-Puchades et al., 2002).

Identifying *Taenia*

Species belonging to this genus have the largest body sizes of all the cestodes in the order Cyclophyllidea, their length is usually measured in tens of centimeters or even several meters. Cestodes belonging to this genus exhibit a set of unique morphological characters, including: Gross anatomy (strobila length and number of proglottids or segments); rostellum of the scolex with or without hooks (commonly

Figure 2. Rostellar hooks and suckers of *Taenia kotlani* from a snow leopard. Source: S. Ganzorig and S. L. Gardner. License: CC BY.

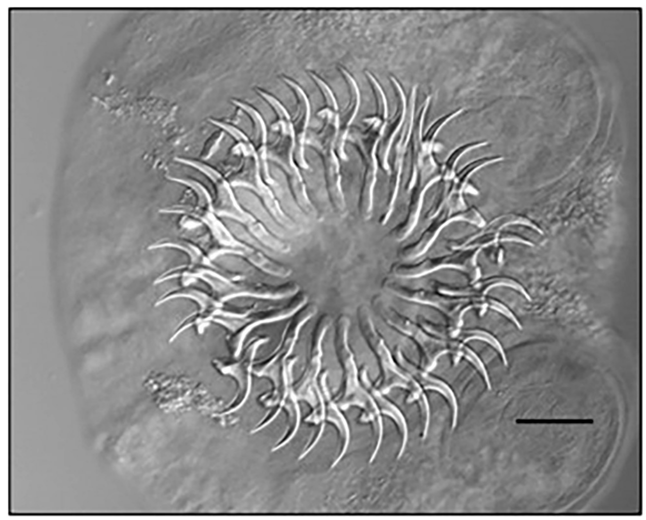

Figure 3. Rostellar hooks of *Taenia polyacantha*. Source: S. Ganzorig and S. L. Gardner. License: CC BY.

called armed or unarmed) and those that do have hooks having 2 rows of characteristically shaped hooks (Figures 1–4); a single set of reproductive organs with a bi-lobed ovary, many testes, and a laterally branched gravid uterus filled with spherical eggs possessing thick and radially striated shells (Figures 5–9). Larval stages are mostly cysticercus-type with scolex invaginated within, or associated with, a bladder; or modification such as strobilocercus, armatetrathryridium, coenurus, pseudocoenurus, or polycephalic metacestodes (Figures 10 and 11). The **cysticercus** is the basic type of larval form for *Taenia* cestodes, characterized by a single

Figure 4. Rostellar hooks of *Taenia crassiceps*. Source: S. Ganzorig and S. L. Gardner. License: CC BY.

Figure 5. Young proglottids of *Taenia crassiceps*. Source: S. Ganzorig and S. L. Gardner. License: CC BY.

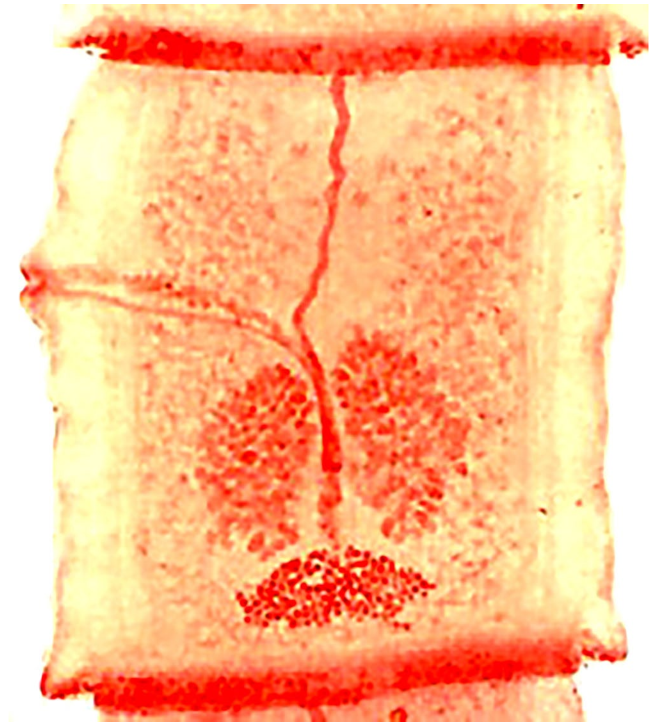

Figure 6. Mature proglottid of *Taenia crassiceps*. Source: S. Ganzorig and S. L. Gardner. License: CC BY.

bladder with 1 scolex; a **strobilocercus** possesses an elongated segmented body, while an **armatetrathyridium** (**fimbriocercus**) has an unsegmented body. A coenurus type-larva has a bladder filled with fluid and an internal germinal layer that produces multiple scolices that bud off of this germinal layer. **Polycephalic type** larval forms are more rare and have several scolices arising from a central bladder, such as found in *T. endothoracica* (Kirschenblatt, 1948) (Figure 12).

