Foodborne Toxoplasmosis

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Toxoplasmosis can be due to congenital infection or acquired infection after birth and is one of the leading illnesses associated with foodborne hospitalizations and deaths. Undercooked meat, especially pork, lamb, and wild game meat, and soil contaminated with cat feces on raw fruits and vegetables are the major sources of foodborne transmission for humans. The new trend in the production of free-range organically raised meat could increase the risk of Toxoplasma gondii contamination of meat. Foodborne transmission can be prevented by production practices that reduce T. gondii in meat, adequate cooking of meat, washing of raw fruits and vegetables, prevention of cross contamination in the kitchen, and measures that decrease spread of viable oocysts into the environment.

Toxoplasma gondii infections are widely prevalent in human beings and food animals [1]. Felids are the key species in the life cycle [2] of this parasite because they are the only hosts that excrete the environmentally resistant stage, the oocyst, in their feces. Humans become infected postnatally by ingesting tissue cysts from undercooked meat, consuming food contaminated with oocysts, or by accidentally ingesting oocysts from the environment. Clinical toxoplasmosis in humans has been linked epidemiologically to ingestion of T. gondii in food [1], and foodborne transmission is one of the major sources of T. gondii infection.

Clinical disease resulting from T. gondii infection occurs as acquired infection in immunocompetent persons (usually mild), disease in immunosuppressed persons (usually due to reactivation of chronic infection), congenital disease, and ocular disease (congenital or acquired) [3–5]. In a recent assessment of foodborne illnesses in the United States, toxoplasmosis was identified as the second leading cause of foodborne illness–related deaths and fourth leading cause of foodborne illness–related hospitalizations (an estimated 327 deaths, and 4428 hospitalizations annually) [6]. In addition, over 4800 infections are estimated to result in acute ocular disease annually [7], and 400–4000 congenital cases are estimated to occur in the United States annually [8]. Internationally, toxoplasmosis has also had a significant effect on health; for example, in Greece, researchers recently found toxoplasmosis to be in the top 5 contributors of foodborne illnesses to years of life lost, years lived with disability, and disability-adjusted life years per million persons (9.7, 14, and 23 years, respectively) [9].

TRANSMISSION OF T. gondii

Infected Meat

In the United States, poultry, pork, and beef are the main meats consumed. In a recent nationwide study of the prevalence of T. gondii in retail meat, viable organisms were isolated from only 7 of 2094 pork samples and none of 2094 beef or 2094 chicken samples [10]. However, parasitological surveys based on retail meat samples do not provide a true assessment of risk from fresh meat because nearly half of the pork and a substantial amount of chicken are injected with salts and water, which can kill T. gondii tissue cysts [11]; the product is labeled with the...
ingredients of the treatments and the term “enhanced” meat may also be used [10]. Further, most retail chicken sold in the United States is frozen, which also kills *T. gondii* cysts. In this section, we will discuss meat sources of *T. gondii* for humans.

**Pigs**

Currently, there is no national identification system for individual pigs destined for human consumption, and pigs are not tested for *T. gondii* infection at slaughter. Meat from breeder pigs is generally processed for sausages and it is highly unlikely that *T. gondii* survives most commercial processing procedures (cooking, freezing, salting), suggesting that breeder pigs are not an important source of *T. gondii* transmission to humans; however, market pigs are a more likely source. The prevalence of *T. gondii* is declining, but even a 1% infection rate in market pigs would amount to 1 million infected pigs going to market for human consumption; a 50 kg market pig produces over 300 servings of meat.

An upsurge in consumer demand for “organically raised” and “free range” pork products has resulted in increasing numbers of pigs being raised in nonconfined systems. Swine producers have been recruited to produce animals for the organic market to fulfill a consumer demand for organically raised free-range pork that has increased an average of 20% per year in sales since 1990. Organic program standards [12] require that all animals raised must have access to the outdoors, including access to pasture for ruminants. Access to grass, soil, feed, or water contaminated with cat feces, or to rodents and wildlife infected with *T. gondii*, during outdoor pasturage substantially increases the risk of exposure of pigs to *T. gondii*. Kijlstra et al. [13] found that 0 of 621 conventionally raised pigs were seropositive for *T. gondii*, while 38 of 1295 (2.9%) pigs raised in “animal friendly” management systems were seropositive for *T. gondii*. Recently, viable *T. gondii* was isolated from 17 of 33 organically raised pigs from Michigan [14] (Table 1).

