FRI BRIEFINGS

Foodborne Parasites

A Review of the Scientific Literature Review

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Parasites — What are they?

The word "parasites" conjures up images of gross-looking tapeworms, roundworms, and fleas, or of blood-borne diseases such as malaria and schistosomiasis. Many have been considered problems confined to tropical countries and places with poor sanitation and therefore of little concern to the U.S. However, recent outbreaks of parasitic diseases have demonstrated the inaccuracy of these assumptions. Not all parasites live only in the tropics [as witness the Milwaukee *Cryptosporidium* outbreak (*179*)], and consumers in the U.S. can be exposed to parasites that originate in the tropics because of increasing international travel [*Angiostrongylus* in tourists returning from Jamaica (*252*)] and globalization of food markets [*Cyclospora* on raspberries from Guatemala (*128*)]. Finally, some of the most important parasites are neither tapeworms, insects, nor blood-borne.

Parasites are organisms that obtain their food from other living creatures. A "good" or well-adapted parasite does not kill its host because it depends on the host for a steady supply of food over a long period of time. Usually parasites are smaller than their food source and this distinguishes them from predators such as tigers, which also eat other living things. Some parasites live in only one species of animal but many parasites, particularly the worms, spend part of their lives reproducing sexually in a final or definitive host and developing asexually as larvae during another part of their life in an intermediate host of a different species. Different life cycles will be described in a later section.

It has been estimated that humans harbor about 300 species of parasitic worms and over 70 species of protozoa (*27;51;212*). Many of these have co-existed with us for thousands of years and have been identified among human remains by archaeologists (*62;104;116;123;173;213;231*). We may have inherited some parasites from our primate ancestors, while others were acquired from companion and food animals. Not all parasites are foodborne and some are very rare.

This review will summarize information on the more common foodborne parasites, including three types of worms and several protozoa. The worms include tapeworms (cestodes), flukes (trematodes) and roundworms (nematodes). Protozoa are one-celled organisms but are larger and more complex than bacteria. These parasites are generally not susceptible to antibiotics that kill bacteria but there are effective drugs to treat some (not all) parasitic infections.

What foods have the potential for carrying parasites?

Parasites of concern to food safety professionals include several worms, ranging from a few centimeters to several meters in length, and protozoa, single celled organisms (*202;212*) (Table 1). Many parasitic infections are asymptomatic, others cause acute short-lived effects, and still others may persist in the body causing chronic effects (*195*).

Protozoa

Protozoan parasites may be present in freshwater sources that have been contaminated with human or animal feces; fruits and vegetables grown or washed with such contaminated water may have parasites on their surface and be sources of infection. *Toxoplasma* is sometimes present in raw meat, particularly pork, and thorough cooking is needed to destroy it. Some protozoa are very species specific and can survive in only one species of animal, but others, including many human pathogens, can live in humans and in other animals and these animals may act as reservoirs continually shedding parasites into the environment. Protozoan parasites have a resistant resting stage (cyst or oocyst) which can withstand some drying and disinfectants.

Foodborne parasitic worms

Cestodes (tapeworms): Meat and fish may contain larval tapeworms that can develop into adults in the human intestine. The pork and beef tapeworms are the best known (*Taenia solium* and *T. saginata*, respectively) but there are also other species with larval stages in fish muscles. Tapeworm eggs may be present on fruits or vegetables fertilized with human wastes or washed with contaminated water. If humans consume the eggs of *T. solium*, the larvae hatching from the eggs burrow out of the intestine and travel to the muscles, brain, and other parts of the body where they encyst and may cause serious problems.

Nematodes (round worms) include the following human parasites: *Trichinella, Ascaris*, and *Anisakis*, *Angiostrongylus* and *Gnathostoma*. Some nematodes, such as *Ascaris*, have a simple life cycle that does not require an intermediate host but may be passed from one human to another by fecally contaminated water or vegetables. Others, including *Trichinella, Gnathostoma,* and *Anisakis*, exist as cysts in muscles of meat or fish and may (*Trichinella*) or may not (*Anisakis* and *Gnathostoma*) develop into adults in humans who consume infected meat. *Angiostrongylus* utilizes two intermediate hosts and may be present in snails and on leafy vegetables.

Trematodes (flatworms or flukes) usually have two or more intermediate hosts. Some may be present on aquatic vegetables or foods washed in contaminated water (*Fasciola* and *Fasciolopsis*) while others encyst in fish (*Clonorchis)* or crabs and wild boar (*Paragonimus*).

How much of a problem are parasites?

Worldwide, parasites infect millions of people (Table 2.) In some underdeveloped regions, they are a major cause of childhood diarrhea and stunting of growth and cause significant economic losses related to human health and to agriculture (*72;111; 233*).

In the U.S. the number of people affected by parasites is proportionally much smaller than in underdeveloped parts of the world, and viruses and bacteria are more frequent causes of foodborne illness in the U.S. However, parasites are becoming more of a concern for the following reasons:

- Increasing imports of fruits, vegetables, and ethnic foods, some of which originate in countries without modern sanitary facilities and inspection systems, may introduce parasites.

Table 1. Parasites found in different foods.

Foods	Protozoa	Nematodes	Tapeworms	Flukes
Beef			*Taenia saginata*	
Pork	*Toxoplasma*	*Trichinella*	*Taenia solium, Taenia asiatica*	
Other meat	*Toxoplasma, Cryptosporidium* (lamb, mutton)	*Trichinella* (cougar, walrus, bear, horse, wild boar) *Gnathostoma* (frogs, snakes)		*Paragonimus* (wild boar, guinea pig)
Milk	*Cryptosporidium*			
Fish		*Anisakis, Gnathostoma*	*Diphyllobothrium*	*Clonorchis*
Crabs, shrimp		*Gnathostoma*		*Paragonimus*
Clams, mussels, oysters	*Cryptosporidium, Toxoplasma*			
Snails, slugs		*Angiostrongylus*		
Squid		*Anisakis*		
Fruits, vegetables (raw)	*Cyclospora, Cryptosporidium, Giardia*	*Angiostrongylus, Ascaris*	*Taenia solium, Echinococcus*	*Fasciola, Fasciolopsis*
Water	*Cyclospora, Cryptosporidium, Giardia, Toxoplasma*	*Ascaris, Gnathostoma*?	*Echinococcus*	*Fasciola, Fasciolopsis*

Table 2. Estimated cases of food- and waterborne parasitic diseases.

Parasite	U.S. (reference)	World (reference)
Anisakis simplex	~50 (*13*)	~2000 (*13*)
Ascaris lumbricoides		1,472,000,000 (*53*)
Clonorchis sinensis		7,000,000 (WHO web site; *277*)
Cryptosporidium parvum	3000,000 (*186*)	
Cyclospora cayetenensis	16,264 (*186*)	
Entamoeba histolytica		48,000,000 (WHO web site)
Fasciola hepatica		2,4000,000 (WHO web site)
Giardia lamblia	2,500,000 (*38*)	
Opisthorchis spp.		18,500,000 (WHO web site; *277*)
Paragonimus		>20,000,000 (WHO web site)
Taenia spp.	>1000 neurocysticercosis/yr (*31*)	50,000,000 (*134*)
Toxoplasma gondii	225,000 (*186*)	500,000,000 (*180*)
Trematodes		>40,000,000 (WHO web site; *1*)
Trichinella spiralis	52 (*186*)	

- Immigrants from under-developed countries may be infected with parasites that could be transmissible to others, particularly during food preparation.
- The popularity of raw or lightly cooked foods, such as sushi and raw pork sausages, may increase exposure to parasites.
- As our population ages and more people have deficient immune systems, parasitic infections may have more severe consequences, as demonstrated in *Cryptosporidium* outbreaks (*101;137*).
- Although parasitic infections may not be very frequent in the U.S., some parasites can cause severe chronic effects such as neurological problems caused by the pork tapeworm (neurocysticercosis) and by *Toxoplasma* and liver cancer associated with *Clonorchis* (*138;159;277*).
- An interesting issue being considered by some parasitologists is the potential spread of parasitic diseases as global warming proceeds. Some diseases are presently confined to tropical and subtropical areas because cysts or intermediate hosts are not cold hardy. But if lake temperatures warm up and winter temperatures moderate, some diseases may encroach on temperate areas (*7*).

