

Helminths

Oto Melter

- Definition in medical microbiology (parasitology): Worms which are parasitic to humans
- Group (class): cestodes (tapeworms), nematodes (roundworms), trematodes (flukes)
- 70% of world's population is infected (more in poor sanitary conditions, endemic regions)

TREMATODA

Class of flatworms that comprises those flukes that are internal parasites

Schistosoma species (q.76)

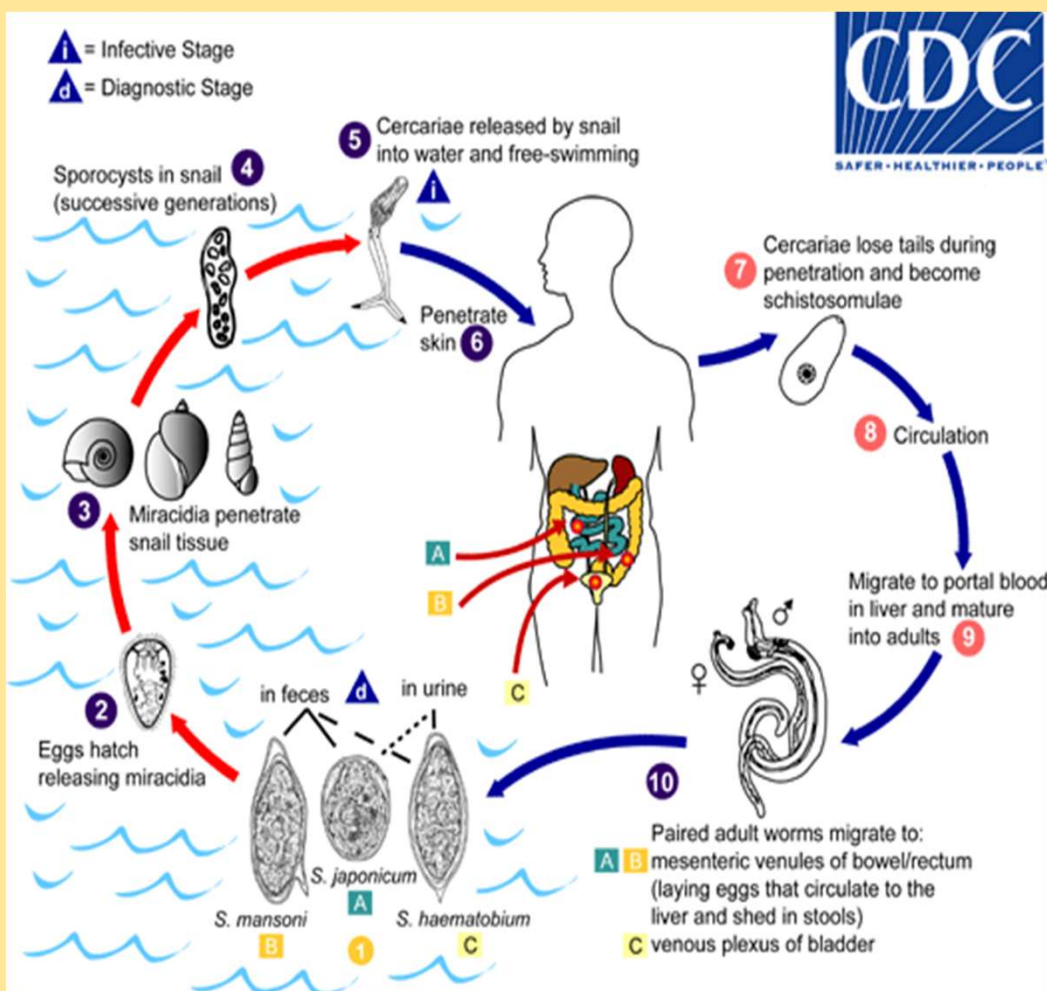
- **AGENT: Trematoda (flukes** – small cca 1 cm leaf like worms, human infections are mainly caused by ***Schistosoma mansoni*, *S. haematobium*, or *S. japonicum*, intermediate hosts:** freshwater snails (tropics and subtropics)

(*Schistosoma mansoni* - primarily across sub-Saharan Africa and some South American countries (Brazil, Venezuela, Suriname) and the Caribbean, with sporadic reports in the Arabian Peninsula., *S. haematobium* is found in Africa and pockets of the Middle East., *S. japonicum* is found in China, the Philippines, and Sulawesi. Despite its name, it has long been eliminated from Japan. The other, less common human-infecting species have relatively restricted geographic ranges. *S. mekongi* occurs focally in parts of Cambodia and Laos. *S. intercalatum* has only been found in the Democratic Republic of the Congo; *S. guineensis* is found in West Africa. Instances of infections with hybrid/introgressed *Schistosoma* (*S. haematobium* x *S. bovis*, x *S. curassoni*, x *S. mattheei*) have occurred in Corsica, France, and some West African countries.)

- 200 milion people are infected, 200,000 per year die)
- **INFECTION: Schistosoma** (cercariae – 1st larval stasium) **penetrate the skin of persons** who come in contact with contaminated freshwater, typically when swimming, bathing, or washing. Over several weeks, the **parasites migrate through host tissue and develop into adult worms inside the blood vessels of the body**. Once mature, the worms mate and females produce eggs. Some of these **eggs travel** to the **bladder** or **intestine** and are **passed** into the **urine** or **stool**.

See also: https://www.youtube.com/watch?v=Ww3DfF_0qmQ

Schistosoma cycle (q.76)



Schistosoma eggs are eliminated with feces or urine, depending on species ¹. Under appropriate conditions the eggs hatch and release miracidia ², which swim and penetrate specific snail intermediate hosts ³. The stages in the snail include two generations of sporocysts ⁴ and the production of cercariae ⁵. Upon release from the snail, the infective cercariae swim, penetrate the skin of the human host ⁶, and shed their forked tails, becoming schistosomulae ⁷. The schistosomulae migrate via venous circulation to lungs, then to the heart, and then develop in the liver, exiting the liver via the portal vein system when mature, ^{8 9}. Male and female adult worms copulate and reside in the mesenteric venules, the location of which varies by species (with some exceptions) ¹⁰. For instance, *S. japonicum* is more frequently found in the superior mesenteric veins draining the small intestine **A**, and *S. mansoni* occurs more often in the inferior mesenteric veins draining the large intestine **B**. However, both species can occupy either location and are capable of moving between sites. *S. intercalatum* and *S. guineensis* also inhabit the inferior mesenteric plexus but lower in the bowel than *S. mansoni*. *S. haematobium* most often inhabits in the vesicular and pelvic venous plexus of the bladder **C**, but it can also be found in the rectal venules. The females (size ranges from 7–28 mm, depending on species) deposit eggs in the small venules of the portal and perivesical systems. The eggs are moved progressively toward the lumen of the intestine (*S. mansoni*, *S. japonicum*, *S. mekongi*, *S. intercalatum/guineensis*) and of the bladder and ureters (*S. haematobium*), and are eliminated with feces or urine, respectively ¹.

Schistosoma diagnosis (q.76)

- **Stool or urine samples** can be examined **microscopically for parasite eggs** (stool for *S. mansoni* or *S. japonicum* eggs and urine for *S. haematobium* eggs).
- **Schistosoma PCR - outperform standard microscopy on stools and urine and could be part of reference methods** combined with WB-based **serology**, which remains a gold standard for initial



Fig. Eggs of *S. mansoni* in an unstained wet mount (CDC Atlanta), size 114 – 180 μm x 40 – 80.