**Cattle**

The ingestion of beef or dairy products has not been considered important in the epidemiology of *T. gondii* because cattle are not a good host for this parasite [15]. However, we cannot be sure that beef does not play a role in *T. gondii* transmission as only relatively small amounts of beef have been tested for viable *T. gondii* parasites with negative results, and epidemiologic studies have linked undercooked beef to *T. gondii* infection (although the link was not definitive, see the “Risk Factors and Attributable Risk” section).

**Chickens**

In the United States, the per capita yearly consumption of poultry is estimated to be 37.2 kg and approximately 8.5 billion chickens are killed annually for human consumption. As noted above, in a recent survey, *T. gondii* was not isolated by bioassay from any of the 2094 chicken meat samples obtained from retail stores in the United States [10]. However, because many of the chicken meat samples were injected with enhancing

<table>
<thead>
<tr>
<th>Species</th>
<th>Source</th>
<th>No. Bioassayed and Tissue</th>
<th>% Positive</th>
<th>Reference(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pigs</td>
<td>Abattoir, Maryland</td>
<td>50 diaphragms</td>
<td>24</td>
<td>Jacobs et al. 1960 [59]</td>
</tr>
<tr>
<td></td>
<td>Abattoir, Iowa</td>
<td>1000 sow hearts</td>
<td>17</td>
<td>Dubey et al. 1995 [60]</td>
</tr>
<tr>
<td></td>
<td>Massachusetts, 1 herd</td>
<td>55 market hogs hearts and tongues</td>
<td>92.7</td>
<td>Dubey et al. 2002 [61]</td>
</tr>
<tr>
<td></td>
<td>Retail meat, nationwide</td>
<td>2094 pork</td>
<td>0.3</td>
<td>Dubey et al. 2005 [10]</td>
</tr>
<tr>
<td></td>
<td>Maryland, herd</td>
<td>38 pigs</td>
<td>36.8</td>
<td>Dubey et al. 2008 [62]</td>
</tr>
<tr>
<td></td>
<td>Michigan</td>
<td>33 organic pigs</td>
<td>51.5</td>
<td>Dubey et al. 2012 [14]</td>
</tr>
<tr>
<td>Sheep</td>
<td>Abattoir, Maryland</td>
<td>86</td>
<td>9.2</td>
<td>Jacobs et al. 1960 [59]</td>
</tr>
<tr>
<td></td>
<td>Retail meat</td>
<td>50 lamb chops</td>
<td>4</td>
<td>Remington, 1968 [63]</td>
</tr>
<tr>
<td></td>
<td>Abattoir, Maryland</td>
<td>68 lamb hearts</td>
<td>77.9</td>
<td>Dubey et al. 2008 [64]</td>
</tr>
<tr>
<td>Goats</td>
<td>Retail meat</td>
<td>112 seropositive hearts</td>
<td>25.8</td>
<td>Dubey et al. 2011 [18]</td>
</tr>
<tr>
<td>Cattle</td>
<td>Abattoir, Maryland</td>
<td>60 diaphragms</td>
<td>0</td>
<td>Jacobs et al. 1960 [59]</td>
</tr>
<tr>
<td></td>
<td>Abattoir, Ohio</td>
<td>350 mixed tissues</td>
<td>0</td>
<td>Dubey and Streitel, 1976 [65]</td>
</tr>
<tr>
<td></td>
<td>Retail meat, nationwide</td>
<td>2094 beef</td>
<td>0</td>
<td>Dubey et al. 2005 [10]</td>
</tr>
<tr>
<td>Chickens</td>
<td>Retail meat, nationwide</td>
<td>2094 breast meat</td>
<td>0</td>
<td>Dubey et al. 2005 [10]</td>
</tr>
<tr>
<td>Deer</td>
<td>Alabama</td>
<td>19</td>
<td>21</td>
<td>Lindsay et al. 1991 [66]</td>
</tr>
<tr>
<td></td>
<td>Mississippi</td>
<td>73</td>
<td>28.7</td>
<td>Dubey et al. 2004 [67]</td>
</tr>
<tr>
<td></td>
<td>Iowa, Minnesota</td>
<td>88</td>
<td>17</td>
<td>Dubey et al. 2008 [68]</td>
</tr>
<tr>
<td>Black bear</td>
<td>Pennsylvania</td>
<td>28</td>
<td>35.7</td>
<td>Dubey et al. 1995 [69]</td>
</tr>
<tr>
<td></td>
<td>Pennsylvania</td>
<td>10</td>
<td>70</td>
<td>Dubey et al. 2004 [67]</td>
</tr>
</tbody>
</table>