Identification of *Taenia* spp. based only on morphological criteria is not easy due to the overlap of characters. So, other criteria such as biological (such as host or site of infection) and geographical (such as location or distribution) are used in combination. Hook morphology, size, and number are the most significant features for the identification of *Taenia* spp. in both the adult and larval stages. This is especially important for the identification of larval stages, because the metacestode, in addition to the soft body tissues, such as the strobilocercus or hemistrobilocercus, possesses only a scolex armed with hooks. A study on hook morphometrics (Tufts et al., 2016) showed that hook shape and length were important characteristics for the identification of larvae of Taeniidae. Knowledge of the morphology of adult worms, including the characteristics of mature and gravid segments are needed for proper identification.

Loos-Frank (2000) provided characteristics for the 44 species and subspecies of the genus *Taenia*. Besides hook morphometrics, the most important characteristics were number and distribution of testes, cirrus sac or pouch position, and the presence of a vaginal sphincter. The dimensions of the cirrus pouch, number of uterine branches, and size of ovarian lobes were of lesser importance.

For study of these animals and to identify them using morphology, a freshly collected specimen must be relaxed in water, and then killed and fixed using appropriate methods followed by staining and mounting of the specimens on microscope slides in gum Damar. All these steps are crucial for correct identification. In some species, even the combination of various identification criteria does not enable an accurate identification. However, progress in

Figure 7. Gravid proglottid of *Taenia crassiceps*. Source: S. Ganzorig and S. L. Gardner. License: CC BY.

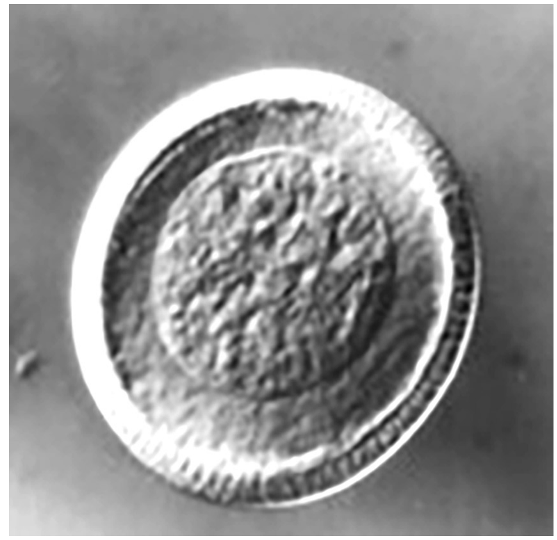

Figure 8. Egg of *Taenia kotlani*. Source: S. Ganzorig and S. L. Gardner. License: CC BY.

Figure 9. Egg of *Echinococcus multilocularis*. Source: S. Ganzorig and S. L. Gardner. License: CC BY.

molecular techniques, such as DNA sequencing of various genes has provided improved tools for the precise identification of taeniid cestodes.

Sequencing of the mitochondrial and nuclear genes has helped not only to accurately identify *Taenia* spp., but also to provide valuable genetic characterization which has supported and validated species and genera. Molecular markers for the precise identification of taeniid cestodes include partial fragments of mitochondrial *cox1*, *cytb*, *nad1*, and/or nuclear DNA sequences of 12S rDNA,18S rDNA, phosphoenolpyruvate carboxikinase (*pepck*), DNA polymerase delta (*pold*) and others. Relatively recently, complete mitochondrial genome sequences have been made available for all three human-*Taenia* species, and *T. crassiceps*, *T. hydatigena*, *T. multiceps*, and *T. pisiformis* (Jeon et al., 2007; Jia et al., 2010). Analysis of the complete mitochondrial genome revealed highly variable genes such as *nad6*, *nad5*, *atp6*, *nad3,* and *nad2* (Jia et al., 2010). Cryptic species within some closely related species were found, for example *T. polyacantha* and *Taenia=Hydatigera taeniaeformis* isolates. Lavikainen and colleagues (2008) reported essential nucleotide differences in 2 mitochondrial gene sequences in isolates belong to *T. polyacantha* which has a distribution across a huge geographic area extending from Europe to North America and suggested that these represented cryptic morphological species. In this case, the molecular data and the morphological data appear

Figure 10. Cysticercus of *Taenia hydatigena* with evaginated scolex. Source: S. Ganzorig and S. L. Gardner. License: CC BY.

