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Comprehensive Review of Key Taenia Species and Taeniosis/Cysticercosis Disease in Animals and Humans

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Abstract- This manuscript provides a comprehensive review of the Taenia genus, encompassing 44 reported species, and their impact on domestic and wild animals as well as humans. The review focuses on 10 important Taenia species and covers various aspects including their description, life cycle, epidemiology, clinical signs of taeniosis and cysticercosis, diagnosis, treatment, control, and prevention.

While humans primarily serve as the definitive hosts for Taenia asiatica, T. saginata, and T. solium, they can also become intermediate/accidental hosts for larval forms (metacestodes) of Taenia crassiceps, T. multiceps, T. serialis, T. solium, and T. Taeniaeformis.

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While humans primarily serve as the definitive hosts for *Taenia asiatica, T. saginata,* and *T. solium*, they can also become intermediate/accidental hosts for larval forms (metacestodes) of *Taenia crassiceps, T. multiceps, T. serialis, T. solium,* and *T. Taeniaeformis*. These larval forms can cause a range of pathologies in the brain, liver, muscle, eye, and subcutaneous tissue. Human cysticercosis, particularly from *T. solium*, results in significant hospital treatment costs, loss of productivity, and even death.

Cysticercosis caused by eight out of the ten reviewed Taenia species in domestic livestock leads to economic and productivity losses. *Taenia solium, T. asiatica,* and *T. hydatigena* are associated with porcine cysticercosis; *T. saginata* causes bovine cysticercosis; *T. hydatigena, T. multiceps* and *T. ovis* cause cysticercosis in sheep and goats; and *T. pisiformis* and *T. serialis* cause cysticercosis in rabbits.

Control and prevention interventions primarily focus on *Taenia solium* infection. Strategies employed include meat inspection, mass screening and treatment of human carriers, treatment and vaccination of pigs, improved sanitation and slaughtering facilities, and health education. However, sustainability remains a significant challenge in effectively controlling this cosmopolitan zoonotic parasite.

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I. Introduction

Taeniosis and cysticercosis are parasitic infections caused by various adult and larval forms of tapeworms in the genus Taenia in animals and humans leading to production losses, negative socio-economic consequences, nervous and muscular disorders, and even death in very severe instances.

The life cycles of the tapeworms are indirect, involving both intermediate and definitive hosts. Many domestic animals like cattle, goat, sheep, and pigs function as intermediate host where ingested eggs hatch and develop into infective larvae that localize in muscular structures and visceral organs. Humans and dogs are the definitive hosts of many tapeworms where ingested larvae develop into mature adults that shed their eggs into the environment. Humans could also be infected by the larval forms that could lead to neurocysticercosis which is associated with epileptic seizures.

In general, taeniosis and cysticercosis in animals and humans often manifest mild clinical signs except human neurocysticercosis and few other cases with massive infection by adult worms and larvae. Production losses are associated with carcass condemnation, reduced productivity, and high medical costs for managing neurocysticercosis in humans. Diagnoses of these diseases involves history taking, physical examination, meat inspection, coprology, serology, molecular and imaging techniques. Treatment is achieved by use of anthelmintics, anti-inflammatory, anticonvulsive drugs, and other supportive or nonspecific treatments. Control and prevention interventions include massive screening and treatment of carriers, improved human sanitary practices, better animal husbandry practices, meat inspection, vaccination and treatment of pigs, health education, and safe eating habits.

This review discusses the descriptive morphology, lifecycle, and epidemiology of 10 Taenia species, the clinical signs, diagnosis, treatment, prevention, and control of taeniosis and cysticercosis in animals and humans.

II. Description of 10key Tapeworm Species

Tape worms are classified under the Genus *Taenia*, Family *Taenidae*, Order *Cyclophyllidea*, Subclass *Eucestoda,* Class *Cestoda*, Phylum *Platyhelminthes*, and Kingdom *Animalia* (Taylor et al., 2015). There are 32 species and three subspecies of tapeworms based on Verster's (1969) taxonomy of the genus Taenia Linnaeus (Verster, 1969) which has been updated by (Loos-Frank, 2000) to 39 species and five subspecies, totaling to 44 species/subspecies. He also supplied more information on the hosts affected, geography range, synonyms, larval characteristics, and number of hooks. To capture the species of greater

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veterinary and zoonotic importance, this review focus on the following 10 species of the genus Taenia:

a) Taenia Asiatica (SYN. Taenia Saginata Asiatica)

Taenia asiatica is predominantly found in Asia, and its morphology and lifecycle are similar with *Taenia saginata* except that in the intermediate pig host it is localized in the liver. The adult worm measures about 3.5 m long, has a scolex with four suckers and the rostellum is surrounded by two rows of rudimentary hooklets. It has posterior protruberances in the gravid proglottid, which are absent in all other tapeworms. The metacestode differs morphologically from that of *T. saginata* in having wart-like formations on the external surface of the bladder wall (Taylor et al., 2015).