How can parasites be controlled?

Some basic strategies such as sanitation and proper cooking of foods are useful in combating all parasites. Other approaches may be useful for some parasites but not for others. Below is a brief summary of methods which have been investigated, and Table 3 lists references which describe published research investigating the efficacy of different methods as applied to different groups of parasites.

<u>Sanitation and Hygiene</u>

- Proper disposal of human and animal wastes to prevent contamination of foods and drinking water sources is an excellent and basic strategy for preventing many parasitic infections that are transmitted by the fecal–oral route. However, in many developing countries these wastes serve as fertilizer for crops. Composting of this material could kill parasite eggs.
- Control of flies, cockroaches, and other insects may prevent dispersal of infective stages of parasites to foods.
- Thorough washing of raw vegetables and fruits may remove cysts, oocysts, and eggs of parasites, but it is difficult to adequately clean some leafy vegetables and berries.

- Frequent handwashing, use of clean utensils, and measures to prevent cross-contamination during food processing are also important.

Animal Husbandry and Inspection

- Husbandry practices that limit exposure of pigs to contaminated feed and feces have been successful in developed countries in drastically reducing human infections with *Trichinella* and pork tapeworms.
- Rodent control is also important to prevent pigs from consuming rodents carrying parasites.
- Infected animals may be treated with drugs to kill parasites, and vaccines are being developed to prevent infections with certain parasites.
- Inspection systems can detect parasites in pork, beef, and fish. These systems ensure that nearly all meat reaching consumers in the U.S. is free of parasites.

Marination, Pickling, Smoking, Fermentation

- Hot smoking processes kill *Anisakis*, but these parasites do survive cold smoking.
- Marination of herring in 2.6% acetic acid and 8–9% salt kills *Anisakis* after 6 weeks, but 12 weeks are required if the salt concentration is 5–6%.
- Traditional Mexican methods of salt pickling of pork kill tapeworm larvae (cysticerci).
- Fermentation of meat to produce dry sausages and ham inactivates both protozoa and larvae of parasitic worms. Low pH and low water activity combine to kill parasites so that less acidic products may require an a_w<0.9 to be safe.

Cooking and Heat Treatment

All infective stages of parasites are destroyed by adequate cooking of foods and boiling of water. However, microwave cooking does not reliably kill

Table 3. References on Control of Parasites

	Protozoa	Trematodes	Nematodes	Cestodes
Sanitation, hygiene	(*180*)	(*1*)	(*10*)	(*105;266*)
Animal husbandry	(*23;61;81;183;275*)	(*1*)	(*41;180*)	(*69;84;105;144;193; 265;266*)
Vaccination, medication	(*21;183;190*)			(*84;105;126;142;*146; 166;218;244;*247;269*)
Heat, cooking	(*14;60;91;121;143; 177;272;273*)	(*1*)	(*41;175*)	(*175;236*)
Freezing, refrigeration	(*78;150;160;169; 175; 177*)	(*1;73*)	(*13;41;131;175; 184;279*)	(*74*)
Chlorination, disinfectants	(*14;45;48;49;*76; 128;145;151;*229;268; 271;278*)	(*124*)	(*208;283*)	
Irradiation	(*67;164;175;282*)	(*1;42;175;254–256*)	(*175;211;214*)	(*4;56;97;175*)
UV light	(*30;118;125;167; 194;240*)		(*43*)	
Ozone	(*49;113;153;240; 271;280*)			
Pressure	(*251*)		(*92;191*)	
Ultrasound	(*11*)			
Marination, pickling, smoking, fermentation	(*85;175;177;276*)	(*1;75;175*)	(*95;149;175;283*)	(*175;236*)

all parasites in meat and fish because heating is uneven and cooler spots may permit survival. Consumers are advised to cook pork and any wild game that may be infected with trichinae to an internal temperature of 160ºF (71°C). Cooking fish for 10 min at 60°C or 7 min at 70°C will kill *Anisakis* (*13;279*).

<u>Freezing</u>

For food to be eaten raw, such as fish and some meats, freezing for several days can inactivate or kill some parasites.

- Fish should be frozen at –30°C for ≥15 hours in a commercial blast freezer or at –20°C for ≥7 days in a domestic freezer to kill *Anisakis* (*184*). Some other parasitic worms require longer or shorter periods at freezing temperatures.
- Freezing meat at 5ºF (–17°C) for 20 days, –10ºF (–23.3°C) for 10 days or –20ºF (–29°C) for 6 days destroys trichinae in pork (*41;175*), but this may not be adequate for trichinae in wild game. Infective trichinae have been found in polar bear and grizzly bear meat frozen for 24 months (*41;131*).

<u>Filtration and Chlorination and Other Disinfectants</u>

- Filtration systems can remove protozoan cysts and oocysts from water. However, several outbreaks of cryptosporidiosis associated with surface water that had been filtered indicate that these systems are not always effective.
- Chlorination eliminates bacteria and some parasites from water, but cysts and oocysts are resistant to chlorine.
- Soaking of vegetables in a 1.5% bleach solution, vinegar, potassium permanganate solution (24 mg/L), or saturated cooking salt destroyed infective larvae of some nematode and trematode parasites. However, viable trematodes were detected in fish stored for a week in salt (3 g salt/10 g fish) at 26°C.
- A 10% solution of ammonium hydroxide killed 94% of *Ascaris* eggs after 3 hours but other disinfectants were less effective.

<u>Other Physical Processes</u>

- Irradiation can destroy parasites on some raw foods. Lower doses of irradiation (0.5–0.7 kGy) damage larvae and inhibit infectivity, but larger doses (6–7 kGy) are required to kill all the trichinae in meat. Irradiation doses of 0.1–0.15 kGy have been reported to kill trematode cysts in fish. However, doses of 5 kGy may be necessary to completely inactivate protozoan oocysts (*282*).
- High hydrostatic pressure has been reported to be a potentially useful non-thermal method for killing *Anisakis*.
- Ultraviolet light can disinfect water containing *Giardia* cysts.
- Ozone kills protozoan parasites in water.
- Ultrasound treatment inactivates *Cryptosporidium* oocysts in water.

<u>Life Cycle Targets</u>

Another approach to the control of parasites involves an examination the life cycles of parasites to find weak links where the cycles may be broken. For example, persons carrying adult tapeworms can be treated with anthelminthic drugs to eliminate adult worms that are producing eggs and thereby reduce the incidence of cysticercosis.

Parasites spend some time in the environment as cysts or eggs but these are resistant to desiccation and other stresses. *Fasciola* cysts, for example, can survive in running water for as long as 122 days and in pasture for up to a year, and *Giardia* cysts can survive for months in cold water.

Many parasites live in one or more animals during different stages of their life cycle, and control of these animals could potentially reduce parasite numbers. However, it is impossible to completely control populations of wild animals and it is not practical to attempt to eliminate some intermediate hosts such as snails and small crustaceans from every water source. Some parasites can complete their life cycles in other animals, including domestic and wild carnivores and omnivores. For example, wolves, bears, and other fish-eating mammals and birds can also serve as definitive hosts for the fish tapeworm, *Diphyllobothrium*, and there are reports that dogs (*141*) and bear (*260*) can serve as intermediate hosts for the pork tapeworm, *Taenia solium.* Beavers and other wild and domestic animals can harbor protozoa infective to humans. These animals act as reservoirs of infection and therefore proper treatment of human wastes may not completely eliminate the threat of these parasites.

Life Cycles of Parasites

Parasitic worms usually have distinct larval and adult stages which often live in different species of animals. Animals that harbor the mature adult worms are called **definitive hosts**; animals that harbor the immature, larval forms are **intermediate hosts**. Parasites may be present in other animals (**transport hosts**) but not undergo any growth or development in them. Some parasites have a complex life cycle involving several host animals. In other cases, an animal or human with poor sanitary habits may directly reinfect themselves. Most parasites have a resistant, resting stage (egg or cyst) which can survive for long periods in the environment and may survive sanitizing treatments. Larval worms, embedded in meat, fish, or shellfish, are moderately thermotolerant and may not be killed by light cooking.