\(^a\) Modified from Dubey and Jones 2008 [70].
consumption in the United States was found to be 53.4% [18].

Groups in the United States. In a recent study, the seroprevalence of T. gondii in free-range poultry will probably increase the prevalence of T. gondii in chickens consumed by humans. Unlike indoor raised chickens, the prevalence of T. gondii in free-range chickens is very high (United States, 17%–100%) [16]. The prevalence of T. gondii in chicken eggs is extremely low and the ingestion of uncooked eggs is not considered an important risk for toxoplasmosis [16].

Sheep
Approximately 3.5 million lambs are slaughtered for food in the United States each year, and the per capita consumption of lamb meat is about 0.3 kg per year [17]. Results of a recent study and previous surveys indicate the prevalence of T. gondii in lambs can be high (Table 1).

Goats
Although pasteurization will kill T. gondii in goat’s milk, unpasteurized raw milk is sold by small goat farmers and goat cheeses made from raw milk could be a source of T. gondii infection. Little is known of the excretion of T. gondii in goat’s milk [1]. Goat meat is also very popular with many ethnic groups in the United States. In a recent study, the seroprevalence of T. gondii antibodies in goat meat destined for human consumption in the United States was found to be 53.4% [18].

Horses
In France, severe human toxoplasmosis has been epidemiologically linked to ingestion of horse meat imported from Canada and Brazil [19] and viable T. gondii has been isolated from US horses slaughtered for export [20]. However, horse meat is not frequently used for human consumption in the United States.

Venison and Other Game
Deer are popular and abundant game animals in the United States. Antibodies to T. gondii are highly prevalent (30%–60%) in white-tailed deer; viable T. gondii was isolated from 17%–29% (Table 1). Other game animals frequently hunted in the United States each year, including bear, elk, moose, and wild pig, may also be sources of T. gondii infection; for example, the prevalence of T. gondii in black bears is very high (Table 1).

Role of Oocysts
Environmentally resistant oocysts are essential in the life cycle of T. gondii [2]. Only cats are known to excrete T. gondii oocysts in their feces, which contaminate soil and can be ingested by animals, or by humans on uncooked fruits and vegetables. Although cats can be reinfected with T. gondii, most shed oocysts in their feces only for several weeks once during their life. Approximately one-third of households in the United States own a cat; there are approximately 78 million domestic cats and 73 million feral cats (reviewed by Conrad et al., 2005) [21]. Oocysts can survive in the environment for long periods—for example, oocysts survived outdoors in Texas (6°C–36°C) in native cat feces, uncovered, for 46 days, for 334 days when covered, and outdoors in soil buried at the depth of 3–9 cm in Kansas for 18 months. The oocyst stage of T. gondii is highly resistant to disinfectants and freezing—for example, oocysts survived at −21°C for 28 days [22] but are killed by temperatures above 60°C [23]. Ultraviolet rays also will inactivate oocysts, depending on the dose [24, 25].