Life Cycle

The definitive host for *T. asiatica* is humans while pigs act as natural intermediate hosts, but cattle, goats and certain monkey species were found to be infected with the metacestode forms (Eom et al., 1992; Fan, 1988). Mature cysts are detected in the intermediate host after four weeks following ingestion of the eggs which hatch in the intestines and the oncospheres traverse through the hepatic portal circulation to the liver. The metacestodes are mainly found in the liver of pigs, but could also be found in lungs, omentum, serosa, mesentery, and peritoneum (Chung et al., 1996; Eom et al., 1992; Zhang et al., 1999). It has been reported that humans start excreting motile tapeworm segments along with the stool, about 0 to 35 proglottids daily, two to four months following ingestion of viable cysts in infected pigs' liver (Chang et al., 2006; Chao et al., 1988; Eom et al., 1992). Humans acting as intermediate host, as with *Taenia solium,* are not reported (Ale et al., 2014).

Epidemiology

The risk factors for transmission of *T. asiatica* are consumption of raw pork viscera for human infection and open defecation for infection of the intermediate host. Since the consumption of raw pig viscera is more associated to social, cultural, and religious practices of certain groups of people, the prevalence therefore is more localized in certain foci such as islands within many Asian countries (Ale et al., 2014).

b) Taenia Crassiceps

Adult worms grown in the hamster gut have varying lengths, but gravid proglottids with viable eggs are found in the 82nd proglottid at 27–34 days post inoculation. Its scolex has four suckers and the rostellum bears thorn-shaped hooks (Willms & Zurabian, 2010). The microscopic structure of immature and maturing proglottids are similar but appear smaller in size than those obtained from natural infections. Mature tapeworms have a continuous array of apoptotic cells in the sub-tegumentary tissues suggesting constant replacement by new cells. The testes and vas deferens in mature proglottids have filiform spermatids, with a single axoneme and an elongated helicoidal nucleus inserted between the axoneme and the spiral cortical microtubules. The spermatids conform to type III spermiogenesis. The larval metacestode stage reproduces asexually by exogenous budding (Willms & Zurabian, 2010), which may enhance intraspecific variation and formation of new strains (Smyth & Smyth, 1964).

Life Cycle

The indirect lifecycle of *T. crassiceps* involves a definitive host (foxes and dogs) where the adult worm lodges in the small intestine releasing infective eggs that are expelled outside with the host feces are ingested by the intermediate hosts (wild rodents). Hatched oncospheres cross the intestinal epithelium, lodge in body cavities and subcutis tissues; multiply asexually by exogenous budding (Loos-Frank, 2000) and differentiate to the cysticercus (metacestode) cysts that are ingested by the definitive host where it grows into adult within the duodenum (Willms, 2008).

Epidemiology

Taenia crassiceps is a cosmopolitan cestode parasite endemic to the northern hemisphere, including Europe, North America, and Asia. Main transmission route to the intermediate host (dogs, cats, and humans) is through ingestion of infective eggs along contaminated feed or water. Environmental contamination with infective eggs leading to cysticercosis is also a risk factor for infection (Wünschmann et al., 2003).

A 38-year-old man with severe acquired immunodeficiency syndrome (AIDS) with lesions of a fluctuant, painful, subcutaneous, and intermuscular tumor embedded in deep tissues of the forearm was found to be caused by cysticerci of *Taenia crassiseps* (François et al., 1998). Many other *T. crassiceps* cysticercosis cases in immunosuppressed humans involving the cerebellum, subcutis, muscle, upper limb and eye (subretinal, anterior chamber) have been reported in France, Austria, Germany, Canada, Switzerland and United States of America (Ntoukas et al., 2013).

c) Taenia Hydatigena (SYN. *Taenia Marginata, Cysticercus Tenuicollis*)

Adult worm measures up to 5 m, and its large scolex has 2 rows of 26 and 46 rostellar hooks, respectively. Mature gravid proglottids are 12 mm long and 6 mm wide, and their uterus has 5–10 lateral branches (Taylor et al., 2015). Eggs are oval and 36-39 by 31-35 *μ*m (Köhler, 1997). The cysticercus is semi-transparent, 5–7 cm in size, contains a watery fluid and invaginated scolex with a long neck (Taylor et al., 2015).

Life Cycle

The life cycle is indirect involving dogs and wild canids as definitive hosts whilst the intermediate hosts are sheep, goats, cattle, and pigs. The intermediate hosts are infected through the ingestion of infective eggs. The oncospheres crosses the intestines into the portal veins to the liver where they migrate through the parenchyma within 4 weeks after infection. Within another 4 weeks, the oncospheres develop into mature metacestodes (Cysticercus tenuicollis) and remain attached to the greater omentum, liver, mesentery, and other abdominal organs. The metacestode measures 6 cm long, has a long thin neck with a single scolex (Köhler, 1997; Taylor et al., 2015). The life cycle is completed in the definitive host's small intestine within 51 days after ingestion of the metacestodes and stays infective for more than one year.