Cells of parasitic protozoa vary somewhat at different stages of their life cycle. However, many do not have different definitive and intermediate hosts.

Direct reinfection

Parasite in intestine → eggs or cysts in feces → ingestion of eggs/cysts on contaminated hands, water, fresh fruit or vegetables

- Examples: *Ascaris*, *Cryptosporidium*, *Cyclospora*, *Giardia*, *Entamoeba*

Completion of life cycle in one host

Consumed as encysted larvae in infected meat, these parasites mature in the human GI tract, produce larvae which migrate to the muscles, and encyst. The encysted larvae can only mature when the muscles are consumed by another host animal.

- Example: *Trichinella*

One intermediate host

<u>Snail/slug as only intermediate host</u>

Parasite in human intestine or lung → eggs expelled in feces or sputum → eggs hatch into miricidia (larvae) in water → miricidia penetrate snails and undergo development:

(1) → larvae emerge from snails and encyst in water or on aquatic plants → humans consume contaminated water or plants

- Examples: *Fasciolopsis*, *Fasciola*

(2) → humans consume raw or lightly cooked snails or slugs containing larvae

- Example: *Angiostrongylus*

<u>Shellfish as host</u>

Parasite in human intestine → cysts in feces deposited or washed into water → cysts taken up by clams, mussels, oysters, etc. → humans consume raw or lightly cooked, contaminated shellfish

- Example: *Cryptosporidium*

<u>Mammal as only intermediate host</u>

Parasite in human intestine → eggs or cysts in feces deposited in environment → eggs or cysts consumed by pigs or cattle → larvae or protozoa migrate to muscles → humans consume infected meat

- Examples: *Taenia* spp., *Toxoplasma*

Two intermediate hosts

<u>Snails, crustaceans and fish as intermediate hosts</u>

Parasite in human intestine or lung → eggs released in feces or sputum → eggs hatch into miricidia (larvae) in water → miricidia penetrate snails and undergo development → larvae emerge from snail and penetrate crustacean (crab, shrimp, or crayfish) or fish → humans consume raw or lightly cooked fish or crustacean

- Examples: *Paragonimus*, *Gnathostoma*, *Clonorchis*/*Opisthorchis*

<u>Mammals as intermediate hosts</u>

Parasite in human or animal intestine → cysts in feces deposited in environment → cysts consumed by pigs or other animals → infected meat (e.g. pork) consumed by cats → oocysts in cat feces → oocysts inhaled or ingested by humans

- Example: *Toxoplasma*

Protozoan Parasites

Intestinal protozoan parasites in humans typically cause mild to moderate diarrhea although malnourished children, the elderly, and the immunocompromised may suffer prolonged and intense gastrointestinal symptoms that can be life threatening. Some protozoa can penetrate the intestinal wall and cause symptoms elsewhere in the body. Some infections are asymptomatic. Thick-walled cysts or oocysts are passed in the feces and may be shed for weeks after symptoms have subsided. Many protozoa can live and reproduce in more than one animal species but they do not grow or reproduce in foods or in the environment. Five of the most common parasites will be considered here.

- *Cryptosporidium parvum*, *Cyclospora cayetenensis*, and *Toxoplasma gondii* belong to the Sporozoa group. They have no specialized structures for locomotion and reproduce by both sexual and asexual multiplication. *Cryptosporidium* and *Cyclospora* are coccidian parasites that multiply both sexually and asexually within the human intestine. Following sexual reproduction, they produce oocysts that are passed with the feces and, when ingested by another human or animal, start another round of infection. The sexual cycle of *Toxoplasma* is confined to cats, which eliminate oocysts in their feces. In other animals, including humans, the ingested or inhaled oocysts excyst in the small intestine and the resulting cells penetrate the intestinal wall and disperse through the body. They may have severe effects on newborn offspring of infected mothers. These cells may also encyst in the muscles, heart, brain or other tissues and survive there for years. These encysted forms are also infective to other animals that consume meat containing them.
- *Entamoeba histolytica* moves by means of cytoplasmic extensions or pseudopods and reproduces asexually. Ingested cysts release trophozoites in the intestine. These cells may irritate the intestinal lining, causing bloody diarrhea, and in some cases they migrate to the liver or brain, causing abscesses (*120*). Humans appear to be the main host for this species.
- *Giardia lamblia* has long flagella for locomotion and reproduces asexually. When infective cysts are ingested in contaminated food or water, active trophozoites are released, attach to the intestinal wall and reproduce. As few as 10 cysts may be sufficient to cause prolonged diarrhea (*201*). Many wild and domestic animals also harbor *Giardia*. Some isolates from animals (livestock, dogs, cats, beavers, rats) are infective to humans while other strains appear to infect only animals (*162*).

Toxoplasma

Toxoplasma gondii may be the most widespread of the human protozoan parasites, with up to 40% of persons in developed countries and up to 80% of those in underdeveloped areas of Central and South America estimated to be infected (*130*). In places such as France where it is customary to eat some raw or lightly cooked meat, there is a higher incidence of infection. One survey found that 84% of pregnant women in Paris had been exposed to *T. gondii* before becoming pregnant as compared to 32% of pregnant women in New York. In most cases, infections are asymptomatic but consequences can be devastating for the immunocompromised and for the unborn children of women who become infected during pregnancy (*253*). While a pregnant woman rarely notices that she has become infected, *Toxoplasma* can cross the placenta and infect the fetus. The most common effect of such infection in children is diminished vision or blindness after birth; more severe effects include hydrocephalus, convulsions, and calcium deposits in the brain. Toxoplasmosis is responsible for the deaths of 10–30% of AIDS patients in Europe and the United States and causes encephalitis in many immunosuppressed patients (*130*). Immunocompetent adults may also suffer symptoms of retinitis and enlarged lymph nodes after exposure to infected meat or water (*26;44*).

Two reviews describe the variety of effects *T. gondii* has on human health (*22;253*). There is not a lot of genetic diversity in *T. gondii* but three main lineages have been identified. Current research is seeking to delineate virulence factors and to determine whether some strains are more virulent than others or are more often associated with specific symptoms (*2;16;25;32;65*).

T. gondii can infect virtually all warm-blooded animals, but only cats (both wild and domestic) serve as the definitive host and can excrete up to 800 million infective oocysts in their feces (*64*). A recent survey of cats at spay/neuter clinics in Ohio revealed that 48% of all cats were infected with *T. gondii*, with a higher incidence in outdoor cats (*66*). These oocysts can survive for long periods in the environment and may be spread by the wind or by a variety of insects and earthworms and contaminate foods ingested by humans and other animals. *Toxoplasma* cysts that apparently washed into a reservoir in British Columbia after heavy rains caused the largest reported outbreak of waterborne toxoplasmosis in 1994–1995 (*26*). At least 100 people had acute symptoms and twenty of those suffered retinitis of varying degrees of severity (*28*). It was estimated that several thousand people in the city of Victoria became infected during this outbreak but most were asymptomatic. Domestic and feral house cats and cougars in the area tested positive for toxoplasmosis. At the time, the reservoir water was treated with chloramination but was not filtered.

In animals other than cats, *Toxoplasma* cells migrate out of the intestine and encyst in muscle tissue. These muscle cysts may persist for the life of the animal and are also a source of infection — whether it be cysts in muscles of mice and wild birds that infect house cats or cysts in pork or mutton that infect humans. Pork has been considered the main vehicle for exposure of humans to *T. gondii*. Seroprevalence rates among pigs, particularly young animals, appear to have fallen during the past few decades (*176*) but some surveys still show a high prevalence of *T. gondii* infection in market-weight pigs (*64*). Some recent surveys of meat from grocery stores have demonstrated the presence of *Toxoplasma* in a greater proportion of lamb samples than in pork (*12*). *Toxoplasma* cysts are also found in meat of rabbits and some other domesticated animals but are rarely observed in beef or horse meat. Cysts in raw goat's milk have caused human infections but bovine milk does not appear to be a vehicle of infection.

