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Review

Culinary delights and travel? A review of zoonotic cestodiases and metacestodiases

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Summary Due to increased globalization, food-borne parasitic infections are becoming more prevalent worldwide, including in countries where these parasites and parasitic diseases had previously been well controlled or eradicated. Improved sanitation, health education, and establishment of appropriate food safety mechanisms can go a long way towards the control of many these infections. However, food-borne parasitic infections are still common diseases in developing countries, especially in rural areas. As many of today's travelers are looking to explore more distant locations and partake in the local cuisine, they may be at greater risk of acquiring a food-borne parasitic infection, including those caused by a number of adult and larval tapeworms. This review discusses fish and meat-borne tapeworms and zoonotic metacestodiases of public health importance to both developing and developed countries, with a focus on infection prevention in travelers.

KEYWORDS

Fish tapeworm; Pork tapeworm; Beef tapeworm; Neurocysticercosis; Echinococcoses; Sparganosis

Introduction

Food-borne parasitic infections can be a public health issue for travelers partaking in local foods in endemic areas as well as for the local inhabitants. Some tapeworms also have humans as definitive hosts and, therefore, can be brought from an endemic to a non-endemic region via an infected person. In this article, the most common food-borne tapeworm (cestode) infections are reviewed, focusing on travelers' health issues [1].

1) Fish-borne cestode infections:

Diphyllolobothriaisis is caused by humans ingesting the larval form of a number of species of fish tapeworms from the Family Diphyllobothriidae. After ingesting infected undercooked fish, humans can develop adult tapeworms in their gastrointestinal tracts (diphyllobothriasis) (Figure 1). The most common cause of diphyllobothriasis from freshwater fish is *Diphyllobothrium latum*, otherwise known as the fish tapeworm or the broad tapeworm. In 1976, Hunter *et al*. [2] indicated that "*D. latum* was common in people living in the Baltic countries, the western USSR, Finland, parts of Scandinavia and in certain endemic foci in the US and Canada". Since this early study, molecular analyses have revealed that the family Diphyllobothriidae includes several genus and species which can infect humans via the ingestion of freshwater or marine fish (Table 1) [3-11]. Based on molecular evaluation, a number of parasites previously classified as *D. latum* are now considered independent species. For example, work by Yamane *et al*. [3] in Japan led to *Diphyllobothrium nihonkaiense* becoming a separate species from *D. latum* [12-18].

A review by Wicht *et al*. [9] described 11 species of the genus *Diphyllobothrium* and one species of the genus *Diplogonoporus* as being human health risks. *D. latum* is acquired from eating freshwater fish including pike, burbot, and perch. The other species of *Diphyllobothrium* are acquired from eating marine fish such as pacific salmon [10]. Patients with diphyllobothriasis are frequently reported from a number of Asian and Australasian countries, including Malaysia [8,19], Indonesia [20], Taiwan [5], and New Zealand [21]. Infection with *Diplogonoporus grandis* is relatively common in Japan, but is less common in other countries [22-24]. Most infections with this parasite have been attributed to eating uncooked or undercooked sardines. Morishita [22] reviewed 40 human cases of *D. grandis* in Japan from 1892 to 1967. The majority of cases were middle-aged men. Most of the cases were not aware that they were parasitized until they expelled the tapeworm naturally. It is believed that the natural definitive hosts, for this parasite, are marine mammals, including whales, dolphins, and porpoises [25].

Fish tapeworm infections, especially with *D. nihonkaienze* and *D. dendriticum*, are becoming more common, including in traditionally non-endemic countries in Europe [26,27] and North America [28] where people eat raw fish that has been imported from the Pacific Rim countries [10]. For example, *D. latum* has been reported from non-endemic areas in Chile [29], Argentina [30], and Spain [31] and has been found in freshwater fish from French, Italian and Swiss Alpine lakes [9,31-33] as well as in fish from Canadian freshwater lakes [34,35]. Another species, *D. pacificum*, has recently been confirmed in infected patients in Chile [29].

Due to available rapid freezing techniques, increased speed at which products are shipped around the world, and an increasing demand for “sashimi” and “sushi”, fish-borne tapeworm infections are likely to become more common globally. Human infection prevalence is dependent on the prevalence of the parasites in fish and local food safety knowledge. While infections with fish tapeworms can be prevented through proper cooking techniques and food safety education, cases will likely continue to occur as long as raw fish remains a delicacy in many parts of the world [10,25].