Schistosoma infections (q.76)

- **SYMPTOMS** – cercarial dermatitis (swimmer's itch) could be in the beginning – **penetration of skin by cercariae**; are caused not by the worms themselves but **by the body's relater – symptoms action to the eggs**. Eggs shed by the adult worms that do not pass out of the body can become lodged in the **intestine or bladder**, causing **inflammation or scarring**. Children who are repeatedly infected can develop **anemia** and **malnutrition**. After years of infection, the parasite **can also damage the liver, intestine, spleen, lungs, and bladder**.

Schistosoma - treatment and prevention (q.76)

- **TREATMENT** - Safe and effective medication is available for treatment of both urinary and intestinal schistosomiasis. **Praziquantel** (The drug further causes vacuolization and **disintegration of the schistosome tegument, spasms and paralysis of the worms' muscles**. This paralysis is accompanied - and probably caused - by a rapid Ca^{2+} influx inside the schistosome), a prescription medication, is taken for 1-2 days to treat infections caused by all *Schistosoma* species.
- **PREVENTION** – **control of the reservoir hosts (freshwater snails)**, reduces contamination of water with feces and urine

CESTODA

Class of parasitic flatworms that comprises the tapeworms

see also: <https://www.youtube.com/watch?v=ZdVAxUfBofw>

Taenia species and infections (q.77)

- **AGENT: Tapeworms (cestodes** – large, few meters **ribbon-like worms**, human infections are mainly caused by ***Taenia saginata*** (intermediate host: **cattle**), ***Taenia solium*** (intermediate host: **pig**)
- **INFECTIONS: Humans are the only hosts for these Taenia tapeworms.** Humans pass the tapeworm **segments (proglotids)** and/or **eggs in feces and contaminate the soil** in areas where sanitation is poor. Taenia eggs can survive in a moist environment and remain infective for days to months. **Cows and pigs become infected after feeding** in areas that are contaminated with *Taenia* eggs from human feces.

see also: https://www.youtube.com/watch?v=5_vAuhhmuKw

Taenia infections (q.77)

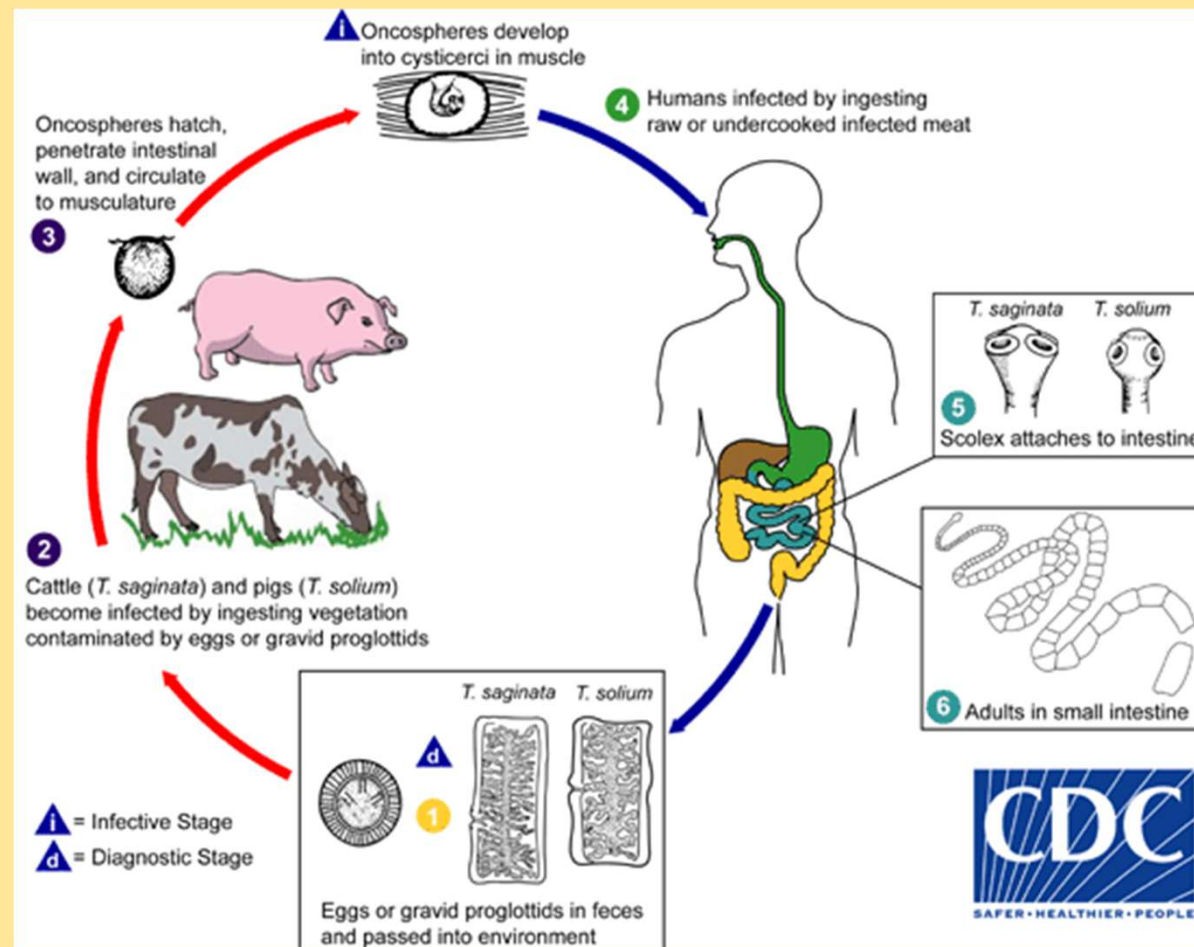
INFECTIONS: Once inside the cow or pig, the *Taenia* eggs hatch in the animal's intestine and migrate to striated muscle to develop into **cysticerci**, causing a disease known as cysticercosis in animals. Cysticerci can survive for several years in animal muscle. **Humans become infected** with tapeworms when they **eat raw or undercooked beef or pork containing infective cysticerci**. Once inside humans, *Taenia* cysticerci **migrate to the small intestine and mature to adult tapeworms**, which produce segments and eggs that are passed in feces.

Taenia infections (q.77)

INFECTIONS: Most people with tapeworm infections have **no symptoms or mild symptoms**. Patients with *T. saginata* taeniasis often experience more symptoms than those with *T. solium* because the *T. saginata* tapeworm is larger in size (up to 10 m) than *T. solium* (usually 3 m). Tapeworms **can cause digestive problems** including abdominal pain, loss of appetite, weight loss, and upset stomach. The most visible symptom of taeniasis is the active passing of **proglottids (tapeworm segments)** through the anus and **in the feces**. In rare cases, tapeworm segments become lodged in the appendix, or the bile and pancreatic ducts.

Infection with *T. solium* tapeworms can result in human cysticercosis, which can be a very serious disease that can cause seizures and muscle or eye damage (see also slide Human cysticercosis)!!!

Taenia cycle (q.77)



Taenia diagnosis (q.77)

- Diagnosis of *Taenia* tapeworm infections is made by **examination of stool** samples; individuals should also be asked if they have passed tapeworm segments.



Fig. Scolex of *T. solium* (on the left, in the middle) and scolex of *T. saginata* on the right (CDC Atlanta).