Epidemiology

The epidemiology and transmission of *Taenia hydatigena* in sheep and dogs are important due to the necrotic hemorrhages in the liver caused by the metacestode. This is exemplified in the territory of Sardinia, Italy where *C. tenuicollis* prevalence of 14.6 % of 30–40-day-old lambs with a total economic cost relating to cysticercosis amounts to almost € 330,000 (Scala et al., 2015). In Iran, *C. tenuicollis* infection rates of 12.87% of slaughtered sheep and 18.04% of slaughtered goats were reported (Radfar et al., 2005), and majority of the cysts were in the omentum. Similarly, prevalence rates of *C. tenuicollis* in slaughtered pigs, goats, and sheep of 6.6%, 45.7% and 51.9%, respectively were reported in Mbeya, Tanzania; 80% of cysts on omentum and 20% on liver; and the metacestodes were confirmed by DNA sequencing of the mitochondrial cytochrome c oxidase subunit 1 gene (cox1) (Braae et al., 2015). On worldwide occurrence of *T. hydatigena* cysticercosis, pigs had higher prevalence in Asia 17.2% (95% CI: 10.6–26.8%) and South America 27.5% (CI: 20.8–35.3%), compared to a low prevalence of 3.9% (95% CI: 1.9–7.9%) in Africa; while cattle had low overall prevalence mean of 1.1% (95% CI: 0.2–5.2%) (Nguyen et al., 2016). In the United Kingdom, 11.3% of dogs are reported infected with *Taenia hydatigena* (Edwards et al., 1979).

d) *Taenia Multiceps (STN. Multiceps Multiceps Coenurus Cerebralis, Taenia Skrjabini, Coenurus Skrjabini, Taenia (Multiceps) Gaigeri, Coenurus Gaige)*

Adults are 40–100 cm long with a small head about 0.8 mm in diameter, four suckers and a double ring of 22–32 rostellar hooks. The large hooks are between 157 and 177 µm long, while the small hooks are 98- 136 µm in length (Loos-Frank, 2000). The proglottids have irregularly alternating genital pores, numerous testes (284 - 354) in a single anterior field and are lateral and posterior to female organs. The vitelline gland is simple and is situated posteriorly to the ovary, which is bilobed (Khalil, Jones, & Bray, 1994). Mature gravid proglottids are 8–12 mm by 3–4 mm in size with a uterus of 18–26 lateral branches each containing eggs (Khalil et al., 1994). The zoonotic metacestode larval stage (Coenurus cerebralis) is a large fluid-filled cyst up to 5.0 cm or more in diameter with clusters of invaginated scolices (several hundreds) on its internal wall (Taylor et al., 2015).

Life Cycle

The indirect life cycle involves definitive hosts (dogs, foxes, wild canids) and intermediate hosts (cattle, goat, sheep, pig, horse, deer, camel and humans. Infective detached gravid proglottids release eggs discharged with feces from dogs that are ingested by intermediate hosts including humans through contaminated food or water (Craig et al., 2007). Released oncospheres in the small intestine penetrate the intestinal mucosa and blood vessels and travels to the brain or spinal cord through the bloodstream. It takes 2–3 months for the oncospheres to grow into mature coenurus cerebralis cysts (Wu et al., 2012). Cysts can also localize in goats subcutaneous and intramuscular tissues. Infected sheep and goats are lifetime cysts reservoirs (Taylor et al., 2015). The lifecycle is completed when tissues of infected sheep or other livestock are ingested by a definitive host where the parasites in the small intestines develop into adult tapeworms (Varcasia et al., 2009).

Epidemiology

Coenurus cerebralis frequently causes the death of infected animals and can lead to huge economic losses of sheep and goats in many countries within Africa and southeast Asia (Sharma & Chauhan, 2006). The parasite also causes infections in humans leading to serious pathological conditions (Mahadevan et al., 2011; Sharma & Chauhan, 2006). The cysts cause increased intracranial pressure leading to clinical signs such as ataxia, hypermetria, blindness, head deviation, headache, stumbling and paralysis (Abo-Shehada et al., 2002; Bussell et al., 1997).

By virtue of the predilection sites of *Taenia gaigeri* metacestodes in the subcutaneous and muscular tissues and other visceral organs of goats and sheep without harboring in the brain and spinal cord, it has been considered as a distinct species different from *Taenia multiceps* (Schuster et al., 2015). However, this assertion has not been totally accepted. Ahmad Oryan et al. 2015) demonstrated all cerebral and non-cerebral samples obtained from experimental infection were 100% identical to each other and their original source and concluded that *T. gaigeri* may not be a distinct species separate from *T. multiceps*. Similarly, T. skrjabini and *T. gaigeri* are considered synonyms of *Taenia multiceps*.

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Genetic variants in *T. multiceps* have been investigated and reported worldwide. Analysis of 233 partial cytochrome oxidase subunit I nucleotide sections for *T. multiceps* revealed high haplotype and low nucleotide diversities. Fifty-one haplotypes were detected circulating in 6 geographic populations. China, Iran, and Turkey had 2 major haplotypes, whereas Italy and Egypt shared 3. Haplotypes from Greece circulate worldwide and displayed similar gene flow values when compared with the other populations (Abbas et al., 2022).

The pooled global prevalence of 5.8% (95% CI 4.7–6.9%) of *Taenia multiceps* in dogs showed highest prevalence (9.1%, 6.5–11.7%) in Asia followed by Europe (5.1%, 3.3–6.9%), Africa (4.2%, 2.9–7.5%) and the least from the Americas (3.3%, 1.3–5.3%) (Abbas et al., 2022).

e) *Taenia Ovis* (SYN. *Taenia Cervi, Taenia Krabbei, Taenia Hyaenae*)

Adult tapeworms are large, measuring 0.5–1.5 m in length, with rostellum having 24–36 hooks. The strobila has a scalloped edge and is often coiled into a spiral. The mature proglottids have a vaginal sphincter and the ovary and vagina cross each other. The uterus of the gravid proglottids has 20–25 lateral branches on either side (Taylor et al., 2015). Cysts localize in the cardiac and skeletal muscle of sheep, and the evaginated metacestode has four suckers and scolex with approximately 23 hooks (Shi et al., 2016).