2) Meat-borne tapeworm infections

The beef tapeworm, *Taenia saginata*, and the pork tapeworm, *Taenia solium*, are distributed globally. Humans are the definitive hosts for both of these parasites, with cattle acting as the intermediate host of *T. saginata* and pigs acting as the intermediate host of *T. solium* (Figure 2). Humans become infected by ingesting cysts in undercooked infected meat. For *T. solium*, humans may also become infected with the larval form if they ingest food contaminated with parasite eggs shed in the feces of an infected person, resulting in cystic lesions in the central nervous system (neurocysticercosis) or other parts of the body (cysticercosis). Prevalence of these tapeworms will vary regionally due to beef and pork preparation and consumption habits, which may be linked to religious observations. One study indicated that dogs may also be suitable intermediate hosts for *T. solium*, therefore, undercooked dog meat may also be a food safety hazard in endemic areas [36].

A third species of human *Taenia* has been reported from Asia ("Asian *Taenia*") [37]. In the past, parasitologists had been puzzled by the fact that *T. saginata* proglottids were expelled from people who ate pork, but not beef in the Philippines, Indonesia, and Taiwan [37-44]. This newly described parasite appears to be very similar in structure to *T. saginata*, but requires pigs as the intermediate hosts rather than cattle (Figure 2) [37,42,44]. This new parasite was eventually given the name *Taenia asiatica* by Eom and Rim [45,46]. However, recent molecular studies, in Thailand and China, have identified tapeworms that are hybrids of *T. saginata* and *T. asiatica* [47-49], leading to the question of whether or not *T. asiatica* is truly as independent species. Furthermore, Fan [37] reported that metacestodes of "Taiwan *Taenia*" (= *T. asiatica*) were established in the liver of not only pigs but also of cattle [50]. Since both pigs and cattle may potentially be infected with *T. asiatica* [37], ingestion of uncooked liver from pigs or cattle could be a possible source for human infection.

Data from rural and remote areas in Sichuan Province, China [51,52] and refugees' villages in Thailand [53] suggest that infection with *T. asiatica* is still quite rare. Field surveys using serology to detect antibody responses to antigens [54] have confirmed infection with *T. solium* (the majority of cases), *T. hydatigena*, and mixed *T. solium* and *T. hydatigena* infections in pigs from China [51,52], Indonesia (Swastika et al. unpublished) and Thailand (Kusolsuk et al. unpublished). To date, these studies have not identified pigs infected with *T. asiatica*.

Eom *et al.* [55] reported that *T. asiatica* was present in Japan based on identification of this species from infected Japanese citizens. However, travel histories were not taken on these patients. Indigenous *T. asiatica* cases, in Japan, were first confirmed in Tokyo in 2010 [56,57]. All taeniasis cases in Japan, except for those cases caused by *T. asiatica* in Tokyo [56,57], are believed to have been imported from other endemic countries [58].

Cultural and religious preferences, regarding meat preparation and consumption, most likely play a role in the transmission of *T. solium*, *T. saginata*, and *T. asiatica* [44]. Taeniases caused by these three species are rather common in remote and rural areas in countries where meat inspection is limited and home slaughtering practices are routinely conducted. However, global travel and immigration can result in travelers to endemic countries becoming infected as well as travelers and immigrants from endemic countries potentially introducing the parasites into non-endemic regions [56,59,60].

3) Other miscellaneous tapeworm infections from local foods

While *Taenia* species result in the majority of human adult tapeworm cases globally, there are a number of other cestodes that can infect humans. For example, adult tapeworm infections may be acquired from eating “backyard” chickens, snails, snakes or frogs infected with *Mesocestoides lineatus* [61-65] or *Spirometra erinacei* [65]. While most patients infected with *S. erinacei* only develop the larval stage (sparganosis), a small proportion of infected individuals develop adult tapeworms [66].

The cestodes *Hymenolepis nana* (the dwarf tapeworm) and *Hymenolepis diminuta* (the rat tapeworm) are known to infect humans through eating beetles containing the cysticercoid larvae of these parasites. *H. nana* can be transmitted via the ingestion of eggs shed in the feces of a human tapeworm carrier. While infected humans typically develop adult tapeworms in their gastrointestinal tracts, *H. nana* infections may cause serious disseminated disease, especially in immuno-compromised individuals [67,68]. Recently, numerous outbreaks of *H. nana* infections have been reported in children in Africa and South America [69-73], indicating that this parasite may be an emerging public health issue in endemic regions.