Taenia gold standard diagnosis microscopy, PCR (q.77)

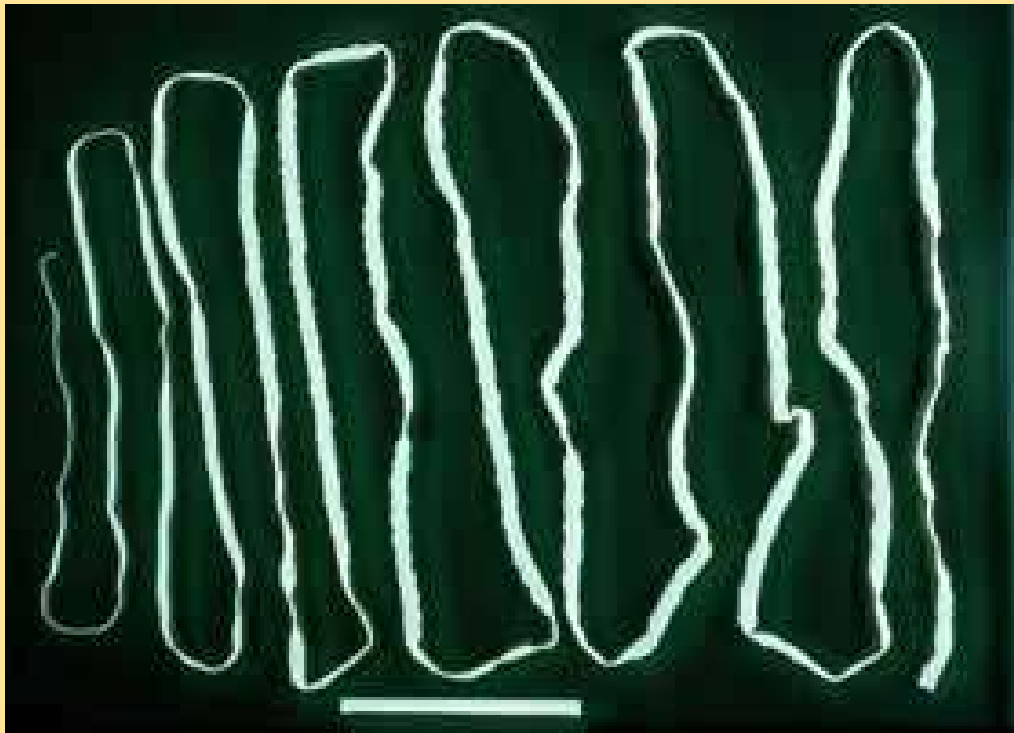


Fig. *Taenia saginata* adult worm. The adult in this image is approximately 4 meters in length (CDC Atlanta).



Fig. Mature proglottid of *T. saginata*, stained with carmine. Note the number of primary uterine branches (>12)(CDC Atlanta).

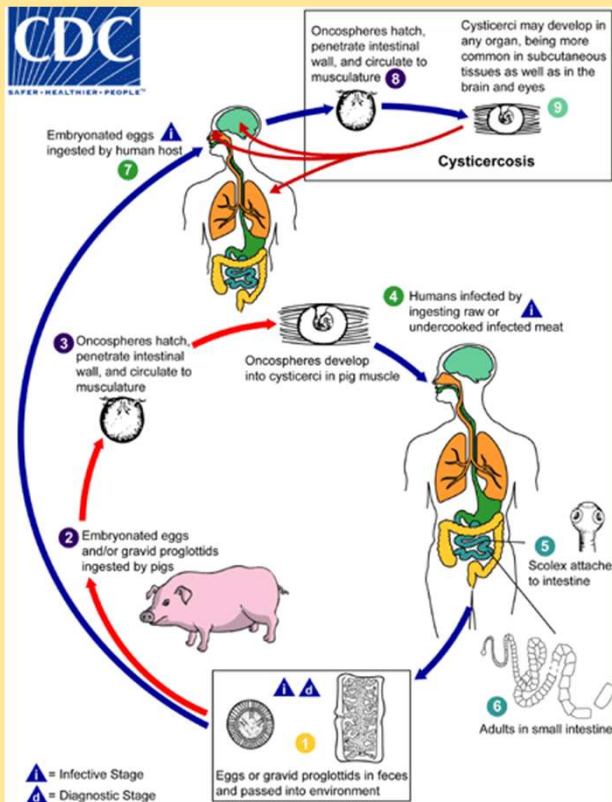


Fig. Microscopy of *Taenia* sp. egg in unstained wet mounts (30-35 um, CDC Atlanta).

Taenia - treatment and prevention (q.77)

- **TREATMENT** - Treatment is available after accurate diagnosis. Your doctor will provide prescription medication, either **praziquantel** or **niclosamide** (killing tapeworms on contact. Adult worms (but not eggs) are rapidly killed, presumably due to uncoupling of oxidative phosphorylation or stimulation of ATPase activity), which is taken by mouth. The medication is also available in a children's dosage.
- **PREVENTION** – **thermal processing** of meat and **meat products/meal** (cooking or freezing)

Human Cysticercosis = tissue tapeworm (q.78)



Diagnosis – serology

See also:
<https://www.youtube.com/watch?v=Y7pvUtCNeWE>

!!! Caused by ingestion of *Taenia solium* eggs from contaminated water or vegetables!!!

Treatment – albendazol (inhibitory effect on tubulin polymerization which results in the loss of cytoplasmic microtubules and degenerative alterations in the tegument and intestinal cells of the worm by diminishing its energy production, ultimately leading to immobilization and death of the parasite), **treatment of neurocysticercosis** depends on the clinical manifestations and the location, number, size, and stage of cysticerci. Anthelmintic chemotherapy for symptomatic neurocysticercosis is almost never a medical emergency. The focus of initial therapy is control of seizures, edema, intracranial hypertension, or hydrocephalus, when one of these conditions is present. Under certain circumstances, a ventricular shunt or other **neurosurgical procedure may be indicated**.

Diphyllobothrium latum (q.77)

The cestode *Diphyllobothrium latum* (the fish or broad tapeworm), **the largest human tapeworm** (over 10 m). Several other *Diphyllobothrium* species have been reported to infect humans

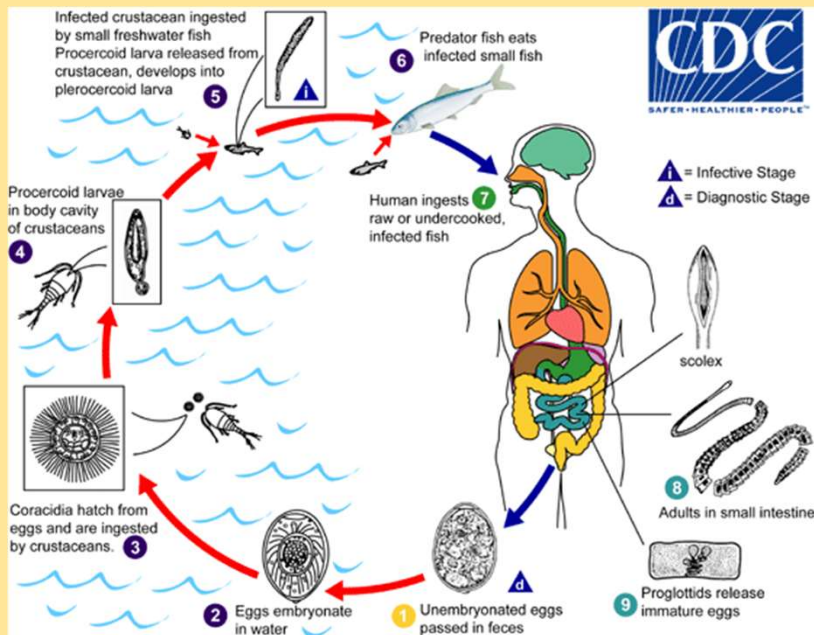


Diagram: 1.st intermediate host – freshwater crustacean
2.nd intermediate host – fish, **definite host** – human/mammals, **Diagnosis** – eggs in stool, PCR, **Treatment** – praziquantel, niclosamide



Fig. *Diphyllobothrium latum* proglottid



Fig. Eggs of *D. latum* in an unstained wet mount of stool. Note the opercula are open.