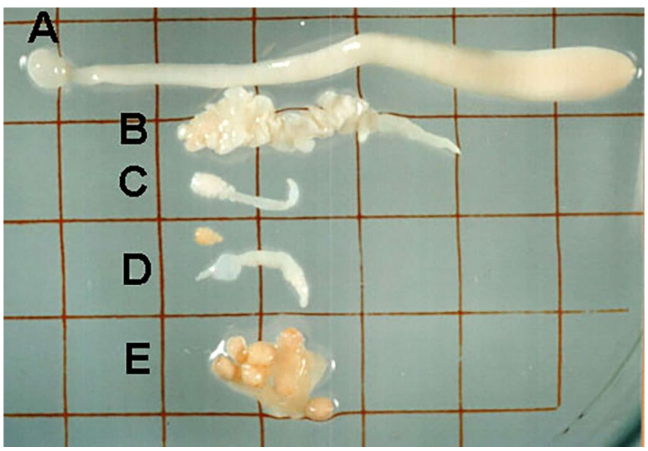

Figure 11. Different types of metacestode in *Taenia*. From top: A) Strobilocercus of *T. taeniaeformis*; B) armatetrathyridium of *T. martis*; C) *T. polyacantha*, tetrathyridium of *Mesocestoides* sp.; D) strobilocercus of *T. retracta*; E) polycephalic metacestode of *T. endothoracicus*. Source: S. Ganzorig and S. L. Gardner. License: CC BY.

to converge, as Rausch and Fay (1988) previously described 2 subspecies of *T. polyacantha* based on differences in the numbers and sizes of rostellar hooks; this could be evidence of post-glacial (Pleistocene Epoch) incipient speciation. Recently, Lavikainen and colleagues (2016) described *Hydatigera kamiyai* based on a Japanese isolate of *T. taeniaeformis* known to be restricted to both arvicoline rodents (voles) and mice belonging to the genus *Apodemus* as intermediate hosts.

Systematics and Phylogeny

As the oldest cestode genus to be described, and the first that had a Latin name ascribed to species in the genus, *Taenia* was used by taxonomists for many species not necessarily belonging to this genus. Because of the propensity of some

Figure 12. Multistrobilate larval form of *Taenia endothoracicus* from a wild gerbil collected and examined in western Mongolia. The adults occur in canids, most likely foxes. Source: S. L. Gardner, HWML. License: CC BY.

taxonomists to split species and assign other species to this genus, there were at one time more than 100 species recognized, but over time, with more accurate methods, the species number has steadily declined. Approximately half of them, or about 40 to 50 species, remained valid for a time, but this number is still decreasing. There are two primary reasons for this: The first being that some species were initially misidentified and are now excluded from the list; and the second reason is due to disagreement among researchers about the number of nominal genera of the subfamily Taeniinae. The species widely regarded as *Taenia* spp. have been placed in from 1 to 6 different genera: The Russian scientist Abuladze (1964) listed 64 species and placed them into 6 separate genera including: *Taenia* Linnaeus, 1758, *Hydatigera* Lamarck, 1816, *Tetratirotaenia* Abuladze, 1964, *Taeniarhynchus* Weinland, 1858, *Multiceps* Goeze, 1782, and *Fossor* Honess, 1937. Verster (1969) recognized only 1 genus (*Taenia*) and validated 32 of 70 species that were described as belonging to genus *Taenia* sensu stricto while Schmidt (1986) lists 88 species in the genus *Taenia* and partly followed Abuladze (1964) in recognizing 3 additional genera: *Insinuarotaenia* Spasskii, 1948, *Taeniarhynchus* Weinland, 1858, and *Monordotaenia* Little, 1967. At about the same time, a new genus named *Fimbriotaenia* had been created by Kornyshin and Sharpilo (1986). However, Rausch (1994), and Loos-Frank (2000) retained only the type genus in their works. Loos-Frank (2000) updated the previous revision made by Verster (1969) and included a list containing 44 species and subspecies belonging to *Taenia* sensu stricto. Here it is important to mention that classifications produced by the researchers above, are based on morphology of adult cestodes with data included on metacestode stages.