Life Cycle

The definitive hosts of this worm are most commonly dogs and sometimes cats and foxes maintaining the adult stage in the small intestines (DeWolf et al., 2013; Jenkins et al., 2014). Gravid proglottids are excreted by the host with over 80,000 eggs per proglottid per day into the environment (Soulsby, 1968). Sheep, goats, and other small ruminants are infected during grazing by eating infective eggs. In the intestine, the oncosphere is released and, through blood circulation, reaches the liver, heart, lungs, spleen, muscles, and other organs, and develops into a cysticercus within three months. These cysts are 6-100 mm in diameter, oval, thin, fluid-filled, and contain a scolex (Soulsby, 1968). The cysts remain viable for only a short period of time, approximately 6 weeks, after which the larva dies, and the cyst becomes calcified and can remain in the tissue for the remainder of the host's life (Rickard & Bell, 1971). The definitive host becomes infected by eating small ruminant viscera with live cysts that grows into adult worm that produces gravid proglottids completing the life cycle (Zheng, 2016).

Epidemiology

Taenia ovis also known as *Cysticercus ovis* or 'sheep measles', occurs throughout much of the world, including New Zealand, Australia, Canada, some African and European countries (Petersen et al., 2008). The first outbreak of *T. ovis* infection in sheep has been reported in Jingtai county, China that affected 58.8% of the animals on the farm (Shi et al., 2016). *Taenia ovis* was also identified from samples collected from 60 wild canids, 57 red foxes (*Vulpes vulpes*) and three wolves (*Canis lupus italicus*) in the Emilia-Romagna region, Italy (Fiocchi et al., 2016).

Infection of small ruminants with *T. ovis* has no clinical signs in infected animals but the presence of viable or calcified cysts in meat and other organs of sheep and goats result in condemnation of the organs or even the entire carcass at post-slaughter inspection (Hajipour et al., 2020).

Meat inspection in the Najafabad slaughterhouse in Isfahan Iran showed *T. ovis* prevalence of 2.9% in sheep and 1.2% in goats, and the prevalence was significantly higher in animals less than one year ($p < 0.0001$), and higher in spring in sheep (8.2%) and goats (2.2%), with an estimated economic loss of US$4167 (Hajipour et al., 2020); and 1.3% in sheep slaughtered in Kermanshah (Hashemnia & Frajani Kish, 2016); and 0.1% in sheep slaughtered in Fars Province (Oryan et al., 2012). Other reported prevalence rates are 3.4% in sheep in Tasmania; and 26% in eastern Ethiopia (Phythian et al., 2018; Sissay et al., 2008); 0.3-3.9% in local goats and 1.7–5.3% in imported goats in Saudi Arabia; and 22% in goats in eastern Ethiopia (Bakhraibah & Alsulami, 2018; Sissay et al., 2008).

f) *Taenia Pisiformis (SYN Cysticercus Pisiformis)*

Adult worms measuring about 2 m long, have a large scolex with narrow strobila and the rostellum with double rows of 34– 48 hooks. Gravid segments have a uterus with 8–14 lateral branches on either side. The cysticercus is a small pea-like transparent cyst and usually occurs in bunches (Taylor et al., 2015)

Life Cycle

Infections in the definitive canine hosts occur when they ingest the internal organs of lagomorphs infected with *T. pisiformis* metacestodes, each of which can develop into an adult worm in the intestines of dogs. After worm maturation, eggs are released into the environment with the detached proglottids in the host's feces. The prepatent period in the dog is around 6–8 weeks. The intermediate hosts (rabbits) become infected when they consume feed and water contaminated with the egg (Foronda et al., 2003; S. Zhang, 2019). Ingested eggs hatch in the small intestine of the intermediate host and penetrate the intestinal wall and pass via the portal system to the liver. Juvenile stages migrate through the liver parenchyma and locate in the abdominal cavity after 2–4 weeks, where they develop into cysts (Cysticercus pisiformis) attached to the wall of the mesentery and omentum (Taylor et al., 2015).

Epidemiology

The worm is distributed worldwide. In China, *T. pisiformis* is a common parasite that infects rabbits. The larvae can cause severe health problems in rabbits, such as liver lesions, digestive disorders, and secondary bacterial infection, resulting in economic losses in the rabbit breeding industry (Zhou et al., 2008). However, due to the absence of effective vaccines and deworming drugs, the parasitic disease is not currently well controlled (Zhang, 2019).

g) *Taenia Saginata* (SYN. *Taeniarhynchus Saginata, Cysticercus Bovis*)

Adult tapeworms are 5–8 m long, with scolex devoid of rostellum and hooks. Mature gravid segments are 16–20 mm long by 4–7 mm wide and the uterus has 15– 35 lateral branches on either side. The mature *Cysticercus bovis* is greyish-white, oval, about 0.5–1.0 by 0.5 cm long, and filled with fluid in which the scolex without rostellum and hooks is usually visible (Taylor et al., 2015).