Surveys of wild animals suggest that up to 80% of black bear and white-tailed deer in the U.S. contain *T. gondii* cysts in their muscles (*130*). Marine mammals also harbor *Toxoplasma*, and one possible source of infection in the marine environment includes shellfish which can filter oocysts from sea water. Raw, contaminated oysters could also cause human infections (*170*).

T. gondii cysts in meat can remain viable for weeks at refrigeration temperatures (1–4ºC) but can be destroyed by freezing at <–12ºC, heat >67ºC, and irradiation (*169*; Table 3) But oocysts spread in the environment by cats may be more difficult to control as they can be a source of infection to cat owners who permit their cats to roam outside and oocysts can adhere to berries and vegetables that are eaten raw (*158*).

Cryptosporidium

During the past decade, numerous outbreaks of cryptosporidiosis have been described. Details on several of these outbreaks are provided in Table 4. Perhaps the most infamous outbreak occurred in Milwaukee in 1993, where over 400,000 people suffered gastrointestinal symptoms and an estimated 69 died. Fatalities occurred primarily among patients with AIDS or other immune system disorders (*87;137;179*). Elderly persons also had an increased risk of severe disease (*198*). The total economic cost, due to medical costs and productivity losses, was estimated at $96.2 million (*50*).

Cryptosporidium can cause mild or severe symptoms depending on the dose of oocysts ingested, the virulence of the strain of *C. parvum*, and the immunocompetence of the affected individuals (*207*). In healthy adult volunteers, the median infective dose was determined to be 132 oocysts (*68*).

Foodborne outbreaks of *Cryptosporidium* have been associated with raw produce apparently contaminated by infected food handlers and cider and unpasteurized milk that may have come into contact with cattle feces. *Cryptosporidium* oocysts can survive on stainless steel surfaces for several hours and are resistant to a 5% bleach solution, indicating the potential for cross contamination (*59*).

Water containing oocysts can be a source of contamination when it is used for washing fresh fruits and vegetables and when it is used as an ingredient in processing foods. When contaminated water was used to make beer and a carbonated cola beverage, there was an 85% loss of viability within 24 hours. In contrast, only a 35% viability loss was observed in orange juice and infant formula made with contaminated water (*89*).

Oocysts can survive in fresh, brackish and salt water at 15 and 30ºC for several months and are readily filtered out of the water and taken up by clams, oysters and other shellfish (*77;88;103; 107;197*). As yet, no outbreaks of cryptosporidiosis associated with shellfish have been reported but surveys of shellfish from various bodies of water including some commercial beds reveal that *Cryptosporidium* is often present (65–81% of sites or times sampled along the Atlantic coast) (*79;80;102; 174*). Cooking will kill these parasites, but those who

Table 4. Recent outbreaks of cryptosporidiosis.

Location	Year	Vehicle of infection	Cases	Deaths	Ref.
Queensland, Australia	2001	Unpasteurized milk	8	0	(*122*)
Ireland	2000	Drinking water	576	0	(*99*)
England	2000	Drinking water	58	0	(*136*)
Washington DC	1998	Raw produce; Foodhandler	88	0	(*228*)
Spokane, WA	1997	Green onions (?); Foodhandler (?)	51	0	(*227*)
Florida	1995	Outdoor water faucet	77	0	(*230*)
Minnesota	1995	Chicken salad	50	0	(*20*)
Las Vegas, NV	1994	Drinking water	78	20	(*101; 237*)
Maine	1993	Cider	213	0	(*189*)
Milwaukee, WI	1993	Drinking water	>400,000	69	(*50; 87; 137; 179; 179; 198*)

prefer raw shellfish have another foodborne pathogen to be concerned about.

C. parvum oocysts have also been detected in flies, and these may serve as a vector by transferring oocysts from feces to foods (*109*).

An excellent recent review discusses detection methods and processing controls that may be useful to the food industry in reducing or eliminating this parasite from human foods (*188*). Attention should be focussed on a clean water supply, the possibility of contaminated raw ingredients, rodent and insect control, and employee hygiene.

Cyclospora

Only recently was *Cyclospora cayetanensis* recognized as a cause of foodborne illness. Several large, multistate outbreaks associated with consumption of imported raspberries occurred in the 1990s. Other outbreaks implicated salad greens, basil, or other berries as vehicles of infection (Table 5). These recent foodborne outbreaks are believed to have resulted from the use of contaminated water in irrigating or in applying pesticides or fertilizers to crops. When oocysts are first eliminated in feces of their host, they are unsporulated and are not immediately infective. Therefore, it is thought that infected food handlers are probably not capable of transmitting this disease. However, the environmental conditions necessary to induce sporulation are unknown and it is possible that sporulation could occur rapidly under some conditions.

Cyclospora is endemic in many developing countries where the lack of clean water and sanitary facilities facilitate transmission by the fecal–oral route. Some epidemiological studies have found an association between ownership of domestic animals and cyclosporiasis. However, humans are the only known host for *C. cayetanensis*. There is evidence that people living in endemic areas and eating local food develop an immunity to *Cyclospora*. People may pass oocysts but experience no gastrointestinal symptoms (*19*). *Cyclospora* causes prolonged diarrhea that can be debilitating particularly in infants and the immunocompromised (*18;90*). There have been a few reports of severe complications of infections including Guillain-Barré syndrome (*232*) and reactive arthritis (Reiter) syndrome (*46*).

Entamoeba

Entamoeba histolytica is an important cause of diarrhea in people in tropical and subtropical countries. Cases in the U.S. generally occur in immigrants, travelers returning from endemic areas, and in persons living in states along the border with Mexico. The closely related and morphologically indistinguishable species *E. dispar* is also found in the human intestine but does not cause diarrhea. Some older data on prevalence and epidemiology of *E. histolytica* may

Table 5. Reported foodborne outbreaks of cyclosporiasis.

Location	Date	Vehicle of infection	Cases	Reference
Germany	2000	Salad	34	(*63*)
Pennsylvania	2000	Imported raspberries	54	(*133*)
Ontario and Florida	1999	Berries	198	(*128*)
Missouri	1999	Basil (imported or domestic)	64	(*172*)
Ontario, Canada	1998	Imported raspberries	315	(*39*)
US (13 states), Canada (1 province)	1997	Imported raspberries	1012	(*129*)
Virginia, Maryland, Washington DC	1997	Basil	341	(*35*)
Florida	1997	Mesclun lettuce	67	(*36; 115*)
US (20 states), Canada (2 provinces)	1996	Imported raspberries	1465	(*34; 82*)

be inaccurate because tests were not capable of distinguishing the two species until recently. *E. histolytica* is the second leading parasitic cause of death (after malaria) and has been estimated to infect 50,000,000 people worldwide of whom 40,000 to 100,000 die yearly. Over one million cases of amoebiasis were reported in Mexico in 1996 (*257*).

Many people exposed to *E. histolytica* remain asymptomatic but even these people may be sources of infection. Recent data from Mexico showed that 340 asymptomatic carriers excreted an average of nearly 4,000 *Entamoeba* cysts/g feces. Cysts from some of these persons were likely to have been *E. dispar* but the large numbers of cysts produced indicate a significant potential for transmission if sanitary conditions are inadequate. Males produced six times as many cysts as females, and these cysts were significantly smaller (*96*).

Studies in an endemic area of Bangladesh revealed that some children develop resistance to *E. histolytica* while others are genetically more susceptible to amebiasis (*119*). These results indicate that it may be possible to produce an effective vaccine. The mucin layer in the intestine inhibits attachment of the amoebae but if it is breached, *Entamoeba* may cause colitis and invade other tissues, particularly the liver (*120;257*). Invasive amebiasis occurs almost exclusively in adults and is reported to be up to ten-fold more common in males (*24;249*).

Epidemiological studies have demonstrated that contaminated drinking water is an important vehicle for transmission in underdeveloped countries. Epidemics have occurred in developed countries when there was a breakdown in a water purification system or cross-contamination between sewage and drinking-water pipes (*17*). Foodborne transmission is often associated with an infected food handler and also occurs when produce is freshened or crops are irrigated with contaminated water. Flies, cockroaches and other insects may also transfer cysts from feces to foods (*163*).