More recent studies based on DNA barcoding, gene sequencing of nuclear and mitochondrial DNA (*COI*, NADH, and other genes), revealed that some old genera could be validated on the base of modern data. It was recently found (Nakao et al., 2013a; 2013b; Lavikainen et al., 2016) that analysis of both nuclear and mitochondrial DNA sequences strongly supports the validity of the genus *Hydatigera* Lamarck, 1816 which is not recognized by most researchers (Verster, 1969; Rausch, 1994; Hoberg et al., 2000; Loos-Frank, 2000). Also, Nakao and colleagues (2013a; 2013b) based on genetic data, proposed a new genus *Versteria* Nakao et al. (2013) for *Taenia mustelae* Gmelin, 1790, an eponym in honor of the late Anna Verster from South Africa.

Based on the above results, the up-to-date family Taeniidae now consists of 4 valid genera: *Taenia*, *Echinococcus*, *Versteria*, and *Hydatigera*. With the resurrection of the genus *Hydatigera* and establishing the new genus *Versteria*, 40 valid species remain in *Taenia* sensu stricto (Lavikainen, 2014). The species *T. mustelae* (Gmelin, 1790) and *T. brachyacantha* (Baer and Fain, 1951) are removed from *Taenia* and placed into the genus *Versteria*. Finally, the genus *Hydatigera* now includes *T. taeniaeformis*, *H. kamiyai*, *T. krepkogorski* Shulz and Landa, 1934, and *T. parva* (Baer, 1924).

The phylogeny of the genus *Taenia* and other taeniid cestodes has been studied by many researchers using both morphological and molecular data. In recent times, with increasing genetic material accumulated in GenBank and other sequence databases, in silico phylogenetic studies are increasing. Hoberg and colleagues (2000; 2005) provided thorough phylogenetic analyses of *Taenia* based on 27 morphological characters of valid species. This analysis did not support the idea of tribes (Taeniini, Fimbriotaeniini) and genera (*Hydatigera*, *Fimbriotaenia*, *Fossor*, *Monotdotaenia*, *Multiceps*, *Taeniarhynchus*, and *Tetratirotaenia*) created by previous researchers, and diagnosed monophyly for *Taenia* (Hoberg et al., 2000).

The phylogeny of *Taenia* based on partial sequences of mitochondrial *cox1* and *nad1* genes was studied by several researchers in the mid-1990s and beyond (Okamoto et al., 1995; De-Queiroz and Alkire, 1998). Those studies included a limited number of examined species (Lavikainen et al., 2008; Lavikainen, 2014). However, even these preliminary studies suggested important findings on origins of human *Taenia* species (De Queiroz and Alkire, 1998) and showed distinct placement of *T. mustelae* and *T. taeniaeformis* in the new phylogenetic trees (Okamoto et al., 1995; De Queiroz and Alkire, 1998). De Queiroz and Alkire (1998) suggested that *T. saginata* and *T. asiatica* are sister taxa and likely represent a single colonization of humans, and *T. solium* represents an independent colonization event. Recent studies based on longer mitochondrial DNA regions or complete genes, and nuclear DNA sequences, such as two protein-coding genes, phosphoenolpyruvate carboxykinase (*pepck*) and DNA polymerase delta (*pold*) were used to estimate the phylogeny of the Taeniidae (Lavikainen et al., 2008; 2010; 2016; Nakao et al., 2013a; 2013b). These studies show that *Taenia* is a highly diverse assemblage, and contrary to Hoberg and colleagues (2000), is paraphyletic, meaning that the classification puts some of the species that are actually in other genera together (Lavikainen et al., 2008). Several species, including *T. mustelae*, *T. taeniaeformis*, *T. krepkogorski*, and *T. parva* were found to be distantly related to other *Taenia* spp. and these results supported creation of the new genus *Versteria* and resurrection of the old genus name: *Hydatigera* (see Lavikainen, 2014).