4) The role of meat inspection

Even countries with the most stringent meat hygiene requirements may experience occasional outbreaks of food-borne parasitic infections [57,59,60]. For example, the recent popularity of "organic pork" in some European countries has the potential for increasing the risk of *T. solium* infection through allowing pigs to root and graze in areas that have been contaminated by a tapeworm carrier. This is especially true in regions with large immigrant populations from endemic countries who work in the agricultural sector [56,58-60]. Illegal meat markets have also resulted in taeniasis outbreaks in low endemicity areas [58]. For example, in Tokyo, Japan, an outbreak of *T. asiatica* occurred in 2010 due to this practice [56-58]. As cysticerci of *T. asiatica* appear as white milk spots on the liver surface and are similar in appearance to lesions caused by the larval stage of the pig roundworm *Ascaris suum* [37], pigs with these liver lesions should always be inspected with extra care in areas where *T. asiatica* is known to occur [56-58].

5) Symptoms and treatment of intestinal tapeworm infections

Intestinal cestode infections usually do not produce severe clinical signs and many tapeworm carriers do not know that they are infected until they start to pass tapeworm segments. Individuals with very heavy infections may experience abdominal pain, anorexia, nausea, diarrhea, and weight loss. Intestinal tapeworm infections are usually treated with antihelminthic drugs such as praziquantel, albendazole, or niclosamide. Chinese traditional medicines have also been used by tapeworm sufferers [51,52].

6) Prevention of food-borne parasite infections in travelers

The simplest way for a traveler to avoid becoming infected with food-borne parasitic infections is simply not to eat uncooked or undercooked fish or meat or even unwashed fruits or vegetables but this advice is likely to fall on deaf ears. Recent sustainable education of local people to cook pork and viscera in Samosir Island, Indonesia has shown drastic decrease in the number of tapeworm carriers [74]. However, enjoying local cuisine is viewed by many as an integral part of the travel experience. In addition, while not consuming meat can prevent a person from becoming infected with certain parasitic disease, including cestodiases and trichinosis, there are other parasites such as soil transmitted helminthes that can be found on fresh vegetation. Therefore, the next best way to prevent food-borne parasitic infections is to make sure that fish, meat and vegetables are appropriately cooked and reach a temperature high enough to kill any parasite larvae or eggs.

7) Larval cestode infections: cysticercosis, echinococcosis, sparganosis

***a) Cysticercosis*: ** Neurocysticercosis, caused by invasion of the central nervous system by the larval stage of *T. solium*, is a leading cause of epilepsy in regions where pigs are raised extensively with access to human fecal material and where meat inspection is lacking (Figure 2) [75]. In addition to epilepsy, patients with neurocysticercosis may experience severe chronic headaches as well as other neurological signs. While clinical signs associated with neurocysticercosis can be severe, patients may be asymptomatic for many years or for the remainder of their lives [76].

Since neurocysticercosis patients become infected through ingestion of *T. solium* eggs shed in the feces of a parasite carrier, a risk factor for cysticercosis/neurocysticercosis is a person infected with the adult form of *T. solium* in the household [77,78]. Individuals with cysticercosis can either become infected via food contaminated by a tapeworm carrier or can be tapeworm carriers that infect themselves due to poor hand hygiene [79,80]. However, since it can take years for symptoms to occur and for a patient to be diagnosed, the actual method of infection for individual patients is often unknown. Molecular analyses are beginning to be used to identify the regional origin of an infection when patients have a travel history that may have allowed for exposure in numerous geographic locations [65,81,82].

In addition to endemic areas in sub-Saharan Africa, South America, and many parts of Asia, cysticercosis cases are now becoming identified in regions previously believed to be free of the parasite. For example, in Bali, Indonesia, when patients were treated with the drug praziquantel for what was presumed to be *T. saginata* infections, some of these individuals developed seizures [44]. It was later determined that these individuals were co-infected with *T. saginata* adult worms and the larval form of *T. solium*, resulting in neurocysticercosis. In non-endemic countries in Europe and North America, numerous cases of neurocysticercosis are also being detected in individuals who either emigrated from an endemic region or had a history of travel to an endemic region [79].