Life Cycle

The lifecycle is indirect involving humans as definitive host and cattle as intermediate host. Infected humans may discharge millions of eggs daily, either free in feces or as detached proglottid segments each having about 250,000 eggs. Following eggs ingestion by cattle, the liberated oncosphere travels via the blood to striated muscles and takes about 12 weeks to develop into infective metacestode that remains viable for many weeks or years. Both living and dead cysts are often present in the same carcass. Humans become infected by ingesting raw or undercooked beef. Development to patency takes 2–3 months in the small intestine (Taylor et al., 2015).

Epidemiology

Taenia saginata is a cosmopolitan zoonotic tapeworm which is highly endemic in Africa, Asia, Latin America, and some other countries, where humans and domestic animals live together under poor sanitary conditions and where raw/undercooked beef is consumed (Pawlowski & Schultz, 1972). It is still prevalent in Europe and causing economic losses due to condemnation, refrigeration and downgrading of infected bovine carcasses. Its persistence is associated to the low sensitivity of current meat inspection protocols; dissemination and survival of eggs in the environment, and cattle husbandry systems that allow grazing on pastures and drinking from water streams (Dorny & Praet, 2007).

Humans infected with adult tapeworm release the worm eggs into the environment through their feces. Transmission to cattle occurs through the contamination of pasture, fodder or water with eggs which are viable for several weeks or months. Direct transmission of eggs through hand raising of suckling calves by tapeworm carriers has been reported but appears to be rare (Murrell, 2005).

When cattle ingest the worm eggs, the oncospheres hatch and migrate through the blood to skeletal and cardiac muscles where they develop into infective cysticerci to humans in about 10 weeks. Cysts in cattle degenerate within a few months and by 9 months a substantial proportion of them are dead and calcified (Dorny & Praet, 2007; Flisser et al., 2005).

h) *Taenia Serialis* (SYN. *Multiceps Serialis, Coenurus Serialis*)

Adult tapeworm is about 0.5 – 0.7 m long, and the scolex is armed with two rows of 26 – 32 hooks. The gravid uterus has 20 – 25 lateral branches on either side. The metacestode cysts may be 4 – 6 cm in size and the scolices are distributed in packed rows within the cyst (Taylor et al., 2015).

Life Cycle

The indirect life cycle involves dogs and foxes as definitive hosts and rabbits and hares as intermediate hosts. Infection of the rabbits is through ingestion of the worm eggs shed by dogs. The intermediate stage, Coenurus serialis, is found in the rabbit, usually subcutaneously or in the intermuscular connective tissue. Coenurus is a fluid-filled cyst with many invaginated scolices surrounded by a fibrous capsule formed by the intermediate host. The final host is infected by ingesting the metacestode that grows into adult worm in the small intestines (Bowman, 2020; Taylor et al., 2015).

Epidemiology

The Coenurus of *Taenia serialis* is reported to have caused exophthalmos in domestic rabbits in Australia (Bethell & Truszkowska, 2010). Rabbits get infected through eating grass contaminated with worm eggs from dogs, or indirectly from grass contamination through wind, rain, birds, and arthropods acting as vectors dispersing the eggs (Dunsmore & Shaw, 1990). Coenurus of *T. serialis* was also reported in the internal abdominal muscles of wild rabbit carcass found in the Qinghai Tibetan Plateau, China (Zhang et al., 2018).

Coenurosis of *T. serialis* is zoonotic when humans are accidentally infected by ingesting eggs through contaminated water, fruits, or vegetables (Benger et al., 1981). Clinical manifestation of seizures, ataxia and other neurological signs are seen in humans with coenurosis involving the central nervous system. The first proven human coenurosis occurred in a 59-year-old French woman in 1933, followed by another case in a two-year old California boy in 1950 (Zhang et al., 2018); and more recently a Nigerian man with larvae in the subcutaneous tissue of the lower jaw (Tappe et al., 2016).

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i) Taenia Solium (SYN. *Cysticercus Solium*)

Adult worms are 3–8 m long with a rostellum, four radially arranged suckers, and 22–32 hooks arranged in two rows: one row of large hooks measuring 0.14–0.18 mm and one row of smaller hooks measuring 0.11–0.14 mm. It has a narrow neck, and a large strobila measuring 2–4 m and consisting of several hundred proglottids. Mature gravid segments are 10–12 mm long and 5–6 mm wide. The ovary is in the posterior third of the proglottid and has two lobes with an accessory third lobe. The uterus has 7–16 lateral branches on either side with dendritic pattern (García et al., 2003; Taylor et al., 2015).

The cysticercus comes in two forms. The most common 'cellulose' form has a 0.5–1.5 cm long fluid-filled bladder with an invaginated scolex. The 'racemose' form is larger, about 20 cm long with no distinct scolex (Taylor et al., 2015).