See also: <https://www.youtube.com/watch?v=qQhaO1pWztw>

Echinococcus species (q.78)

- **AGENT:** Human **echinococcosis** (hydatidosis, or hydatid disease) is caused by the larval stages of cestodes (tapeworms) of the genus *Echinococcus*. *Echinococcus granulosus* causes **cystic echinococcosis**, the form most frequently encountered; *E. multilocularis* causes **alveolar echinococcosis**

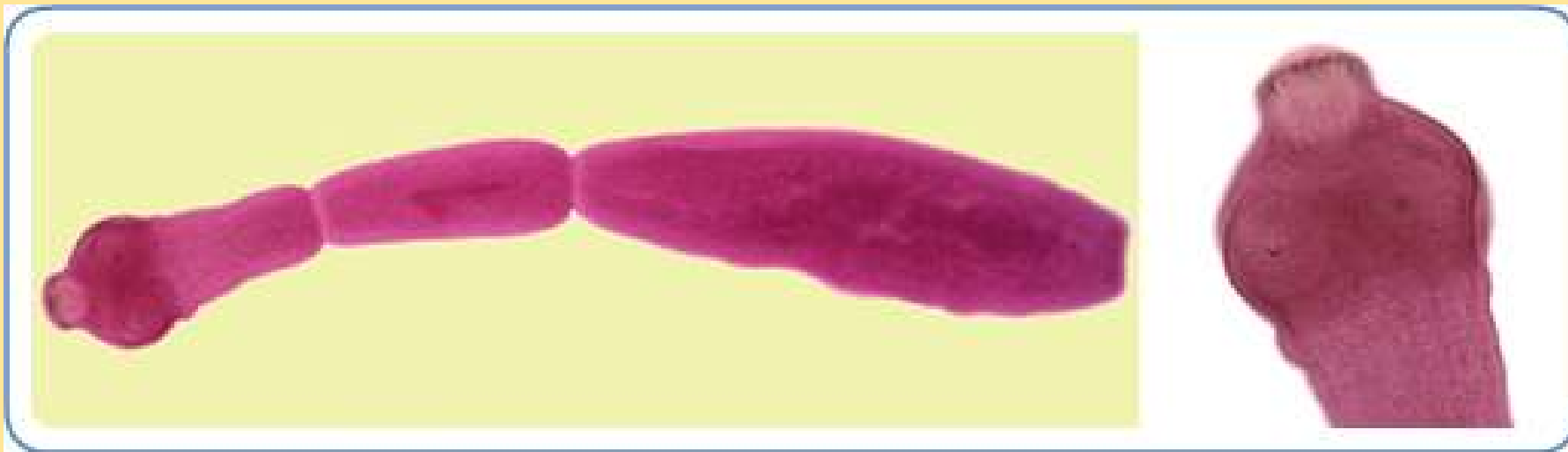
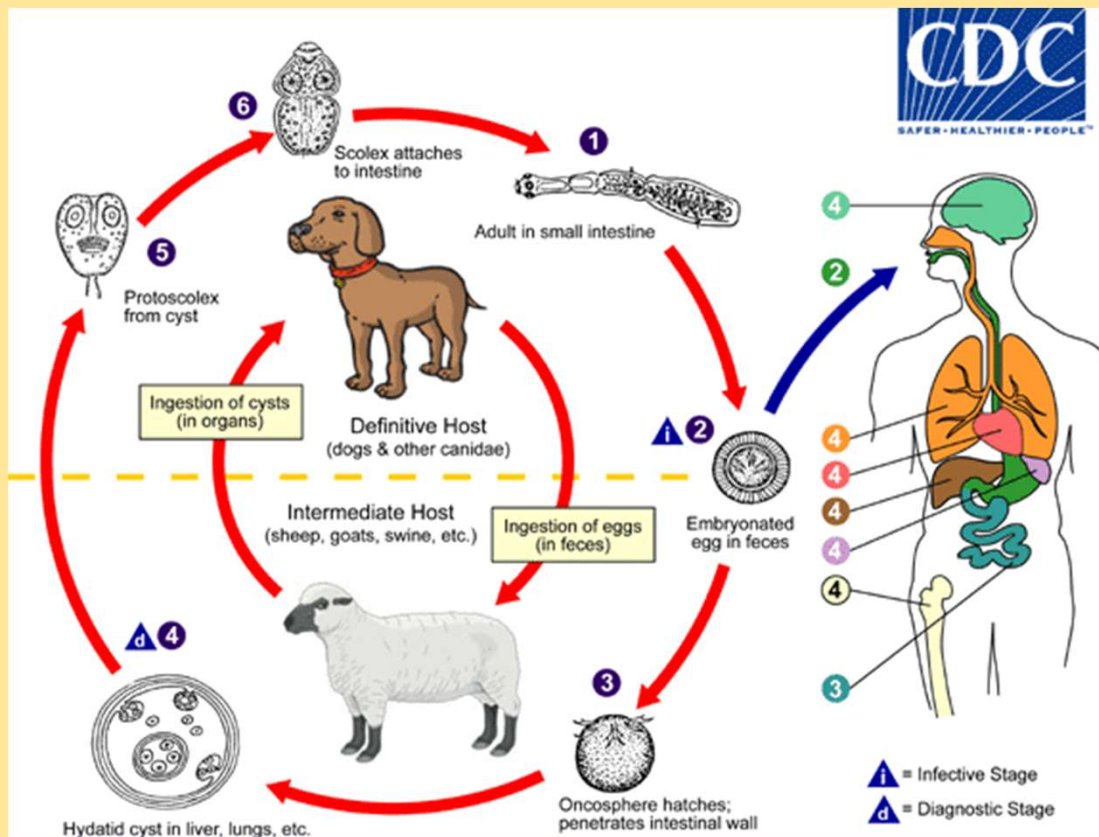


Fig.
Echinococcus granulosus – adult worm, size only 3-6 mm!!!

Echinococcus cycle (q.78)



The adult *Echinococcus granulosus* (2—7 mm long) (1) resides in the **small intestine of the definitive host**. Gravid proglottids release **eggs** (2) image that are passed in the **feces**, and are **immediately infectious**. After ingestion by a suitable **intermediate host**, eggs hatch in the small intestine and release six-hooked **oncospheres** (3) that **penetrate the intestinal wall** and migrate through the **circulatory system** into various **organs**, especially the liver and lungs. In these organs, the oncosphere develops into a thick-walled **hydatid cyst** (4) image that enlarges gradually, producing protoscolices and **daughter cysts that fill the cyst interior**. The **definitive host** becomes infected by **ingesting the cyst-containing organs of the infected intermediate host**. After ingestion, the protoscolices (5) image evaginate, **attach to the intestinal mucosa** (6), and develop into **adult stages** image in 32 to 80 days.