Giardia

According to the Centers for Disease Control, *Giardia lamblia* (*intestinalis*) is the most commonly diagnosed intestinal parasite and causes an estimated two million cases of diarrhea in the U.S. each year (*38*). *Giardia* cysts may be released in the stool for weeks and even months and may be present in concentrations as high as 10^7/g (*202*).

Foodborne giardiasis can result from the use of contaminated water for irrigating or washing fruits and vegetables. A survey, in the U.S. and Central America, of 25 samples of water used to irrigate food crops traditionally eaten raw revealed that 60% contained *Giardia* (*261*). *Giardia* cysts were detected in 2% of seed sprouts tested in Norway; source of the contamination in the sprouts was not the water used for sprouting but the unsprouted seeds themselves (*235*).

Food handlers who are infected themselves or have had contact with the feces of infected children have been implicated in some foodborne outbreaks. An outbreak in 1996 was traced to contaminated ice cream, and poor personal hygiene was cited as a contributing factor (*40*). Prepared foods such as sandwiches, salads, canned salmon, and ice have also been implicated in foodborne outbreaks (*201;241*). *G. lamblia* cysts have also been detected in flies that may serve as a vector for contamination of foods (*109*).

Giardia cysts are present in surface waters, even in areas remote from significant human activity, and apparently originate from wild animals. (Giardiasis in backpackers has been nicknamed beaver fever.) Cysts have also been detected in some groundwater samples (*117*), in well water associated with acute digestive disorders (*100*), and in water distribution systems in cities in Australia (*52*) and Canada (*274*). *Giardia* contamination of surface and well waters may originate from wild animals, domestic animals and human sewage. *Giardia* cysts are highly concentrated in some cattle feces (5800 cysts/g) (*127*) although some strains of *Giardia* do not readily infect humans (*9*). Of 39 outbreaks of this disease associated with drinking water reported to the CDC in 1999–2000, 6 outbreaks, affecting 52 people, were traced to the presence of *G. intestinalis* in inadequately treated well or river water or in water contaminated by cross connections with pipes containing sewage or drinking water for animals (*30;125;165*).

Parasitic Worms — Nematodes

Anisakis *and* Pseudoterranova *(Sealworm, Codworm)*

Anisakiasis was first recognized as a human disease about forty years ago but became more familiar to U.S. consumers about 15 years ago when people occasionally noticed live, wriggling worms in fish that had been cooked in microwave ovens. The increasing popularity of Japanese and other ethnic dishes containing raw fish has aroused more concern about fish parasites (*246*). Fish most commonly identified as vectors for *Anisakis* are chub mackerel and flying squid in Japan and pickled anchovies, raw sardines, cold smoked salmon, raw or pickled herring in Western Europe and the U.S. *Pseudoterranova* infects cod causing losses of $26–50 million annually to fish processors in Atlantic Canada (*184*). Other fish, including whiting, mackerel, pollack, and flounder, may also contain these parasites (*13;86;221;222; 259*). A survey of fish in a Belgian market revealed that approximately 11% were infected (*221*) while a recent survey of farmed salmon in Norway did not find any infected fish (*178*). Some surveys have shown that the rate of infection with anisakid larvae varies by season and increases with fish size (*148*). Water temperatures and seal populations may also affect the abundance of these parasites (*185*).

Dolphins and whales are the normal definitive hosts for *Anisakis*, and seals and sea lions are definitive hosts for *Pseudoterranova*. Adult worms in these marine mammals produce eggs that pass out with the feces, hatch, and the larvae are consumed by shrimp. When fish or squid eat the shrimp, the larvae are released, bore through the stomach wall, and may remain in the abdominal cavity or penetrate nearby muscles. The life cycle is completed when infected fish or squid are eaten by marine mammals (*184;243*).

Humans are an accidental host and these larvae cannot mature in the human gut. Instead the worms burrow into the intestinal or stomach wall and may wander to the liver, lungs or other tissues, causing gastric disturbances and allergic reactions. In fact, some people who appear to be allergic to "fish" are actually allergic to *Anisakis* in the fish muscle (*13*). It should be noted that even if larvae are killed by cooking, this will not completely eliminate the potential for causing allergic reactions in sensitive people (*13;55;71;86;155;181;184;217*).

Ascaris

Ascaris lumbricoides is a common intestinal roundworm parasite infecting an estimated one-quarter of the world's population (*116*). In some areas without adequate hygiene, babies may become infected within months after birth and the subsequent growth of the worms stunts growth and contributes to diarrheal infections and early childhood mortality (*53;192*). Many infected adults do not exhibit symptoms although these worms are known to irritate the intestinal lining and interfere with the absorption of fats and protein. In some cases, *Ascaris* causes more severe infections in the liver or lungs (*154;242*).

Humans are the only known host for this roundworm. Eggs passed out with feces may be ingested by the same or another person who drinks contaminated water, eats with dirty hands, or eats uncooked vegetables that have been fertilized with contaminated human wastes. Upon ingestion, the eggs hatch in the intestine and the worms may migrate to the lungs or liver before returning to the intestine and maturing. Techniques for the detection and enumeration of *Ascaris* eggs on vegetables have been developed and may be useful for screening fresh vegetables for contamination (*234*).

Angiostrongylus cantonensis *and* A. costaricensis *(Rat lungworm)*

As the common name suggests, the normal definitive hosts of these parasites are rats and other rodents. However, individual cases and outbreaks of human infection with these parasites have been reported — usually from Southeast Asia (*157;264*), the Pacific islands (*215*) or Latin America (*161*). Some individual cases have been reported from the U.S. (*140;199*), and an outbreak involving 12 American tourists returning from Jamaica occurred in 2000 (*252*). Because humans are not a natural host, these parasites do not migrate to the lungs in humans but rather to the tissues surrounding the brain where they cause eosinophilic meningitis (*A. cantonensis*) or they remain in the abdomen causing severe intestinal upset (*A. costaricensis*). Usually infections are self limiting although some serious cases (*37;224;281*) and even deaths have been reported.

The usual life cycle of *A. cantonensis* involves a snail or slug as intermediate host with the rat as final host. Infected snails and rats have been detected in the southern U.S. and on many Caribbean islands (*168*). Sometimes freshwater fish, frogs, or crayfish serve as transport hosts. People acquire these parasites by consuming raw or inadequately cooked infected snails or transport hosts (*264*). In a New Orleans case, an 11-year-old boy admitted eating a raw snail on a dare. Infected snails traversing lettuce leaves or other vegetables in the field may deposit infective larvae in their slimy mucus trails (*250*) or small infected slugs may hide amid the folds of vegetable leaves and be eaten inadvertently. In the tourist outbreak a salad was epidemiologically related to infection (*252*), while mint leaves were implicated in a Guatemalan outbreak (*161*).

Gnathostoma *sp.*

Nematodes of the genus *Gnathostoma* cause a foodborne human illness characterized by creeping skin eruptions that are sometimes accompanied by erythema and local edema. Occasionally the worms migrate to the eye or other internal organs and may cause meningitis and other serious illness (*15;171*). This disease occurs primarily in some Asian and Latin American countries although it has been reported in the U.S. and Europe in travelers returning from endemic areas in Asia and Africa (*114;171;226*). Sixteen such travelers were identified at a London hospital for tropical diseases during a twelve-month period (*41*).

Gnathostomes usually utilize two intermediate hosts. Adult worms living in wild or domestic cats and dogs release eggs with the host feces. Larvae hatch in fresh water and are ingested by small crustaceans that are then eaten by fish, frogs, or other animals. In these animals, the larvae migrate out of the gut and encyst in muscles. Consumption of raw or lightly cooked, infected fish, shrimp, frogs, etc. introduces the parasite into humans or other animals. Gnathostomes are active little parasites and migrate out of the gut to various tissues. In cats and dogs, they eventually migrate back to the stomach and complete their life cycle while in humans they often migrate to the skin, causing a creeping eruption.

Cases of gnathostomiasis in Japan have been traced to consumption of raw fish and shrimp (*3;204*) while in Mexico and other Latin American countries, patients often report consumption of cebiche (ceviche), a dish made with raw fish (*206;239*). A survey of swamp eels purchased at markets in Bangkok revealed that 74% contained gnathostomes during the rainy season while only 8% were infected during the dry season (*258*).