HUMAN SEROPREVALENCE IN THE UNITED STATES
Toxoplasma gondii seroreactivity is generally thought to remain for life [1]. Historical serological surveys have been summarized by Dubey [1]. An analysis of the US National Health and Examination Nutrition Study (NHANES) serum samples from 1988 to 1994 in persons over 12 years old showed an overall age-adjusted seroprevalence of 22.5% [26]. A more recent NHANES found a decrease in the age-adjusted T. gondii prevalence in US-born persons 12–49 years old from 14.1% in 1988–1994 to 9% in 1999–2004, and a seroprevalence of 7.7% in US-born and 28.1% in foreign-born women 15–44 years old in 1999–2004 [27] (Table 2). Prior studies have also shown a decrease in T. gondii seroprevalence in the United States over time. For example, in 1962 and 1989, T. gondii seroprevalence was examined among military recruits, showing rates of 14.4% and 9.5%, respectively [28, 29]. Worldwide, foci of high prevalence exist in Latin America, parts of Eastern/Central Europe, the Middle East, and parts of south-east Asia and Africa. A trend toward lower seroprevalence in the last several decades has been observed in many European countries as well as the United States [30].

RISK FACTORS AND ATTRIBUTABLE RISK
Sources of T. gondii infection include the ingestion of cysts in undercooked meat and oocysts in soil contaminated with cat feces, which may be present on uncooked fruits and vegetables. The proportion of infections caused by each of these sources is not known for the general population. However,
recently, a sporozoite-specific antigen (indicator of oocyst infection) was identified and convenience samples of sera were assayed to determine exposure to oocysts [31]. Of 163 persons in the acute stage of *T. gondii* infection, 103 (63.2%) were found to have sporozoite-specific antibodies in their serum samples [31, 32].

A case-control study conducted in 2002–2007 in the United States found numerous foodborne risk factors for recent *T. gondii* infection, including eating raw ground beef; eating rare lamb; eating locally produced cured, dried, or smoked meat sold only in the local city or area; working with meat; drinking unpasteurized goat’s milk; and eating raw oysters, clams, or mussels [33]. In this study, the highest absolute risk was found for ingestion of rare lamb (adjusted odds ratio [AOR], 8.4; attributable risk [AR], 20%) and the highest attributable risk was found for ingestion of locally produced cured, dried, or smoked meat (AOR, 2.0; AR, 22%). A survey of pregnant women in the United States has documented that many do not perceive the risk of *T. gondii* infection from undercooked meat [34].

Numerous epidemiological studies have found undercooked meat to be a risk for *T. gondii* infection, including a multicenter European study of pregnant women where ingestion of inadequately cooked meat (lamb, beef, or game) was identified as the main risk factor [35]. Rare lamb has been circumstantially linked to symptomatic toxoplasmosis in a family in New York City [36]. Rare hamburger and beef have been linked to outbreaks of toxoplasmosis in the United States [37, 38], but other meats could have been responsible for these outbreaks (pork [37], lamb [38]). In Korea, eating contaminated pork was linked to clinical toxoplasmosis and ocular disease [39]. Horse meat originating from Canada and Brazil was implicated in clinical toxoplasmosis from infection with atypical strains in immunocompetent persons [19]. In the southern United States, ingestion of undercooked venison was found to be a *T. gondii* infection risk factor for hunters [40] and was linked to clinical toxoplasmosis with ocular disease [41]. In a retrospective study of 131 mothers who had given birth to children infected with *T. gondii*, 50% recalled having eaten uncooked meat [42]. In addition, a study that compared *T. gondii* prevalence in a community of Seventh Day Adventists, a religious group that follows a diet containing no meat, with a control community that was not Seventh Day Adventist, found that the prevalence of *T. gondii* infection in the Seventh Day Adventist community was approximately half of that in the control community (24% vs 50%) [43]. However, because *T. gondii* is transmitted from multiple sources, and recall of risk factors is often incomplete, it is difficult to establish the specific exposure responsible for infection in an individual.

In addition to being a risk factor in a US case-control study [33], unpasteurized goat’s milk was found to be a *T. gondii* infection risk in family clusters in the United States [44] and the United Kingdom [45], and was linked to toxoplasmosis in an infant [46]. Feeding goat milk whey to pigs was also identified as a source of *T. gondii* infection in pigs [47].

The study by Jones et al. [33] also found a *T. gondii* infection risk from eating raw oysters, mussels, and clams. *T. gondii* has been identified in wild mollusks [48] and is thought to be carried to the oceans through river systems [21] where it is filtered by mollusks. Since *T. gondii* oocysts are environmentally resistant, they are not generally killed by sewage treatment, water, or salt water [49].