Humans are aberrant **intermediate** hosts, and become infected by **ingesting eggs** (2). **Oncospheres** are released in the **intestine** (3), and **hydatid cysts** develop in a **variety of organs** (4). If cysts rupture, the liberated protoscolices may create secondary cysts in other sites within the body (secondary echinococcosis).

more information: <https://www.youtube.com/watch?v=1pUF6lv7p60>

Echinococcus diagnosis (q.78)

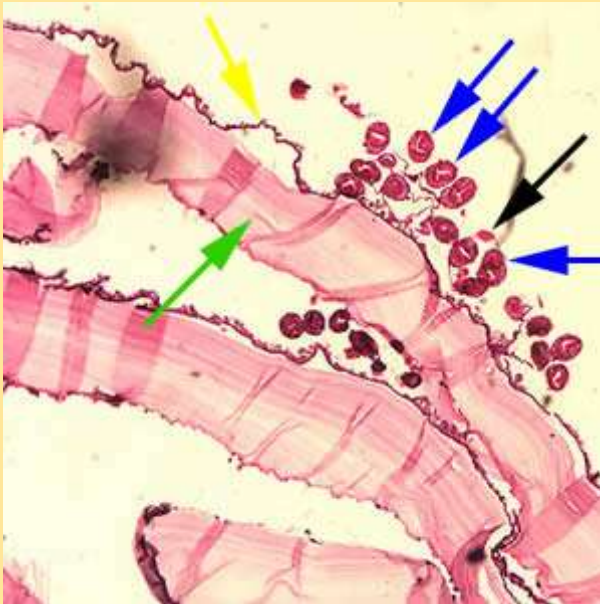


Fig. Cross-section of an *E. granulosus* cyst, stained with H&E. The cyst wall is composed of an acellular laminated external layer (green arrow)(CDC Atlanta).

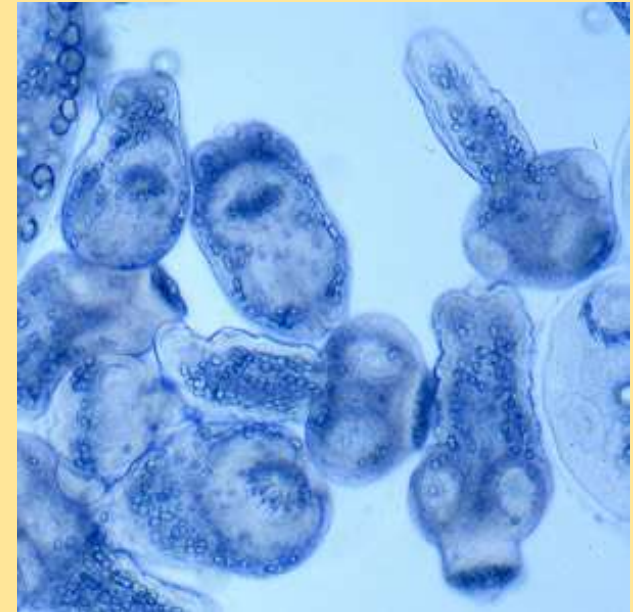


Fig. *Protoscoleces* liberated from a hydatid cyst.

Diagnosis in humans – scan of affected organ, detection of specific IgM and IgG (non specific eosinophilia and increased) IgE

Echinococcus infections (q.78)

- **SYMPTOMS** - **Cystic echinococcosis (CE)**, also known as **hydatid disease**, is caused by infection with the larval stage of ***Echinococcus granulosus***, a ~2-7 millimeter long tapeworm found in dogs (definitive host) and sheep, cattle, goats, and pigs (intermediate hosts). Although **most infections in humans are asymptomatic**, CE causes **harmful, slowly enlarging cysts** in the **liver, lungs**, and **other organs** that often grow **unnoticed and neglected for years**.

Echinococcus infections (q.78)

- **SYMPTOMS - Alveolar echinococcosis (AE)** disease is caused by infection with the larval stage of *Echinococcus multilocularis*, a **~1-4 millimeter long tapeworm** found in foxes, coyotes, and dogs (definitive hosts). Small rodents are intermediate hosts for *E. multilocularis*. Although cases of AE in animals in endemic areas are relatively common, human cases are rare. AE poses a **much greater health threat to people than CE**, causing **parasitic tumors that can form in the liver, lungs, brain, and other organs**. If left untreated, AE can be fatal.

Echinococcus treatment and prevention (q.78)

- **TREATMENT** – praziquantel, albendazol, mebendazole (could be combined be careful **surgical removal of the cysts**)
- **PREVENTION** – deworming of dogs, slaughter inspection of livestock

NEMATODA (Roundworms)

Large phylum of worms with slender, unsegmented, cylindrical bodies

see also: <https://www.youtube.com/watch?v=yzHc-WcJ1WI>

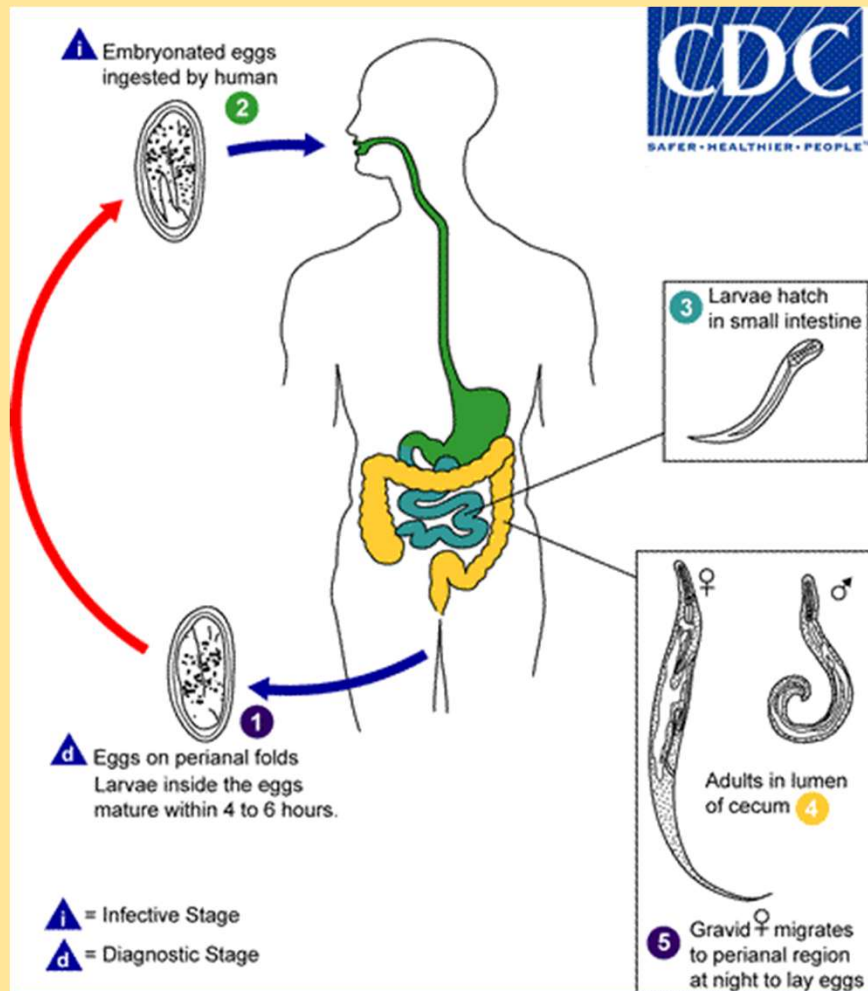
Enterobius vermicularis (q.79)

- **AGENT:** The **nematode (roundworm)** *Enterobius vermicularis* (previously *Oxyuris vermicularis*) also called human **pinworm**. (Adult females: 8 to **13 mm**, adult male: 2 to 5 mm.) **Humans** are considered to be **the only hosts** of *E. vermicularis*.