Cysticercosis is considered a worldwide emerging disease due to travel and globalization [83], although the actual number of cases globally is not known. The gold standard for the diagnosis of neurocysticercosis is neuroimaging such as computed tomography (CT) scans and magnetic resonance imaging (MRI) [84]. However, there are a number of serological tests that can be used for ancillary diagnostics [85,86], such as the immunochromatographic rapid test (ADAMU-CC, ICST C. Ltd., Saitama, Japan) (Figure 3) [78].

b) Echinococcoses**:** Echinococcoses are caused by accidental ingestion of eggs of several species of the genus *Echinococcus* (Figure 4). Recent molecular re-evaluation of *Echinococcus* species have revealed that there are at least nine species, *E. granulosus* sensu stricto, *E. equinus*, *E. ortleppi*, *E. canadensis*, *E. felidis*, *E. multilocularis*, *E. shiquicus*, *E. vogeli* and *E. oligarthra* [87-89]. *E. granulosus* sensu stricto, *E. equinus*, *E. ortleppi*, *E. canadensis*, and *E. felidis* comprise the species group *E. granulosus* sensu lato. All *Echinococcus* species are known to be zoonotic except for *E. felidis*, *E. shiquicus*, and *E. equinus*. *E. felidis* is distributed exclusively in Africa with lions acting as definitive hosts [90]. While *E. felidis* is not known to be zoonotic, human echinococcosis cases in Africa are being evaluated using molecular methods to see if there are, in fact, cases infected with this *Echinococcus* species. Another newly described species is *E. shiquicus*, which has only been found on the Tibetan plateau of western China [91]. The only known definitive host, for this species, is the Tibetan fox (*Vulpes ferrilata*). No human cases have been identified as being infected with this pathogen, but similar to *E. felidis*, this may be due to cases of *E. shiquicus* being previously attributed to another species of *Echinococcus*.

Among the 9 known species of the genus *Echinococcus*, *E. granulosus* sensu stricto and *E. multilocularis* are the most prevalent globally and cause the most human cases. However, recent studies indicate that echinococcosis due to *E. canadensis* may be more common than previously believed and care should be taken to differentiate infections with *E. granulosus* sensu stricto and *E. canadensis* [92,93]. *E granulosus* sensu stricto is typically maintained in a cycle between dogs and sheep, whereas *E. canadensis* is maintained in a cycle between wolves (*Canis lupus*) and domestic livestock and/or wild ungulates [94]. In contrast, *E. multilocularis* is typically maintained between wild canids such as red fox (*Vulpes vulpes*) and/or wolves and small mammals [94].

Humans become infected after ingesting parasite eggs shed in the feces of an infected domestic or wild canid, resulting in cystic lesions that primarily develop in the liver or lungs [95]. Infection can occur from ingesting parasite eggs that were on the hands of the food preparer or from ingestion of food (e.g., vegetables or wild berries) that were contaminated directly from an infected dog or wild canid. Urbanization may be, in part, responsible for the second infection route as wildlife, such as red foxes, are increasing found in urban settings in Europe [96-102]. Diagnosis of echinococcosis is often made via diagnostic imaging (e.g., abdominal ultrasound, computed tomographic scan, magnetic resonance imaging) in conjunction with serological evaluation with tests such as imunochromatography (ADAMU-AE, ADAMU-CE, ICST Co. Ltd., Saitama, Japan) [103-105] (Figure 3).

***c) Sparganosis*:** As summarized in Table 1, adventurous eaters may be at risk for infection with less common cestodes through the ingestion of amphibians and reptiles [65,66,106-111]. For example, sparganosis, which is caused by the larval stage of *S. erinacei*, has been associated with eating snakes in Asia, but may also be acquired through ingestion of frogs or backyard chicken [65,66,106-110].

8) Symptoms, treatment and prevention of larval cestode infections

Symptoms associated with larval cestode infections are dependent on the location of the larval stage of the parasite. *T. solium* cysticercosis has variable clinical signs depending on the location of the cysts, with cysts located in the central nervous system tending to cause the most severe disease, including epilepsy, severe chronic headaches and stroke [84,112-115]. In contrast, cysts located in other body systems, such as subcutaneous cysts, can be relatively benign. Infection with *Echinococcus* spp. can present as hepatic disease, due to cysts in the liver, and can be misdiagnosed as hepatic cancer by physicians in non-endemic regions that are not familiar with this parasitic zoonosis. Clinical manifestations associated with echinococcosis are often due to the larval cysts pressing on surrounding anatomic structures, secondary bacterial infection of the cysts, or anaphylaxis caused by the rupture of a cyst. Creeping eruption, caused by *S. erinacei*, can result in pruritic lesions as the larval stage migrates in the subcutaneous layer of the skin [65,66,106,107].