Life Cycle

This zoonotic worm has an indirect life cycle involving humans as the only definitive host of the adult worm and acting as intermediate host with pigs for the cysticercus stage. Adult worms release gravid proglottid segments excreted by the host with feces in chains, each having around 40,000 eggs, concentrated over a small area. Eggs could resist destruction in the environment for a relatively prolonged period. After ingestion by a susceptible pig the oncosphere traverses the gut wall into the blood and develops into cysticercus mainly in striated muscles but also in the lungs, liver, kidneys and brain. Humans become infected by ingesting raw or inadequately cooked pork having viable cysticerci which grow into adult tapeworms in the small intestine. The prepatent period is 2 – 3 months (Taylor et al., 2015).

The human final host may also function as an intermediate host and become infected with cysticerci. This is most likely to occur from the accidental ingestion of *T. solium* eggs via unwashed hands or contaminated food. There is also a minor route of autoinfection in a person with an adult tapeworm, from the liberation of oncospheres after the digestion of a gravid segment that has entered the stomach from the duodenum by reverse peristalsis (Taylor et al., 2015).

Epidemiology

Taenia solium taeniosis-cysticercosis infection is prevalent worldwide, but higher in areas where sanitation is a major challenge, and pig production and processing are still extensively managed. Endemicity of this disease in many Latin American, African, and Asian countries is associated to poverty, ignorance, lack of suitable diagnostic and management capacity and appropriate prevention and control strategies (Torgerson & Macpherson, 2011). Significantly higher porcine cysticercosis seroprevalence has been found in communities practicing open defecation than those that do not (Secka et al., 2010). Similarly, higher seropositivity for human cysticercosis are significantly associated with open defecation, older age group and presence of tapeworm carriers (Nguekam et al., 2003; E Sarti et al., 1994; Elsa Sarti et al., 1992; Secka et al., 2011).

Generally, cysticercosis leads to high economic burden linked to pork production losses, high hospitalization costs and reduced productivity for persons with neurocysticercosis (Pawlowski et al., 2005). Increasing numbers of autotochtonus and imported cases of cysticercosis are being reported In Europe, United States of America, Australia, and Kuwait (Pawlowski et al., 2005; Shandera et al., 2002; Zammarchi et al., 2013).

About 2.5 million people are infected with *T. solium*, and there are 50,000 deaths annually due to neurocysticercosis (Pawlowski et al., 2005). Neurocysticercosis is also the leading cause of epilepsy in many low- and medium-income countries, contributing up to 30% of epilepsy cases in endemic areas, with an estimated disease burden of 2–5 million loss in disability-adjusted life years (DALYs) (Torgerson & Macpherson, 2011).

Taenia solium in pork is ranked first food-borne parasite of public health concern during a joint FAO/WHO expert meeting in 2012. Furthermore in 2015, it has been identified as a leading cause of deaths from food borne diseases with a total of 2.8 million disability-adjusted life-years (DALYs). Major contributors of these DALYs are from Africa, South America, and Southeast Asia (WHO, 2016).

j) Taenia Taeniaeformis (Syn. Hydatigera Taeniaeformis, Taenia Crassicollis, Strobilocercus Fasciolaris, Strobilocercus Crassicollis, Broad Neck Tapeworm)

The adult tapeworm measures up to 70 cm long, has a large scolex with a double row of rostellar hooks and no distinct neck region. The neck is broad as the scolex, and segmentation begins immediately behind the scolex. The scolex has a large double circlet of 30 to 40 hooks and four clearly lateral suckers. The large hooks are arranged with double and alternating circlet of hooks measuring 0.36 - 0.44 mm for the anterior crown and 0.25 - 27 mm for the posterior one (Al-Jashamy & Islam, 2007). The uterus has five to nine lateral branches and the posterior proglottids are bell-shaped (Taylor et al., 2015).

The metacestode stage is a strobilocercus (Strobilocercus fasciolaris), which is a small cyst connected with an evaginated scolex by a segmented juvenile strobila (Taylor et al., 2015).

Life Cycle

Eggs from the adult worm are ingested by the intermediate host along contaminated feed or water. Hatched oncosphere develops to metacestode in the liver of rodents and infective to definitive host after about 9 weeks. When a cat ingests rodents with infective metacestode, the scolex attaches to the wall of the intestine and develops into adult tapeworm. Cats begin shedding worm eggs 6 weeks after ingesting the metacestode and could remain infected for up to about 2 years (Taylor et al., 2015).

Epidemiology

This zoonotic parasite has a cosmopolitan geographic distribution. Adults occur in small intestines of definitive hosts which are carnivores of the families Felidae, Canidae and Mustelidae, including domestic cats and dogs (Nichol, et al., 1981). The intermediate hosts are mouse, rat, cat, muskrat, squirrel, rabbit, other rodent, bat, and human harboring the larval stage *Cysticercus fasciolaris* in the liver. They get infected through water or feed materials contaminated with infected cat feces. Sporadic larval infection cases in human were reported from Argentina, Czechoslovakia, Denmark, and Taiwan (Ekanayake et al., 1999; Nichol et al., 1981). Occurrence of *Strobilocercus fasciolaris* in the liver of man found during postmortem has been reported in Europe (Stěrba & Barus, 1976).

III. Clinical Signs

a) Taeniosis

Human taeniosis arising from infection with adult *Taenia asiatica, T. saginata,* and *T. solium* are generally clinically inapparent (Dorny et al., 2005); however, infections with *T. saginata* could sometimes be associated with loss of appetite and diarrhea (Kaufmann, 1996). Anal pruritus, mild abdominal pain, nausea, change in appetite, weakness, weight loss, headache, constipation, dizziness, and diarrhea have also been reported (Silva & Costa-Cruz, 2010).