Enterobious vermicularis infections (q.79)

- **SYMPTOMS** - The most common clinical manifestation of a pinworm infection is an **itchy anal region**. When the infection is heavy, there can be a **secondary bacterial infection** due to the irritation and scratching of the anal area. Often the patient will complain of teeth grinding, and insomnia due to disturbed sleep, or even abdominal pain or **appendicitis**. Infection of the female genital tract has been well reported.

Enterobious vermicularis cycle (q.79)



1: **Eggs** are deposited on perianal folds.

2: **Self-infection** occurs by transferring infective eggs to the mouth with hands that have scratched the perianal area.

3: **Person-to-person transmission** can also occur through handling of contaminated clothes or bed linens. Enterobiasis may also be acquired through surfaces in the environment that are contaminated with pinworm eggs (e.g., curtains, carpeting). Some small number of eggs **may** become **airborne and inhaled**. These would be **swallowed** and follow the same development as ingested eggs. Following ingestion of infective eggs, the larvae hatch in the small intestine...

4: and the **adults** establish themselves in the **colon**.

5: The time interval from ingestion of infective eggs to oviposition by the adult females is about one month. The life span of the adults is about two months. **Gravid females migrate nocturnally outside the anus and oviposit** while crawling **on the skin of the perianal area**. The larvae contained inside the eggs develop (the eggs become infective) in 4 to 6 hours under optimal conditions.

1: **Retroinfection**, or the migration of newly hatched larvae from the anal skin back into the rectum, may occur but the frequency with which this happens is unknown.

Enterobius vermicularis diagnosis (q.79)



Fig. Adult males of *Enterobius vermicularis* measure up to 2.5 mm long by 0.1-0.2 mm wide; adult females measure 8-13 mm long by 0.3-0.5 mm wide (CDC Atlanta).



Fig. Eggs of *E. vermicularis* in a wet mount (size around 50 um)

Diagnosis - Microscopic
identification of **eggs collected in the perianal area** is the method of choice for diagnosing enterobiasis. This must be done in the morning, before defecation and washing, by **pressing transparent adhesive tape** (“Scotch test”, cellulose-tape slide test) on the perianal skin and then examining the tape placed on a slide. Alternative method – material stool, **Enterobius specific PCR**

E. vermicularis treatment and prevention (q.79)

- **TREATMENT** – either **mebendazole** or **albendazole**
- **PREVENTION** – **washing hands** with soap and warm water after using the toilet, changing diapers, and before handling food is the most successful way to prevent pinworm infection. In order to **stop the spread of pinworm and possible re-infection**, people who are infected should bathe every morning to help remove a large amount of the eggs on the skin. Showering is a better method than taking a bath, because showering avoids potentially contaminating the bath water with pinworm eggs. Infected people should not co-bathe with others during their time of infection. In institutions, **day care centers**, and schools, control of pinworm can be difficult, but mass drug administration during an outbreak can be successful. **Teach children the importance of washing hands to prevent infection.**

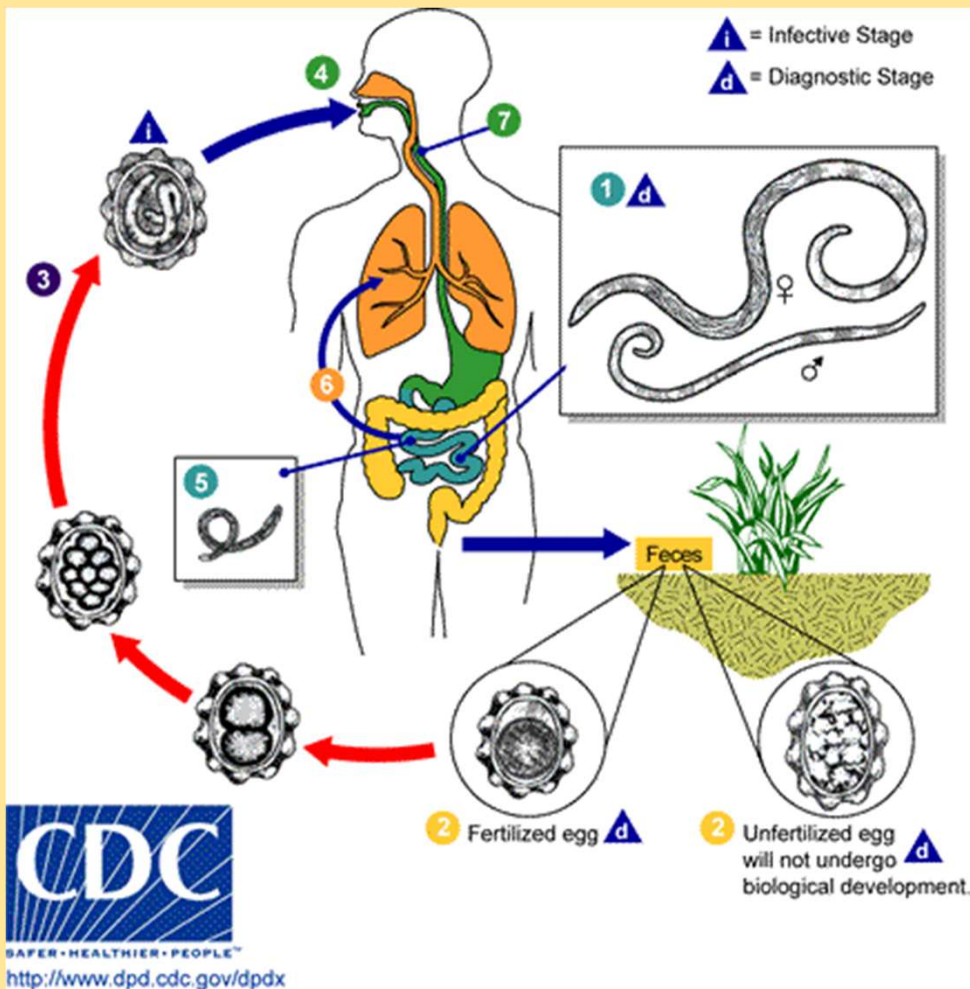
Ascaris lumbricoides infections (q.79)

- **AGENT:** *Ascaris lumbricoides* is **the largest nematode** (roundworm) parasitizing the human intestine. (Adult females: 20 to 35 cm; adult male: 15 to 30 cm.)

SYMPTOMS - people infected with *Ascaris* **often show no symptoms**. If symptoms do occur they can be light and include **abdominal discomfort**. Heavy infections can cause **intestinal blockage** and **impair growth in children**. Other symptoms such as **cough** are **due to migration of the worms** through the body. Ascariasis is treatable with medication prescribed by health care provider.