Phylogenetic analysis using the mitochondrial *cox*1 gene partial nucleotide sequences from cestodes with different types and degrees of asexual multiplication during metacestode stages indicate that asexual development and multiplication among taeniid cestodes was independently derived and these characteristics have no value in higher taxonomy. However, taeniid cestodes with larvae that have a armatetrathyridia (*Taenia polyacantha*), strobilocercae (*T. taeniaeformis*), pseudocoenurae- or polycephalic-type (*T. endothoracicus*) metacestodes are branched distinctly from all other taeniids (Figure 13). So far, according to the newest taxonomy of Taeniidae the phenomenon of asexual multiplication is found in representatives from all 4 genera: *Taenia*, *Hydatigera*, *Versteria*, and *Echinococcus*.

Distribution and Hosts

Geographic and host distribution of species of *Taenia* sensu lato are highly variable. All the human *Taenia* and the species that are closely associated with livestock and domestic carnivores are well-known and are represented mostly by geographically cosmopolitan species (*T. solium*, *T. saginata*, *T. hydatigena*, *T. multiceps*, *T. ovis*, *T. pisiformis*, *T. serialis*, *T. solium*, and *T. taeniaeformis*). Distribution of the rest of the species in the genus is limited at various geographic scales. The large variety of both ungulates and carnivores in Africa supports the existence of at least 13 endemic species of *Taenia*, which makes Africa the area with the highest area of endemicity of species in the genus. In the Holarctic zoogeographic region more than 20 species have been reported, however, only 7 species (*T. arctos*, *T. crassiceps*, *T. intermedia*, *T. krabbei*, *T. laticollis*, *T. macrocystis*, and *T. polyacantha*) are fully distributed throughout the Holarctic

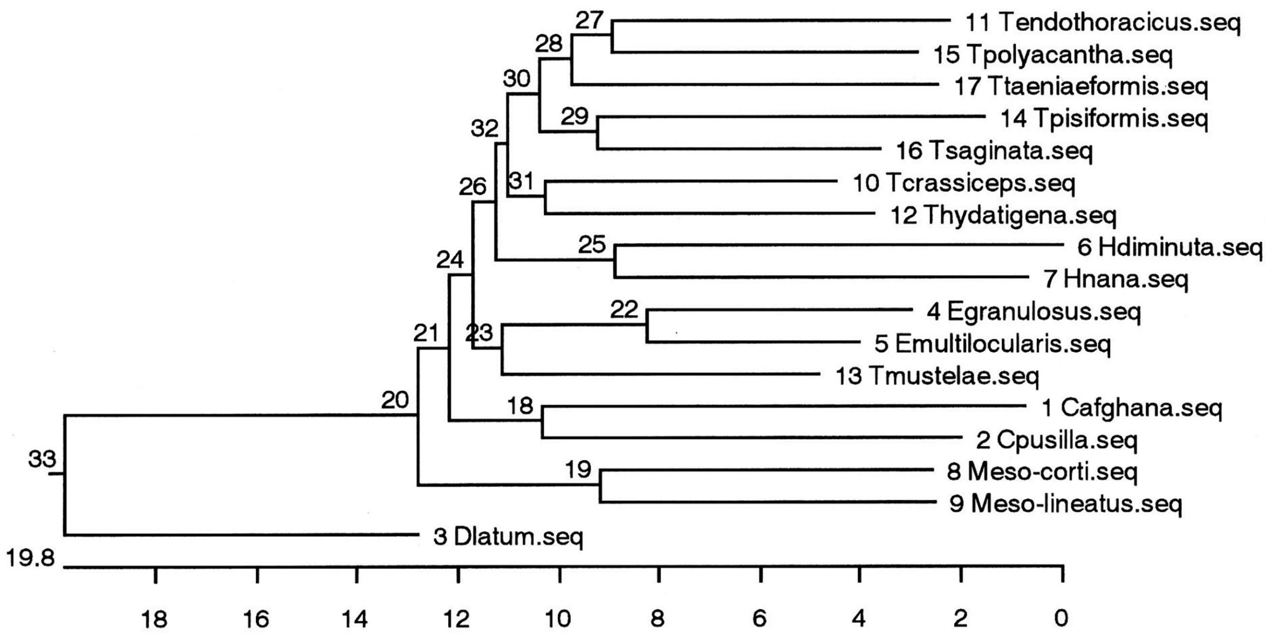

Figure 13. Phylogenetic tree of cyclophyllid cestodes constructed from neighbor joining (NJ) analysis of the mitochondrial *cox*1 gene partial nucleotide sequences. Source: S. Ganzorig. License: CC BY.