Dogs, foxes, wild canids, and wild felids infected with adult tapeworms do not manifest clinical signs.

b) Human Cysticercosis

Human cysticercosis are associated with infections caused by larval metacestode forms of *Taenia solium, T. serialis, T. crassiseps,* and *T. multiceps* all affecting the brain leading to neurocysticercosis or coenurosis; whilst *T. taeniaformis, T. serialis,* and *T. crassiseps* are reported to affect the liver, subcutaneous tissue, muscle, eye, and upper limb. People with neurocysticercosis may either show no clinical sign for life or manifest epileptic seizures, headaches with or without accompanying intracranial hypertension, focal neurological symptoms, and cognitive disabilities (Garcia et al., 2014). Coenurosis signs include seizures, ataxia, hypermetria, blindness, head deviation, headache, stumbling and paralysis (Abo-Shehada et al., 2002).

c) Animal Cysticercosis

Animal cysticercosis are associated to the larval metacestode forms of *T. saginata* and *T. hydatigena* in cattle; *T. solium*, *T. asiatica* and *T. hydatigena* in pigs; *T. ovis, T. multiceps* and *T. hydatigena* in sheep and goats; and *T. pisiformis* and *T. serialis* in rabbits. They mostly affect muscle, liver, lungs, omentum, peritoneum, subcutaneous tissue, heart, eye, and brain. Infections are mostly asymptomatic and usually detected during meat inspection after slaughter or during necropsy. *Coenurus cerebralis* causes death in sheep when localized in the brain. Cysticercosis in animals causes economic losses due to condemnation of parts or whole carcasses. Exophthalmos has been reported in rabbit eyes. *Taenia pisiformis* larvae are reported to cause severe health problems, liver lesion, digestive disorders, secondary bacterial infections leading to economic losses in the rabbit industry in China (Zhou et al., 2008).

IV. Lesions

Adult tapeworms are often found in the lumen of the small intestines of the definitive hosts during necropsy.

Cysticerci infections in the intermediate hosts manifest macroscopic lesions which varies depending on the worm species and their predilection sites. For example *Taenia hydategenia* cysticerci in lambs caused hepatic fibrotic foci, open pits in the liver capsule, and presence of the metacestodes within hemorrhagic streaks in the liver parenchyma, abdominal fluid, omentum; and adhesions and ribbons of fibrotic tissue involving the liver and diaphragm or omentum and body wall (Sweatman & Plummer, 1957).

Human neurocysticercosis arising from *T. solium* infection are characterized by presence of viable or degenerative cysts, immune system induced granuloma formation and prelesional edema, and residual calcified cysts in the brain (Garcia et al., 2018).

V. Diagnosis

Adult tapeworm infections could be identified by microscopic examination of stool and anal swab samples using sedimentation and concentration techniques, although it may not directly differentiate the eggs at species level. Expelled gravid proglottids found on beds or in underwear or whole worm with scolex could also be examined microscopically to identify the species. Coprological evaluation is the most traditional and widely used method for diagnosing tapeworm infections, but it is less sensitive and specific.

Taenia eggs are oval to spherical in shape, containing oncospheres covered with a thick wall embryophore, and measuring 34 – 39 x 31 – 38 μm (Kaufmann, 1996). Research is undertaken to advance diagnostic tools for differentiating taenia eggs at species or sub-species level using morphologic criteria and molecular techniques. Detailed morphologic examination of the proglottid segments and eggs could ease species identification. Ziehl-Neelsen staining, egg shape and size have been found to be highly specific and varying sensitivity to differentiate taenia eggs and proglottids of *T. solium* and *T. saginata* (Jimenez et al., 2010).

Porcine and bovine cysticercosis are detected during meat inspection at animal slaughterhouses. Light infections could be difficult to detect by meat inspection, but heavy infections are characterized by macroscopic presence of cysts in the muscles of the carcass and visceral organs.

Serological techniques are developed for evaluating the presence of antibodies against taenia spp. or antigens of taenia spp. in fecal, serum, cerebrospinal fluid, and saliva samples from both humans and animal species. These include enzyme linked immunosorbent assay (ELISA) for copraantigen testing (gold standard), antibody and antigen ELISA, Compliment Fixation test, haemagglutination, latex agglutination, radioimmunoassay, and electroimmuno-transfer blot (EITB) (Flisser et al., 1990; Mayta et al., 2008). ELISA techniques are limited by cross-reactions of different taenia species.

Molecular diagnostic tools are also being developed with greater sensitivity and specificity for identifying taenia species. The widely used techniques include Nested PCR, Multiplex PCR, species specific oligonucleotides multiplex PCR, and RNA sequencing of single tapeworm egg isolates from stool samples (González et al., 2000; Jeon et al., 2009; Sadlowski et al., 2021).

Imaging techniques are also used solely or as a conjunct to clinical, microscopy, serology, and molecular tools for the confirmation of neurocysticercosis or extraneural human and animal cysticercosis cases. The widely used tools include radiography, computerized tomography scan, and magnetic resonance imaging. Histologic examination of biopsy samples is also used for examining cysticerci cysts.