Trichinella spiralis *(Trichinosis)*

T. spiralis is a cosmopolitan parasite occurring in numerous carnivores and omnivores. Humans in the U.S. have traditionally acquired this nematode by eating encapsulated larvae in raw or lightly cooked pork. Improved swine feeding practices and regular inspections at slaughterhouses have drastically reduced the incidence of trichinae in raw pork in the U.S. During 1997–2001, only 17% of cases were associated with commercial pork and 13% of cases were traced to non-commercial pork (*41*). However, a small percentage of commercial hogs, estimated at 0.1% (*175*), still contain this parasite. Occasional large outbreaks still occur, reminding us to cook potentially contaminated meat well. In 1990, 105 people in the U.S. contracted trichinosis in two outbreaks traced to raw sausage made from pork from commercial hogs (*219*). Commercially prepared raw sausage and contaminated ground meat were responsible for 52 case of trichinosis in Germany in 1998–1999 (*37*). In some European countries raw horse meat, also a vehicle for infection (*6*), is an ingredient in traditional foods.

Trichinosis in the U.S. is a notifiable disease and cases have steadily declined from the late 1940s when there was an average of 400 cases of overt illness per year to 1997–2001 with an average of 14 cases/year (*41*). Some recent outbreaks have been traced to wild boar, walrus or bear meat (*110*), and wild game meat was reported to be the most common source of infection in the U.S. during 1997–2001 (*8;41;131;270*). Bear meat was responsible for five outbreaks accounting for 29 (40%) cases, and cougar and wild boar meats were associated with one case each. Wild game is a source of trichinosis in other countries as well. At least 16 cases associated with walrus meat were reported from Canada in 2002 (*131*). In February 2003, an outbreak in Poland affecting at least 124 people is believed to have been caused by infected wild boar meat although other wild game might have been involved (*216*).

Trichinella completes one round of its life cycle in one host animal. After infective larvae in meat are ingested, they excyst in the intestine, mature, and a new generation of infective larvae is produced. They burrow out of the intestine and travel throughout the body. Highest concentrations of larvae in pigs are found in the diaphragm and tongue but they are also present in various skeletal muscles. The encapsulated larvae may remain alive for many years, but often they become calcified and die within 6–12 months. In order for the larvae to mature, the infected muscle must be eaten by another carnivore.

Parasitic Worms — Trematodes

Clonorchis/Opisthorchis *(Liver flukes)*

In eastern and southeastern Asia, several related parasitic worms of the genera *Clonorchis* and *Opisthorchis* lodge in the liver of infected humans and other animals causing blockage and hyperplasia of the bile passages. Light infections may cause mild symptoms of liver dysfunction while heavier infections result in hepatitis and digestive disorders. Several epidemiological studies have demonstrated a significant association between chronic infection with these liver flukes and a type of liver cancer, cholangiocarcinoma (*277*).

Liver flukes have a complex life cycle involving two intermediate hosts, snails and fish. Humans and other fish-eating animals complete the life cycle by eating raw, infected fish and digesting out the cysts. Then the larvae migrate to the liver, mature, and produce eggs.

Traditionally, cases of this disease have been confined to Asia. The parasites have been detected in fish, cats and other animals in most Asian countries and also in Siberia, Kazakstan, the Ukraine, and Germany. With the influx of Asian immigrants to Australia and other Western countries since the 1970s, human infections with liver flukes have been diagnosed in numerous countries where the disease is not endemic (*57*).

Liver flukes are unlikely to become an established or widespread problem in the U.S. However, these parasites may be present in immigrants from Asian countries and there is a potential for contaminated freshwater fish to be imported from endemic areas.

Fasciola hepatica *(Liver fluke)*

F. hepatica is a well-known parasite of domesticated ruminants causing significant economic losses in the cattle and sheep industries of some countries (*124;156;210*). Human cases usually occur in parts of countries in South America, North Africa and the Middle East where sanitary facilities are inadequate and clean water is not available. In some areas of Bolivia more than 60% of the local population is infected, and a large outbreak affecting 10,000 people occurred in Iran in 1988 (*75;182;238*). Human outbreaks and cases may occur where this parasite is a livestock problem but also occur in areas where the animal parasite burden is low (*182*). People in developed countries are also occasionally infected if salad greens have been contaminated (*112;139*).

Disease symptoms include fever, abdominal pain, weight loss and enlarged liver. Some evidence suggests that heavy or chronic infections of this parasite are associated with liver tumors (*124*). Experimental data demonstrated that *Fasciola* infections in mice can cause an increase in mutations in nearby liver cells (*98*).

Adult *Fasciola* inhabit the liver, producing eggs that pass out with the feces. The eggs hatch in water, larvae penetrate snails and undergo further development before leaving the snail and encysting in water or on vegetation in or near the water. During rainy spells, cysts may also be present on field plants such as dandelion leaves. *Fasciola* cysts can survive in running water for as long as 122 days, in pasture for up to a year, and even for a few months in hay (*124*). Humans often become infected from eating watercress (*112;139*) and a variety of other plants (*75;124*) growing near contaminated fields and from drinking contaminated water (*70;135*).

Fasciolopsis buski *(Fasciolopsiasis, Intestinal fluke)*

F. buski is the largest trematode infecting humans, with adult worms typically 8–10 cm long. Worms most commonly inhabit the intestines of farm pigs and school age children in Asian countries. Anemia, headache, and gastric distress characterize mild infections while heavier infections cause severe abdominal pain, malnutrition, edema, and sometimes intestinal blockage.

This parasite requires a single intermediate host. Eggs are deposited in feces, hatch in water, and the larvae penetrate snails and undergo development. After 4–6 weeks the parasites emerge from the snails and encyst in water or on aquatic plants. Consumption of contaminated water or of raw aquatic vegetables allows for completion of the life cycle (*108*).

This parasite is not likely to be a problem in the U.S. except among immigrants and foreign travelers. Contaminated vegetables that might be imported from endemic areas would probably be dried or canned and both processes would destroy the parasite.

Paragonimus *(Lung fluke)*

Nine species of the trematode *Paragonimus* reside in many parts of the world, including North America, and infect the human lung and occasionally other tissues, including the brain. Symptoms of diarrhea, abdominal pain, and fever may occur early after infection and progress to coughing and thoracic pain as the worms settle in the lungs. Infections are sometimes initially misdiagnosed as tuberculosis, which can delay effective treatment (*196;267*).

The life cycle of this parasite includes two or more intermediate hosts: a freshwater snail, then a crab or crayfish, and sometimes an animal which eats the crabs and then is consumed by humans. The worms can mature only in humans and some wild carnivores. When other mammals, such as wild boar, consume infected crabs, *Paragonimus* cannot complete its life cycle but migrates to the muscles and encysts. If humans consume infected boar meat, the worms emerge from the cyst and migrate to the lungs where they mate and produce eggs.

Most commonly, people become infected by eating raw or pickled crabs, including a Chinese delicacy called “drunken crab” (*47;54;147*). But some cases in Japan have been traced to undercooked wild boar meat (*196;245*), and undercooked guinea pig meat is believed to be a vector in some South American countries (*132*). Many of the cases diagnosed in the U.S. occur in immigrants who were already infected when they came to this country or continue to eat imported raw crustaceans (*187*). Cases acquired in the U.S. have been traced to consumption of raw crayfish (*58;225*). Neither pickling nor salting destroys *Paragonimus*, but adequate cooking will make crabs, crayfish and meat safe to eat.

Parasitic Worms — Cestodes

Taenia *spp.*

Tapeworms of the genus *Taenia* may be the most familiar of foodborne parasitic worms, with adults measuring 3–5 meters in length in the intestine of human hosts. Three species are of primary concern to humans and all have intermediate stages in important domestic animals: *Taenia saginata* in cattle and *Taenia solium* and *Taenia asiatica* in hogs. There have been reports that other mammals, including dogs and bear (*141;260*), can serve as intermediate hosts for *T. solium*, reindeer can harbor *T. saginata*, and goats and monkeys can harbor *T. asiatica* (*29*).