Epilepsy-associated neurocysticercosis is often treated with anti-seizure medication. Antiparasitic drugs such as praziquantel or albendazole are often accompanied by administration of a corticosteroid [112-118]. Surgery for cysticercosis may be an option dependent on cyst location [119]. Active *Echinococcus* cysts may be treated with albendazole, surgical intervention or a combination of both, while some cases can be monitored without the need for intervention [120-122]. Sparganosis is usually treated with praziquantel and/or surgical intervention to remove the larvae.

Conclusions

There are numerous cestodes that can result in food-borne parasitic infections via the ingestion of infected fish and meats or contaminated vegetation. Through globalization, travelers and immigrants are often at a greater risk for acquiring food-borne parasitic infections or bringing parasites to new locations. In essence, parasites can be considered “travelers” as they are conveyed around in the world in people and animals as well as via meat, fish, and contaminated vegetation. Appropriate meat inspection and food hygiene practices can go a long way to preventing many of these infections. However, no food can ever be guaranteed to be absolutely safe and travelers, as well as individuals living in countries that are endemic for these parasites, must remain ever vigilant.

Conflict of interest

None.

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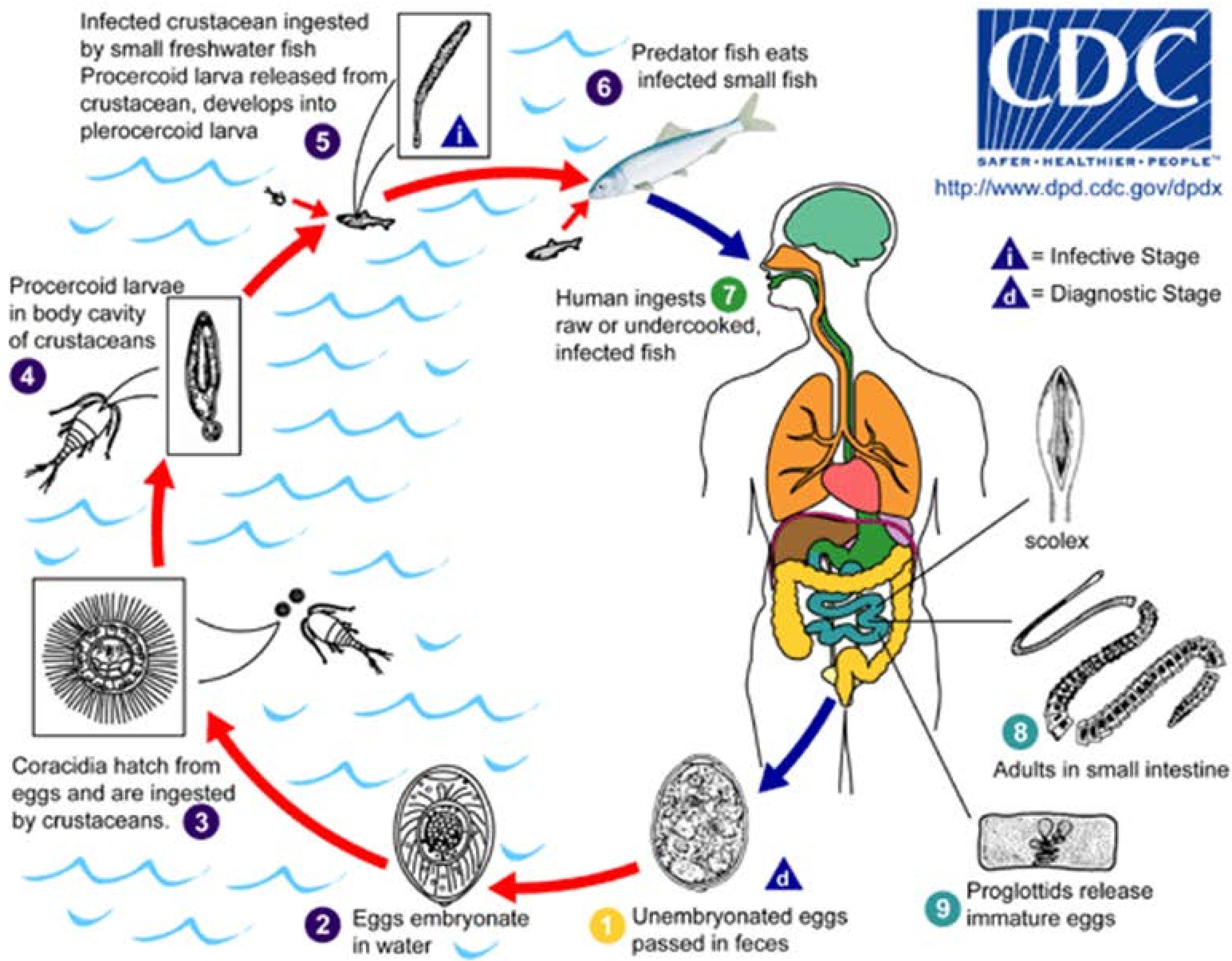
Figure Legends