VI. Treatment

The adult tapeworm human and animal carriers are cured by anthelminthic drugs such as albendazole, oxfendazole, niclosamide, and praziquantel. In addition, Yomensan is the drug of choice for treating *T. saginata* infection in man (Pawlowski & Schultz, 1972). The treatment and management of cysticercosis including neurocysticercosis in humans is thoroughly described in the 2005 WHO/FAO/OIE Guidelines on Taeniosis/cysticercosis (Murrell et al., 2005). Depending on the location, severity, and inflammatory reaction to the cysticerci, the groups of medications they listed for use include analgesics, anti-inflammatory, antiepileptic drugs, corticosteroids, praziquantel, albendazole, or surgery interventions.

Porcine cysticercosis is treatable by oxfendazole. Oxfendazole is shown to have 100% efficacy in curing porcine cysticercosis for a duration of 3 months after its administration (Gonzales et al., 2001).

Heavily infected bovine and porcine carcasses are usually condemned, buried, or incinerated when detected during meat inspection. The lightly infected carcasses could be treated through freezing, boiling, or pickling in common salt (Murrell et al., 2005).

VII. Control and Prevention

The goal of controlling and preventing taenia infections in humans and animals is to break the cycle of transmission between the intermediate and final host through various interventions that significantly reduce the risk of acquiring taeniosis and cysticercosis. Although *Taenia solium, T. saginata, T. serialis, T. crassiseps, T. taeniaformis,* and *T. multiceps* are all zoonotic parasites affecting humans, *T. solium* is the most important species receiving global attention due to its greater negative impact on human health than the other taenia species.

General intervention strategies for the control and prevention of taenia infections as described in the WHO/FAO/OIE Guidelines on Taeniosis/cysticercosis (Murrell et al., 2005) are as follows:

1. Meat inspection to prevent human infection. Inspection of cattle, sheep, goats and pig carcasses at abattoirs helps identify metacestode infected carcasses that could be condemned and destroyed or treated thus eliminating the risk of infecting humans. Limitations to this intervention are the low sensitivity in detecting mildly infected carcasses, absence of meat inspection in many rural endemic areas, and the sales and consumption of meat that has not passed through official meat inspection processes.
2. Control of cattle and pig marketing. The marketing of infected life animals and carcasses by farmers and traders could potentially lead to transmission of the disease through maintenance of its lifecycle. Central and local governments need to develop strategies, regulations, penalties, and incentives for controlling the marketing of cattle and pigs to ensure reduced risk of disease transmission in disease endemic communities. Enforcing marketing control strategies remains a challenge to overcome the implementation of control programs.
3. Improve farm management to prevent cattle and pigs accessing human feces. Raising animals in confined areas and preventing them access to human feces would greatly reduce the risk of ingesting taenia eggs found in human feces. Sustained implementation in poor rural endemic communities is still a big challenge to overcome.

Sustained implementation in poor rural endemic communities is still a big challenge to overcome.

4. Vaccination of pigs against *T. solium* infection. Injectable TSOL18 (cysvax™) vaccine has been licensed for use in pigs by India since 2016. Concurrent administration of oxfendazole treatment and TSOL 18 vaccination has been found highly effective in reducing porcine cysticercosis in Uganda (Nsadha et al., 2021), Tanzania (Kabululu et al., 2020), Cameroon (Lightowlers & Donadeu, 2017), and Nepal (Poudel et al., 2019). Orally administered vaccines (S3Pvac and S3Pvac-phage) have also proven effective in reducing porcine cysticercosis (Morales et al., 2011). When oral vaccines become operationalize, it will be much easier to administer thus reduces costs and ease implementation of vaccination programs.
5. Screening and treatment of farm workers and tapeworm carriers at endemic community settlements. This intervention requires a one-health approach involving veterinary and medical professionals working together to control a zoonotic parasite. Administration of niclosamide or praziquantel is effective in treating human tapeworm carriers. This would reduce the transmission of taenia eggs into the environment that could eventually be ingested by cattle, pigs and humans leading to cysticercosis. The major challenge in underdeveloped rural communities is detecting tapeworm carriers as no major clinical signs are manifested by persons with taeniosis and health posts are ill equipped to diagnose taenia infections in humans. Infection in pigs may also go unnoticed in the absence of official meat inspection or disease surveillance programs.
6. Improved sanitation. Open air defecation by humans in areas where sanitary facilities are not available poses risk to roaming pigs and cattle for contracting cysticercosis. Provision of latrines in rural areas and improved sewage system in urban areas would decrease exposure to human feces which is a risk factor for cysticercosis transmission in cattle and pigs.
7. Proper treatment of sewage and sludge to kill taenia eggs. The presence of viable taenia eggs in sewage and sludge is still a risk to animals and humans when pasture, feed and drinking water for animals are contaminated as well as human food and water becoming contaminated.
8. Health education. Educating people at high risk of contracting taenia infection would facilitate implementation of control interventions. Public awareness of taenia lifecycle, disease manifestations, and the negative economic impact on livestock production, high hospital cost and losses in disability-adjusted life years (DALYs) associated with neurocysticercosis, could trigger attitudinal changes that could break the disease transmission in highly endemic areas.

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