Although *Taenia* spp. are cosmopolitan, modern sanitary facilities and animal husbandry practices in developed countries have greatly decreased risk of infection (*265*). However, in some regions of the world these parasites are a significant problem. *T. solium*, in particular, may be present in as many as 20% of hogs (resulting in loss of productivity) and causes debilitating human disease that is difficult and expensive to treat (*72;134;220*).

Taenia life cycles involve two mammalian hosts. Adults in the human intestine may live for more than twenty years, producing several thousand eggs daily that pass out with the feces. If these are consumed by an intermediate host, they develop into larvae (cysticerci) which migrate to the muscles. Consumption of raw or inadequately cooked, infected beef or pork introduces the larvae into the human intestinal tract where they mature into adult worms. Infections may be asymptomatic or may generate non-specific complaints such as altered appetite, abdominal pain, diarrhea or constipation.

Humans may also serve as the intermediate host for *T. solium* (but not for *T. saginata* or *T. asiatica*). When *T. solium* eggs are ingested via dirty hands or fecally contaminated vegetables, larvae hatch in the small intestine and travel to various tissues and organs in the body where they encyst causing cysticercosis. Some studies report that up to 40% of carriers of adult worms also have cysticercosis, indicating that fecal–oral transmission, either directly or via contaminated food or water, is common. Use of untreated urban sewage sludge on pastures may cause cysticercosis in cattle or hogs while untreated human wastes containing *T. solium* eggs, if used as a garden fertilizer, could cause cysticercosis in humans (*29*).

The most serious consequences occur when the larvae reach the brain, causing neurocysticercosis that often triggers headaches, seizures, and other neurological symptoms (*93*). This is the most common parasitic disease of the central nervous system and is a major concern in some areas of Latin America, Africa, Asia, and Eastern Europe (*83;94;200;203;205;223*). Even in the U.S., where infection with adult tapeworms is relatively rare, more than 1000 cases of neurocysticercosis occur each year (*31*). Most cases are diagnosed in immigrants from endemic areas, and approximately 10–12% of emergency room visits for seizures in southern California and New Mexico were due to this disease. Cases acquired in the U.S. can sometimes be traced to contacts with immigrants, including cooks, infected with the pork tapeworm, who may cause foodborne outbreaks of neurocysticercosis (*33;209*).

Diphyllobothrium *spp. (Fish tapeworm)*

Diphyllobothrium spp. has long been associated with cultures that consume raw or lightly cooked fish (*231*). At present, human infections are most common in Finland, Scandinavia, Alaska, Canada, Japan, and Peru (*61*).

Humans are one of the primary definitive hosts and the adult tapeworm may grow to a length of ten meters in the intestine. Eggs pass out with feces, hatch in water, and the larvae are eaten by a copepod. Fish that eat copepods become infected and then pass the parasites on to humans who eat raw fish. *D. latum* is widely distributed in pike and, to a lesser extent, in walleye and yellow perch in central Canada and has also been found in fish in northern Minnesota and northern Michigan. Trout and salmon may carry the larvae of *D. latum* in South America but not in North America. Some other species of *Diphyllobothrium* have been isolated from salmon in Japan and Alaska. Wolves, bears, and other fish-eating mammals and birds can also serve as definitive hosts for some species of *Diphyllobothrium*. Their feces will contain parasite eggs that can wash into lakes or streams.

Usually the presence of one worm causes no symptoms but many worms can cause abdominal pain, diarrhea, and anemia. Humans cannot serve as true intermediate hosts for this parasite (as is the case for the pork tapeworm). However, consumption of water containing newly hatched larvae or infected copepods can give rise to a condition called sparganosis. The ingested larvae penetrate the intestinal wall and migrate to tissues just under the skin causing some discomfort before they die.

Echinococcus *spp.*

The adult stage of this tapeworm lives in dogs, foxes and other canids and intermediate stages normally infect sheep, goats, pigs, horses, and cattle. Humans can also serve as an intermediate host if they ingest tapeworm eggs in contaminated water or on raw, contaminated vegetables. The larval tapeworms form fluid-filled cysts (called hydatid cysts) in the liver, lungs and other organs of intermediate hosts. Tissue damage may be severe in some cases (*106;262*). This disease is endemic in some areas of north Africa, Asia, the Middle East (*5;263*), and some European Mediterranean countries (*152;248*) and occasional cases may be seen in the U.S., usually among immigrants.

Summary

Parasites do not cause as many outbreaks of foodborne disease in the U.S. as viruses and bacteria. However, even though they are less common, some parasites can cause severe illness in elderly or immunocompromised individuals and others can have serious effects even in the immunocompetent. The organisms most likely to be of concern in the U.S. are *Anisakis*, *Cryptosporidium*, *Cyclospora*, *Giardia*, *Taenia solium*, *Toxoplasma*, and *Trichinella*. Other organisms considered in this review are uncommon in temperate climates and in areas with good sanitary facilities. However, there is the potential that some of them could be present on imported foods or in foods prepared by infected food handlers. With increasing international travel, there is also the possibility of exposure to these parasites in other countries.

Although the incidence of trichinosis has decreased in the U.S. there are still some infected pigs and pigs can also carry *Toxoplasma*. Therefore, proper cooking of pork remains important. In addition, wild game can be an important source of both of these parasites and should be well cooked. Freezing of wild game meat cannot be relied on to kill parasites.

Taenia solium, the pork tapeworm, is seldom detected in pork in the U.S. It poses the most danger to humans when the eggs are ingested and the larvae travel to the brain causing neurocysticercosis. The issue here is not the proper cooking of pork but sanitation — proper disposal of human wastes, clean hands, and washing fresh fruits and vegetables that might have been contaminated with feces containing tapeworm eggs.

Raw fish can contain *Anisakis* and some other less common parasites and, if it is to be eaten raw, should first be frozen to kill the parasites. There is a potential risk that raw shellfish will contain protozoan parasites, such as *Cryptosporidium*. Elderly and immunocompromised persons should avoid or be very cautious about consuming raw meat, fish, or shellfish.

Giardia, *Cryptosporidium*, and *Cyclospora* are all spread by the fecal–oral route and therefore sanitary procedures will aid in preventing transmission. However, these parasites may also live in a variety of domestic and wild animals and outbreaks have occurred even in developed countries where sanitary systems for human wastes are adequate. Untreated surface waters may contain these parasites and fruits and vegetables may contain resistant oocysts or cysts of these parasites if they are washed or irrigated with contaminated water.

Proper cooking of meat and fish and washing of fresh fruits and vegetables — which are standard procedures for preventing other foodborne diseases — will also be effective in killing or removing parasites from foods. Several other procedures, including freezing, irradiation, UV light, and ozonation, may also be useful in killing some parasites.

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http://fri.wisc.edu/docs/pdf/parasites.pdf

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FRI Briefings

Cryptosporidium and *Cyclospora*

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prepared by M. Ellin Doyle, Ph.D.
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***Cryptosporidium* strikes over 400,000 people in Milwaukee!**
***Cyclospora* causes diarrhea in more than 1,000 residents of the USA and Canada!**

Such dramatic outbreaks have enhanced our awareness of the potential for food- and waterborne microbes to affect large numbers of people in the USA. According to the latest *World Health Report*, "Almost half the world's population suffers from diseases associated with insufficient or contaminated water and is at risk from waterborne and foodborne diseases, of which diarrhoeal diseases are the most deadly" (*1*). As these recent outbreaks demonstrated, the USA is not an island and our citizens are also vulnerable to food- and waterborne pathogens.

What are these unfamiliar organisms and where have they come from? Parasitic protozoa are not common in developed countries. Few people, even in the medical establishment, knew much about *Cyclospora* and *Cryptosporidium* until recently. At one time it was thought that *Cyclospora* was a blue-green alga because it appeared to share some structural and chemical features with this group of prokaryotes. Later observations revealed that *Cyclospora* is a eukaryotic organism related to the coccidian parasites *Cryptosporidium* and *Isospora* and more distantly related to the microsporidia *Septata* and *Enterocytozoon*. Although some of these protozoa were isolated long ago from a variety of animal hosts and a few were known to cause human diarrhea in some tropical countries, it has only been during the past few decades, with the increase in numbers of immunocompromised persons (transplant patients, those undergoing chemotherapy, and AIDS victims) that they have become widely recognized as significant causes of human diarrhea. As recent outbreaks have demonstrated, however, immunocompetent individuals are also at risk for infection.