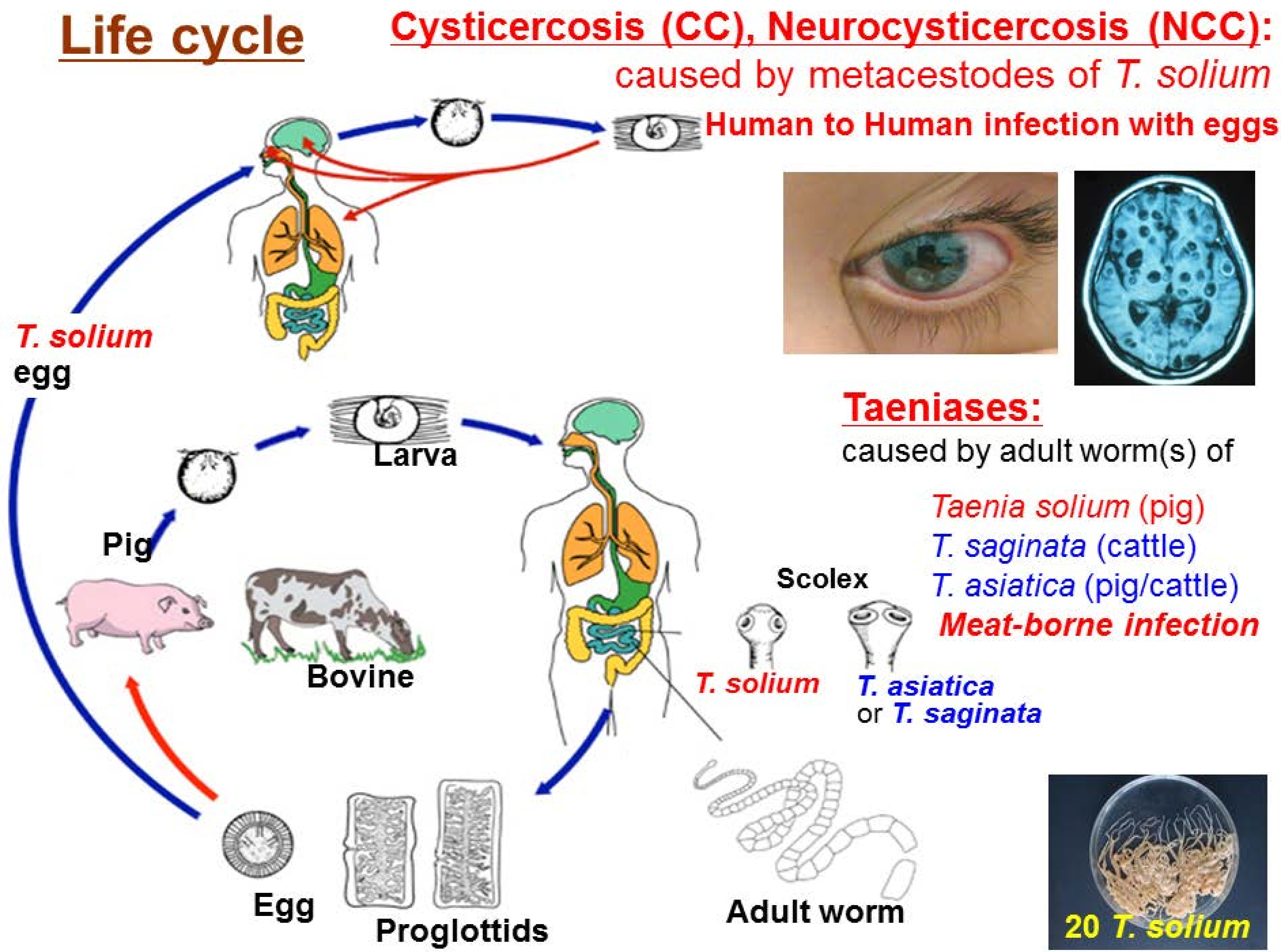
Figure 1. Life cycle of *Diphyllobothrium* spp. (from CDC, Atlanta, no need to get permission).