region. The distribution of about 5 to 8 species is limited to the Palearctic region (*T. endothoracicus*, *T. kotlani*, *T. martis*, *T. parenchumatosa*, and *T. retracta*) and the Nearctic region (*T. omissa*, *T. pencei*, *T. pseudolaticollis*, *T. rileyi*, and *T. taxidiensis*). The Australian region has no endemic species and those in the Oriental and Neotropical regions are poorly known but *T. talicei* is known from larval forms in rodents of the genus *Ctenomys* in Bolivia and the life cycle has been recently worked out (Rossin et al., 2010). The life cycle of *T. saigoni* found in *Macaca* spp. in Vietnam remains unknown (Loos-Frank, 2000). Specific identification of the bicephalic metacestode found in rats in Malaysia is also lacking (Kamiya et al., 1987). Many of the definitive hosts are endangered or rare and have been protected by local or international conventions. So far, collecting adult cestode specimens from hosts in the mammalian order Carnivora is now impossible or difficult in many areas.

Progress has been made to enable the study of alternative definitive host models for taeniid species. Included in these successes were alternate hosts for *Echinococcus multilocularis*, *Taenia crassiceps*, *T. hydatigena, T. pisiformis*, and a few other species (Kamiya and Sato, 1990; Sato et al., 1993; Toral-Bastida et al., 2011). As models, immunosuppressed laboratory rodents were used to obtain sexually mature cestodes from infection with metacestodes. The alternative host model might be helpful for the study of unknown metacestodes from various intermediate hosts, as well as specific determination of taeniid eggs.

The definitive hosts for *Taenia* cestodes represent 8 families of Carnivora (Abuladze, 1964; Loos-Frank, 2000). Of these, the canids and felids host the majority, or about 18 to 17 species, respectively. Other carnivores, such as mustellids and hyaenids are found to be hosts for up to 10 species. So far, by the greatest number of *Taenia* species parasitized, the carnivores could be placed in the following order: canids, felids, mustelids, hyaenids, ursids, viverrids, herpestids, and procyonids. Rodents, lagomorphs, and ruminants serve as the main intermediate hosts for *Taenia* spp. The small mammals (rodents, lagomorphs, and insectivores) and large mammals (various ruminants) are principal intermediate hosts for half equally of all *Taenia* species, respectively.

Human *Taenia* and Other Species of Medical Importance

As mentioned briefly above, human forms of *Taenia* include 3 species, *T. solium*, *T. saginata*, and *T. asiatica*, with humans serving as the sole known definitive host. Human *Taenia* is characterized by wide distribution (*T. solium* and *T. saginata* have a worldwide distribution), great size (up to 25 m), and great longevity with individual cestodes being known to live for the lifespan of the host, which can amount to decades in an individual. Humans become infected with *T. solium* and *T. asiatica* when they consume raw infected pork or pig liver and with *T. saginata* when they eat raw infected beef. Due to the pathogenicity in humans, *T. solium* is called pork tapeworm and *T. saginata* is called beef tapeworm. Infection of humans with adult cestodes of these 3 species is called taeniasis. Pork tapeworm (*T. solium)* can cause cysticercosis in humans, also.

As a parasite of humans, *Taenia solium* has a cosmopolitan distribution and has been known about since antiquity. According to the World Health Organization (WHO, 2022), *T. solium* is a leading cause of foodborne-related deaths. The burden is heaviest in countries of Africa, Asia, Central America, and South America.

Taenia asiatica (Eom and Rim, 1993), also referred to colloquially as Asian *Taenia*, is the most recent human species of *Taenia* to have been described. For a long time, it was misdiagnosed as *T. saginata* due to the similarity in their morphological characteristics. It was first identified in Taiwanese Aboriginal people (Eom and Rim, 1993). Humans serve as the definitive host, and infection by this species causes taeniasis. Intermediate hosts include domestic pigs and wild boar, and *T. asiatica* has also been successfully transmitted experimentally to goats, cattle, monkeys, and mice. Humans infected by eating raw or undercooked meat containing larvae of *T. asiatica* suffer from invasive cysticercosis. Distribution of this species is restricted to warm temperate, subtropical, and tropical Asian countries, such as South Korea, Taiwan, Philippines, Thailand, Vietnam, Japan, southeast China, and Nepal (Ale et al., 2014). A survey in Laos (Sato et al., 2018) found *T. asiatica* hybridizing with *T. saginata*.