See also - <https://www.youtube.com/watch?v=uzwcCKJgLkE>

Ascaris lumbricoides (q.79)



Adult worms (1) live in the lumen of the **small intestine**. A female may produce approximately 200,000 eggs per day, which are passed with the feces (2). Unfertilized **eggs** may be ingested but are not infective. **Larvae** develop to infectivity within fertile eggs after 18 days to several weeks (3), depending on the environmental conditions (optimum: moist, warm, shaded soil). After infective eggs are swallowed (4), the larvae hatch (5), **invade the intestinal mucosa**, and are **carried via the portal**, then **systemic circulation** to the **lungs** (6). The larvae mature further in the lungs (10 to 14 days), penetrate the alveolar walls, ascend the bronchial tree to the **throat**, and are **swallowed** (7). Upon reaching the small intestine, they develop into adult worms. Between 2 and 3 months are required from ingestion of the infective eggs to oviposition by the adult female. Adult worms can live 1 to 2 years.

Ascaris lumbricoides diagnosis (q.79)



Fig. Female worm (up to 30 cm, male up to 20 cm)

Diagnosis - Microscopic identification of **eggs collected from stool sample** (alternatively **specific PCR**).

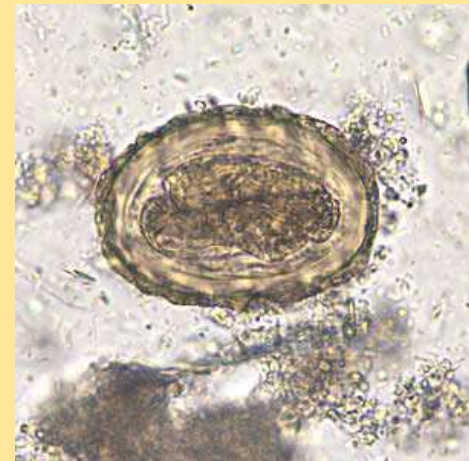


Fig. Fertilized egg of *A. lumbricoides* in an unstained wet mount of stool, 200x magnification. A larva is visible in the egg.

A. lumbricoides treatment and prevention (q.79)

TREATMENT – Anthelmintic medications (drugs that rid the body of parasitic worms), such as **albendazole** and **mebendazole**, are the drugs of choice for treatment of *Ascaris* infections, regardless of the species of worm. Infections are generally treated for **1-3 days**. The drugs are effective and appear to have few side effects.

PREVENTION – Transmission of *Ascaris lumbricoides* infection to others in a community setting can be prevented by:

Not defecating outdoors.

Effective sewage disposal systems.

Other enteric helminths (q.79)

- **Nematodes** - Whipworm (*Trichuris trichiura*), and hookworm (*Ancylostoma duodenale* and *Necator americanus*)
- **Soil-transmitted helminths** refer to the intestinal worms infecting humans that are transmitted through contaminated soil
- found mainly in areas with **warm and moist climates** where sanitation and hygiene are poor, including in temperate zones during warmer months
- **Disease – GIT infection, diagnosis – egg microscopy, treatment - albendazole and mebendazole, prevention – hand washing, wash and cook foods properly**

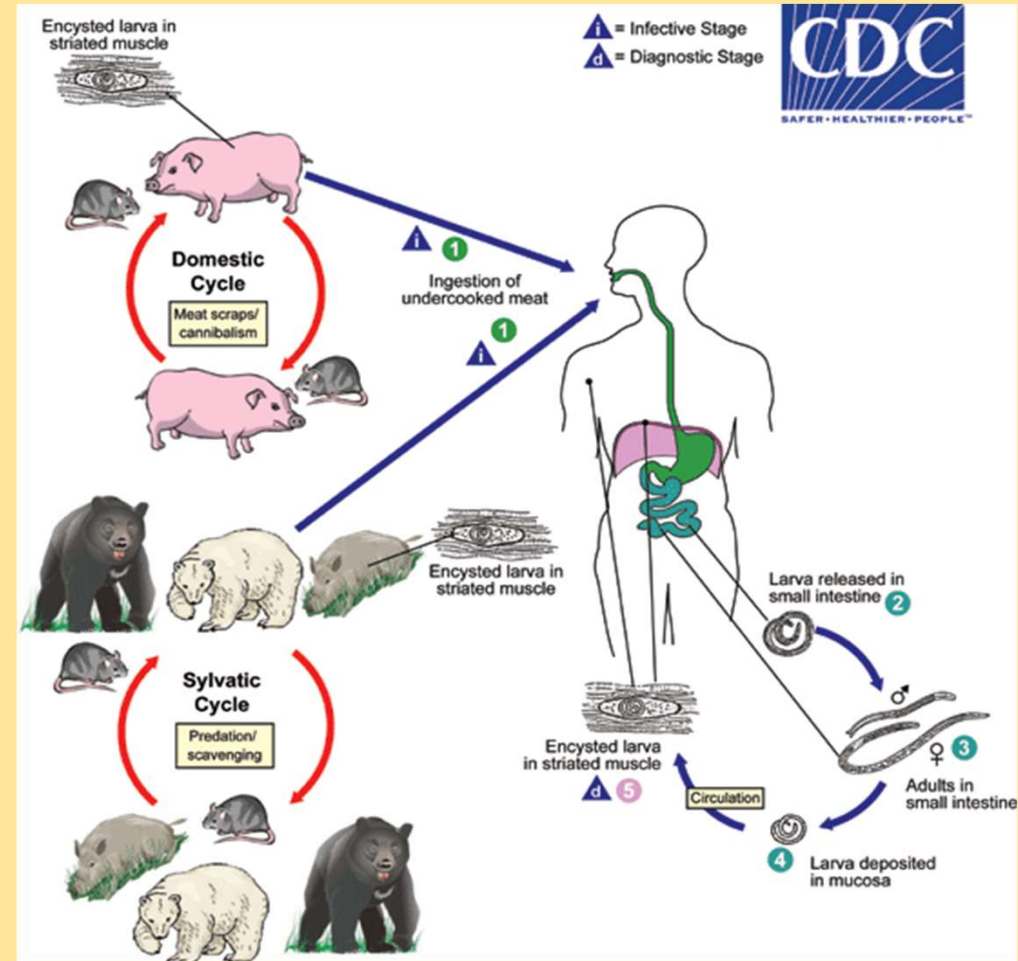
See also <https://www.youtube.com/watch?v=T13clxaG4CU>

Trichinella spiralis (q.80)

- **AGENT:** Trichinellosis (trichinosis) is caused by nematodes (roundworms) of the genus *Trichinella spiralis*.

Trichinellosis is caused by the ingestion of undercooked meat containing **encysted larvae** (except for *T. pseudospiralis* and *T. papuae*, which do not encyst) of *Trichinella* species (1). After exposure to gastric acid and pepsin, the larvae are **released from the cysts** (2) and **invade the small bowel mucosa** where they develop into **adult worms** (3). Females are 2.2 mm in length; males 1.2 mm. The life span in the small bowel is about four weeks. After 1 week, the **females release larvae** (4) that migrate to striated muscles where they encyst (5). **Diagnosis** is usually made based on **clinical symptoms**, and is confirmed by **serology** or identification of encysted or non-encysted larvae in biopsy or autopsy specimens.

see also: <https://www.youtube.com/watch?v=t49SGVEoHGY>,
<https://www.youtube.com/watch?v=5PQXm1t-hvQ>



Trichinella spirallis(q.80)

The first symptoms of trichinellosis are **gastrointestinal**, usually occurring 1-2 days after a person consumes **raw or undercooked meat** from a ***Trichinella*-infected animal**. These symptoms include **nausea, diarrhea, vomiting, abdominal pain**.

The classic trichinellosis symptoms often occur **within 2 weeks** after eating contaminated meat, and can **last up to 8 weeks**: **muscle pain, fever**, swelling of the face, particularly the eyes, weakness or fatigue, headache, chills, itchy skin or rash, cough, diarrhea, constipation.