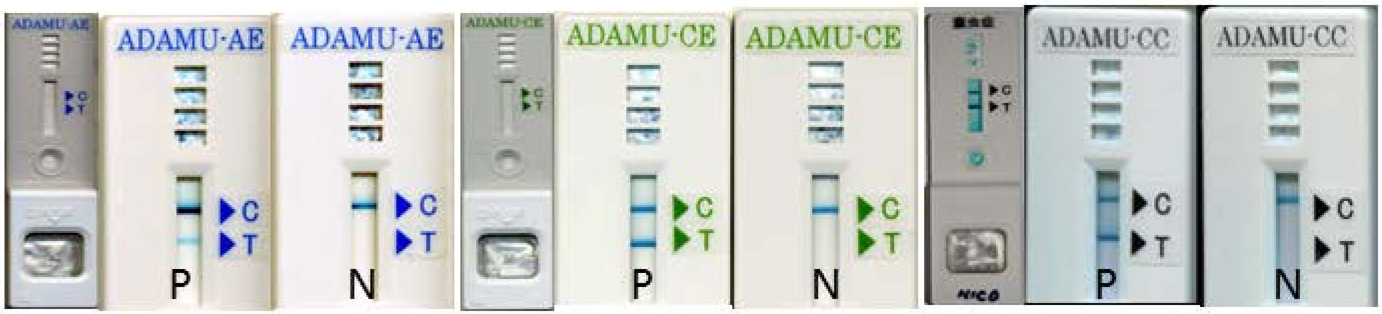
Figure 2. Life cycle of three human taeniid tapeworms, *Taenia solium*, *T. saginata* and *T. asiatica* (modified from CDC). Photos of ocular cysticercosis, neurocysticercosis, and massive taeniasis due to *T. solium* are from [119], [75] and [116], respectively.

Figure 3. Commercially available rapid serodiagnostic kits for alveolar echinococcosis (ADAMU-AE), cystic echinococcosis (ADAMU-CE) and cysticercosis (ADAMU-CC), (ICST Co. Ltd., Saitama, Japan). P: positive, N: negative. One drop of fresh blood is sufficient to get a result within 20 minutes [78,103-105]. These kits will be licensed by the Ministry of Health, Japan.

Figure 4. Life cycle of *Echinococcus granulosus* sensu stricto (from CDC). All *Echinococcus* species complete their life cycles using herbivorous or omnivorous intermediate hosts and carnivorous definitive hosts.


Infected crustacean ingested by small freshwater fish Procercoid larva released from crustacean, develops into plerocercoid larva
5
Predator fish eats infected small fish
6
CDC
SAFER・HEALTHIER・PEOPLE™
http://www.dpd.cdc.gov/dpdx
i = Infective Stage
d = Diagnostic Stage
Procercoid larvae in body cavity of crustaceans
4
Human ingests raw or undercooked, infected fish
7
scolex
8
Adults in small intestine
Coracidia hatch from eggs and are ingested by crustaceans.
3
2
Eggs embryonate in water
1
Unembryonated eggs passed in feces
9
Proglottids release immature eggs