All of these protozoa have a similar life cycle and are likely disseminated by some variation of the fecal–oral route, possibly involving contaminated water and food (*2*). When the oocysts (infectious stages) of *Cryptosporidium*, *Cyclospora*, and *Isospora* are ingested by an individual, they pass to the small intestine where they excyst, releasing sporozoites. These cells invade the enterocytes (epithelial cells lining the small intestine) and undergo a cycle of asexual reproduction to form merozoites. When the merozoites are released from the enterocytes, they disperse to infect other intestinal cells. There may be one or many cycles of this type of asexual reproduction and then a cycle of sexual reproduction producing gametes. Fertilization results in the formation of oocysts, which are then passed out with the feces. In some protozoa, such as *Cryptosporidium*, the oocysts are immediately infective to another host while in others, e.g. *Cyclospora* and *Isospora*, the oocysts must mature for several days or longer before becoming infective.

Infectious stages of *Septata* and *Enterocytozoon* are called spores. When these are ingested and reach the small intestine, the spore contents are injected directly into an enterocyte. These parasites then multiply within the host cells and carry on many cycles of asexual reproduction. Eventually spores are passed out with the feces and are ready to infect another host (*3*).

Depending on the age and immune status of the host, the number of spores or oocysts ingested, and the pathogenicity of the parasites, these protozoa can cause asymptomatic infections, a self-limited diarrhea (usually lasting about 2 or 3 weeks), or a prolonged, severe diarrheal illness which may persist for months. Experiments with healthy human volunteers demonstrated that a dose of only 30 *Cryptosporidium* oocysts was sufficient to induce an infection in some persons, although some others who received higher doses did not develop infections (*4*). It has been hypothesized that invasion of the intestinal cells stimulates the release of cytokines which activate phagocytes. These cells then release soluble factors which increase intestinal secretions of chloride and water, thereby causing symptoms of diarrhea. *Cryptosporidium* is the best studied of this group of parasites, but some fundamental questions concerning its pathogenicity remain, such as the possible production of an enterotoxin. Although the small intestine is the main site of infection, in some heavily parasitized patients, especially in the immunocompromised, the colon and liver may be also be affected. Dissemination to other parts of the body has only been observed regularly with *Septata*.

Surveys to determine the prevalence of oocysts in stool samples generally report a higher incidence of infection in persons from Asia, Latin America, and Africa than in those from Europe and North America. *Cryptosporidium* probably causes the greatest percentage of cases of diarrhea associated with these protozoa and has been linked to outbreaks involving contaminated water in the USA (*5–7*) and England (*8*) and to outbreaks involving contaminated food and drink (*9,10*) as well as to cases of acute childhood diarrhea in developing countries, traveller's diarrhea, and chronic diarrhea in AIDS patients. Although only a small number of adults in developed countries have detectable oocysts in their stool specimens, antibodies to *Cryptosporidium* have been detected in 32–58% of population samples in Western countries (*1*). Therefore, many people in these countries have been exposed to this parasite during their lifetime. The other protozoa have been reported to cause diarrhea, at a lower frequency, in the same groups of people. All of these organisms are frequent causes of diarrhea in AIDS patients. In such patients with chronic diarrhea, 10–20% are infected with *Cryptosporidium* and 6–50% are infected with *Septata* or *Enterocytozoon*. *Isospora* infects approximately 15% of Haitian patients with AIDS but only about 0.2% of U.S. patients. This probably reflects a higher prevalence of isosporiasis in the general population in Haiti as compared to the USA (*1*).

Since the infective stages of these protozoa are present (at concentrations as high as 1,000,000/gram) in feces, some type of fecal contamination is responsible for new cases of diarrhea. Person-to-person transfer may occur in families and institutional settings such as daycare facilities. In a 1995 outbreak in Minnesota, chicken salad was apparently contaminated with *Cryptosporidium* by a food handler who operated a home daycare and had recently changed an infant's diaper. Although the infant was asymptomatic and the woman had washed her hands before preparing the salad, enough oocysts were transferred to the food to cause illness in more than half of the estimated 50 persons attending a social function (*10*).

Water contaminated with oocysts (probably originating from animals) was responsible for the massive outbreak of cryptosporidiosis in Milwaukee (*5*) and for smaller outbreaks affecting 70–100 people in Nevada (*6*) and Florida (*7*) and for an outbreak of cyclosporiasis in Chicago (*11*). *Cryptosporidium* oocysts have also been isolated from cider made from apples which had fallen on the ground in a cow pasture (*9*) and from raw vegetables in Costa Rica (*12*). *Cyclospora* oocysts (of unknown origin) on fresh berries were apparently responsible for an outbreak of diarrhea in Florida in 1995, and *Cyclospora* on raspberries imported from Guatemala was implicated in the 1996 outbreak in the USA and Canada (*13,14*). However, current methodology was not sensitive enough to detect oocysts on fresh fruit associated with these outbreaks. A variety of analytical approaches have resulted in the development of several different assays for the detection of *Cryptosporidium* oocysts in water (*15*), and a PCR assay that can detect as few as 1–10 *Cryptosporidium* oocysts in 10 mL of milk has been devised (*16*). Efforts are underway to modify these assays so that low concentrations of *Cryptosporidium* and *Cyclospora* oocysts can be detected in foods.

Cryptosporidium is notorious for its lack of host specificity, with most isolates from mammals capable of infecting many different mammalian species. In fact, a number of waterborne outbreaks of cryptosporidiosis in developed countries have resulted from contamination of drinking water sources with runoff from agricultural lands where infected cattle have grazed. Animal reservoirs are not well known for other parasitic protozoa. *Cyclospora* oocysts, identical to those observed in human samples, have been isolated from fecal samples from baboons and chimpanzees in Africa (*17*). In addition, the investigation of the Chicago *Cyclospora* outbreak indicated that rodent or bird feces may have contaminated the drinking water supply for a dormitory. No cross connections between water and sewage pipes in the building were detected. But the drinking water, stored in a rooftop tank, was not adequately protected from the environment, and animal feces were observed on the rim of the tank. *Cyclospora* has also been isolated from stool specimens from members of a Peruvian family with diarrhea and from ducks bred by the family (*18*). Although it is not clear that all of these *Cyclospora* isolates are the same species, the zoonotic transmission of *Cyclospora* is a distinct possibility.

High temperatures are known to be lethal to these protozoa and therefore boiled water and adequately heat-processed foods should be safe to consume. Recent experiments evaluating the efficacy of high-temperature–short-time pasteurization treatments demonstrated that heating to 71.7°C for 5, 10, or 15 seconds was sufficient to destroy the infectivity of *Cryptosporidium* oocysts suspended in water or milk (*19*). However, oocysts are more resistant to cold and freezing temperatures (*20*). Oocysts suspended in water retained their infectivity after 168 hours storage at +5°C and at –10°C. At colder temperatures, infectivity was destroyed: at –15, –20, and –70°C, no infective cells remained after 168, 24, and 1 hour of storage, respectively. *Cryptosporidium* oocysts are also notoriously resistant to chlorination, as seen in outbreaks involving chlorinated drinking water. Laboratory experiments demonstrated that oocysts suspended for up to 2 hours in 1.31, 2.63, or 5.25% aqueous sodium hypochlorite were still infective to mice (*21*).

As these data demonstrate, it is possible to eliminate *Cryptosporidium* and probably other oocyst- and spore-forming protozoa from food and water with appropriate conditions of heat and freezing. However, viable oocysts and spores persist in contaminated foods that are eaten fresh, such as fruits and salad ingredients, and in contaminated drinking water. Chlorination will not destroy the oocysts in water, and filtration systems may have an inadequate pore size to exclude oocysts or may become clogged or overwhelmed during certain seasons, such as spring, when snow melts and rains may be heavy. Although much research has been devoted to *Cryptosporidium*, methods for its control and elimination are not yet adequate. Further research is also necessary to refine methods for the detection of the other protozoa and to determine conditions necessary to destroy their spores and oocysts.

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