Trichinella spirallis(q.80)

Symptoms may range **from very mild to severe** and relate to the number of infectious worms consumed in the meat. **Many mild cases** of trichinellosis are **never specifically diagnosed** because they are assumed to be the **flu** or other common illnesses. Furthermore, many people with *Trichinella* infection do not experience any symptoms at all.

If the **infection is heavy**, persons may have **trouble coordinating movements**, and have **heart and breathing problems**. Although rare, **death can occur in severe cases**. For mild to moderate infections, most symptoms go away within a few months.

Trichinella spirallis diagnosis (q.80)

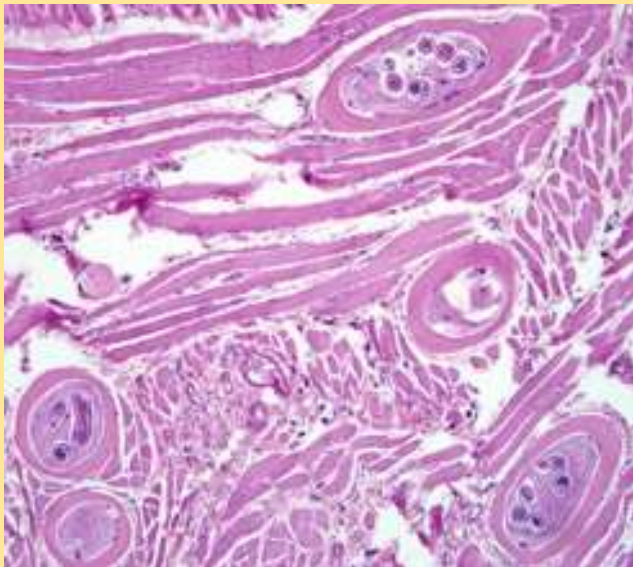


Fig. Encysted larvae of *Trichinella* sp. in muscle tissue of experimental animal (mouse) stained with hematoxylin and eosin (H&E). The image magnification is 200x.

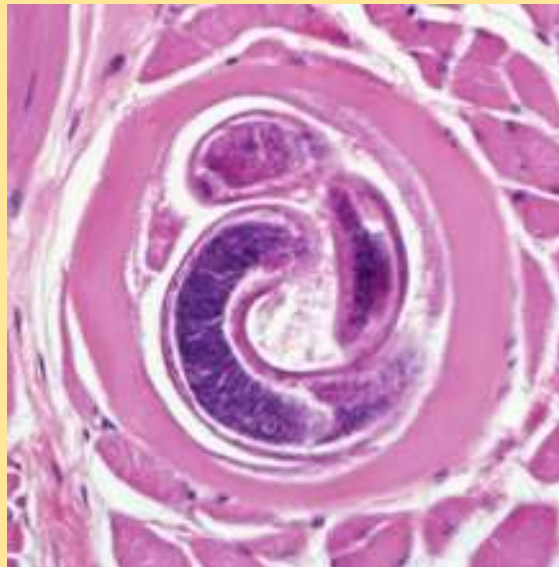


Fig. Encysted larvae of *Trichinella* sp. in muscle tissue, of experimental animal (mouse) stained with hematoxylin and eosin (H&E). Image was captured at 400x magnification.

Diagnosis in humans mostly by serology that detect *Trichinella*-specific antibodies. EIAs utilize antigen preparations that may be crude extracts prepared from homogenates of *T. spiralis* muscle larvae or excretory-secretory (ES) products produced by cultured larvae. **Alternatively** – presence of migratory larvae **in blood using specific PCR**

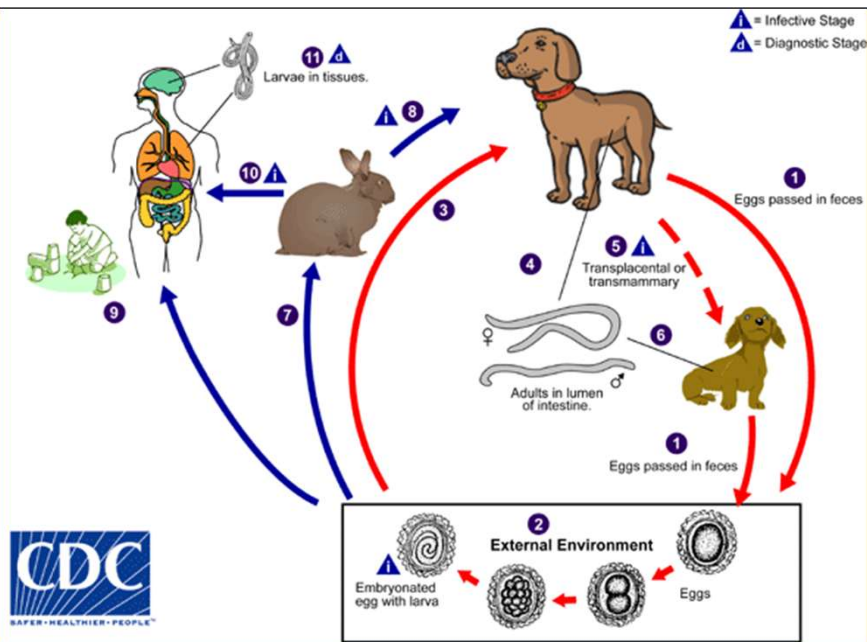
Trichinella spirallis treatment and prevention (q.80)

TREATMENT – albendazol, mebendazol

PREVENTION – Wash hands with warm water and soap after handling raw meat. **Cook or freeze pork and wild game meats.**

Other tissue nematodes (q.80)

AGENTS – They are a heterogeneous group. Four of them—*Toxocara canis*,
The remaining four major tissue nematodes—*Wuchereria bancrofti*, *Brugia malayi*, *Onchocerca volvulus*.



See also:

<https://www.youtube.com/watch?v=rvUcGBeCrul>

Toxocariasis is caused by larvae of *Toxocara canis* (dog roundworm) and less frequently of *T. cati* (cat roundworm), two nematode parasites of animals.

- **Many human infections are asymptomatic**, with only eosinophilia and positive serology. The two main clinical presentations of **toxocariasis** are **visceral larva migrans (VLM)** and **ocular larva migrans (OLM)**. In VLM, which occurs mostly in preschool children, **the larvae invade multiple tissues (liver, heart, lungs, brain, muscle)** and cause various symptoms including **fever, anorexia, weight loss, cough, wheezing, rashes, hepatosplenomegaly, and hypereosinophilia**.
- **Diagnosis** – eosinophilia, specific IgG antibodies

Other tissue nematodes (q.80)

Filarial worms *Wuchereria bancrofti*, *Brugia malayi* most frequent agents causing **filariasis** – **block flow of lymph**, causing edematous arms, legs and scrotum, **transmitted by mosquitoes** *Anopheles* and *Culex*, **diagnosis** – **microfilariae in blood**, **treatment** – **albendazole** combined with diethylcarbamazine

Onchocerca volvulus – skin rash, subcutaneous nodules, ocular lesions causing blindness, transmitted by the bite of a blackfly. **Diagnosis**-microfilariae in skin biopsy, **treatment** – **ivermectin** and/or surgery.

See also: <https://www.youtube.com/watch?v=T13clxaG4CU>

References:

- Lippincott's illustrated reviews, Microbiology, <https://www.cdc.gov/parasites>, <https://www.cdc.gov/dpdx/az.html>