Life cycle
Cysticercosis (CC), Neurocysticercosis (NCC):
caused by metacestodes of T. solium
Human to Human infection with eggs
T. solium
egg
Taeniases:
caused by adult worm(s) of
Taenia solium (pig)
T. saginata (cattle)
T. asiatica (pig/cattle)
Meat-borne infection
Larva
Pig
Bovine
Scolex
T. solium
T. asiatica
or T. saginata
Egg
Proglottids
Adult worm
20 T. solium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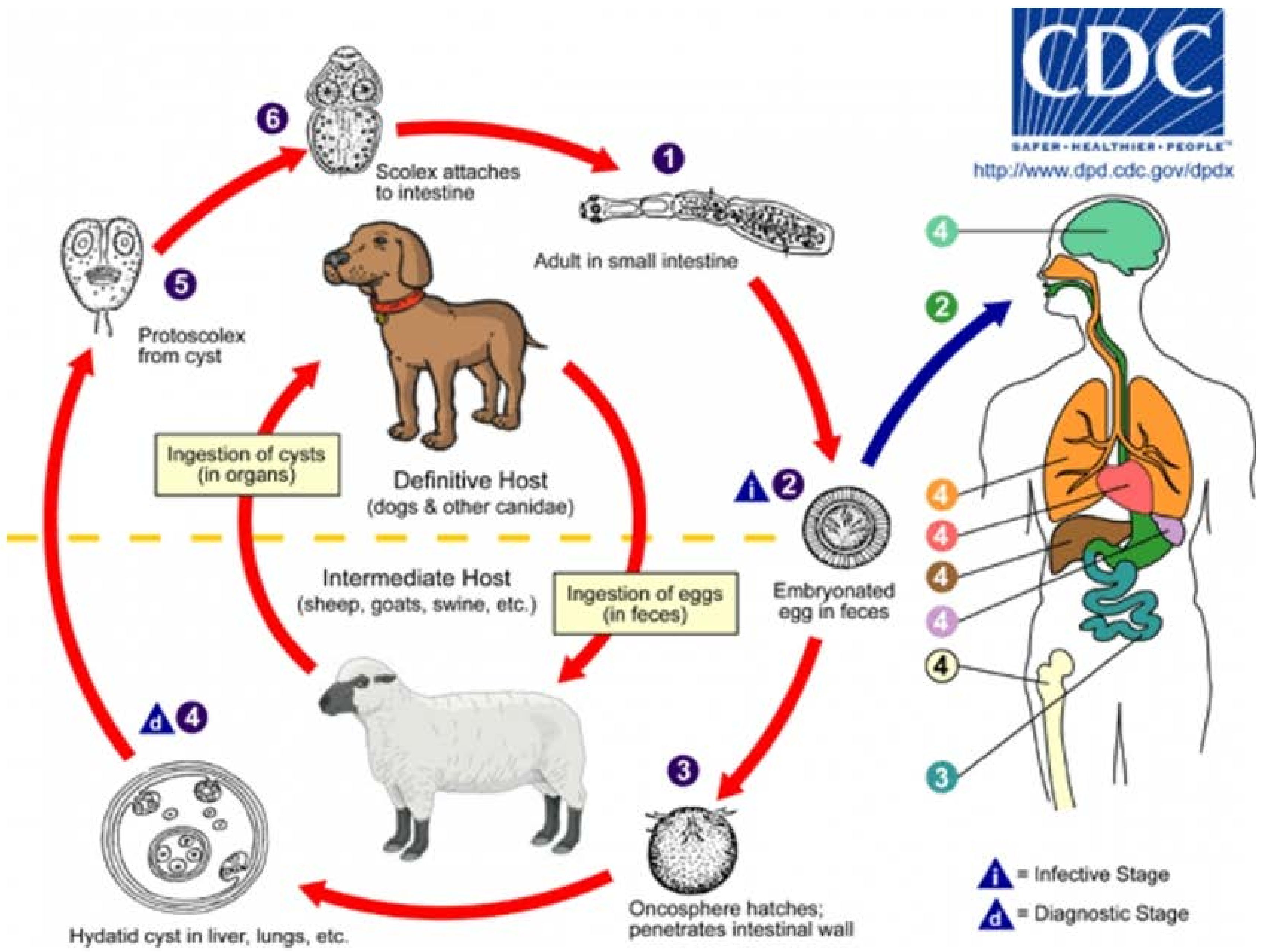
CDC
SAFER • HEALTHIER • PEOPLE™
http://www.dpd.cdc.gov/dpdx
6
Scolex attaches to intestine
1
Adult in small intestine
5
Protoscolex from cyst
Ingestion of cysts (in organs)
Definitive Host (dogs & other canidae)
2
Embryonated egg in feces
Intermediate Host (sheep, goats, swine, etc.)
Ingestion of eggs (in feces)
4
3
Oncosphere hatches; penetrates intestinal wall
Hydatid cyst in liver, lungs, etc.
4
4
4
4
4
4
2
3
i = Infective Stage
d = Diagnostic Stage