Morphologically the adult *Taenia asiatica* is very close to *T. saginata* but may be distinguished by the unarmed rostellum and a large number of uterine branches. Differences are also observed in the metacestode stage as it possesses a wartlike formation on the external surface of the bladder wall. The metacestodes' preferred location is liver and visceral organs, but not in the muscle. Furthermore, it differs by the nature of its intermediate host (pigs versus cattle) and cysticercus development which develops more rapidly in *T. asiatica*) (Eom and Rim, 1993). Nucleotide sequences of nuclear and mitochondrial genes are a reliable method to distinguish *T. asiatica* from *T. saginata*, *T. solium*, and hybrids. The hybridization of *T. asiatica* and *T. saginata* for the first time was reported by Okamoto et al. (2010) in specimens from Thailand, where all 3 human *Taenia* species are sympatric. Later, hybridization was also found in Laos (Sato et al., 2018).

Within the Asia-Pacific region, where all 3 human *Taenia* species occur, it is important to discriminate among these species. A loop-mediated isothermal amplification method (LAMP) for a differential identification of *Taenia* tapeworms from humans was applied by Nkouwa and colleagues (2012). The results suggested a reliable and easy method for identification of all 3 species in the sympatric area, even in field conditions. A LAMP is a single tube technique for the amplification of DNA and does not require a thermal cycler or other expensive equipment.

Other *Taenia* Species that Can Harm Humans

The metacestode stages of 8 *Taenia* species are known to infect humans, namely, *T. crassiceps, T. ovis, T. taeniaeformis, T. hydatigena*, and *T. martis* cause cysticercosis in people*;* while infection by eggs of *T. multiceps, T. serialis*, and *T. brauni* may cause coenurosis. Infection with strobilocercae of f *T. taeniaeformis*, a parasite of wild and domestic felids, has afflicted humans in several countries including Argentina, Denmark, Taiwan, and others. Parasite of canids, *T. crassiceps*, *T. ovis*, *T. hydatigena*, *T. multiceps*, *T. serialis*, and *T. brauni* can infect humans when eggs are accidentally ingested, and these develop into metacestode stages, individually called a cysticercus or coenurus (Miyazaki, 1998). In these cases, the human is acting as an intermediate host (albeit a dead end one), so the location of metacestodes is exactly the same as those found in natural intermediate hosts.

Taenia martis has been found to infect humans, causing cysticercosis in the eye and brain (Brunet et al., 2015). This species is a specific parasite of carnivores belonging to the family of Mustelidae and rodents are the usual intermediate hosts. Transmission to humans probably occurs by the same route as that method that infects the intermediate hosts which is via the oral route with food or water contaminated with *T. martis* eggs.

The majority of the zoonotic *Taenia* species (6 from 8 reported) parasitize various canids as adults, including pet dogs. Domestic pets and wild animals (specifically, carnivores) may cause risk of infection by this cestode to humans. It is important to mention that the larval stages of *T. multiceps*, *T. serialis*, *T. brauni*, and *T. martis* may affect the central nervous system and eye in humans, resulting in significant damage to health, similar to the deleterious effects of *T. solium*.

Taenia Species of Veterinary Importance

About half of the known *Taenia* species are of veterinary importance. All the human *Taenia* species at the metacestode stage also cause cysticercosis in livestock and some wild ungulates. *Taenia saginata* encysts in striated muscles of cattle, *T. solium* infects muscles and other organs of pigs, and *T. asiatica* infects the visceral organs of pigs and wild boar. Carcasses or internal organs of livestock infected with the cysticercae of these cestodes need to be destroyed, which causes great economic loss. Other widely distributed species that cause cysticercosis in livestock and wild ungulates are *T. hydatigena* (which encysts in visceral organs) and *T. ovis* (which infects the skeletal muscles and heart of sheep). Coenurosis caused by *T. multiceps* is a serious disease of the central nervous system of livestock and wild ungulates.

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