### Table 2. Selected US Human *Toxoplasma gondii* Prevalence Studies

<table>
<thead>
<tr>
<th>Year Sampled</th>
<th>Age Group</th>
<th>Source of Serum Sample</th>
<th>No. Tested</th>
<th>% Positive</th>
<th>Reference*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1962</td>
<td>US young adult</td>
<td>Military recruits</td>
<td>2680</td>
<td>14</td>
<td>Feldman 1965 [28]</td>
</tr>
<tr>
<td>1987</td>
<td>≥18 y-old</td>
<td>Maryland community</td>
<td>251</td>
<td>31</td>
<td>Roghmann et al. 1999 [43]</td>
</tr>
<tr>
<td>1999–2004</td>
<td>US age-adjusted 6–49 y, women 15–44 y</td>
<td>NHANES</td>
<td>15 960</td>
<td>10.8, 11.0</td>
<td>Jones et al. 2007 [27]</td>
</tr>
</tbody>
</table>

Abbreviation: NHANES, National Health and Nutrition Examination Study.

* Adapted from Dubey and Jones 2008 [70].

With regard to vaccines, a live sheep vaccine that produces protective immunity for 18 months is available to reduce loss of lambs [50]. In addition, an oral live vaccine can prevent cats from shedding oocysts [51]. However, commercial production of the cat vaccine was discontinued because of its high cost, the need to keep the vaccine frozen, its short shelf...
The government should help encourage and disseminate information about animal production practices to reduce conditions, so in the opinion of the authors, it is best. For humans, vaccination with live mutant or avirulent strains cannot be recommended because these strains may pose a risk to the fetus and there is no guarantee that the strains would not revert and lead to disease, particularly in immunosuppressed persons.

Reducing T. gondii contamination of meat by the meat industry is critical to prevent foodborne transmission of T. gondii to humans. Cats should be kept out of barns and food animal productions areas so that they do not contaminate the soil and animal food storage areas with cat feces that contain T. gondii oocysts, which could be ingested and infect food animals. In addition, appropriate rodent control is essential so that food animals do not become infected with T. gondii by ingestion of rodents that die in their production areas.

The US Department of Agriculture recommends cooking whole cuts of pork, lamb, veal, or beef to 145°F (62.8°C) or higher as measured with a food thermometer placed in the thickest part of the meat, with a 3-minute rest time after cooking [52]. However, in one instance under experimental conditions, T. gondii remained viable at 147.2°F (64°C) with a 3-minute rest [53], so in the opinion of the authors, it is best to cook whole cuts of pork, lamb, veal, or beef to at least 150°F (65.6°C) with a 3-minute rest. Ground meat and wild game meat should be cooked to 160° F (71.1°C) or higher, and poultry should be cooked to 165° F (73.9°C) or higher as measured with a food thermometer. Ground meats, wild game meats, and poultry do not require a rest time. Microwave cooking is unreliable for killing T. gondii.

Irradiation at 0.4–0.7 kGy or high-pressure processing at 300–400 MPa can inactivate T. gondii tissue cysts in meat. However, the effects of irradiation on color and of high-pressure treatment on color and texture have limited consumer acceptance [1, 54]. Freezing meat to an internal temperature of −12°C kills T. gondii tissue cysts [55]. Salting, curing, smoking, and the addition of solutions to meat to enhance color and taste can reduce the viability of T. gondii in meat; however, there is too much variability in these procedures to make a safety recommendation [56–58]. It is also important to prevent cross contamination from raw meat to other foods, especially those eaten raw. Practicing good hygienic measures and cooking meat adequately remain important preventive measures to take to reduce foodborne transmission (Table 3).

In conclusion, T. gondii is a common parasite that can lead to significant illness, particularly in pregnant women and immunosuppressed persons. T. gondii infection can be prevented

<table>
<thead>
<tr>
<th>Table 3. Prevention of Toxoplasma gondii Exposure From Food and the Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>• To prevent toxoplasmosis, meat should be adequately cooked (160°F (71.1°C) for ground meat and wild game meat; 150°F (65.6°C) for other whole cuts of meat with a 3-minute rest; and 165°F (73.9°C) for poultry); (see text). A food thermometer should be inserted in the thickest part of the meat to ensure that it is cooked through.</td>
</tr>
<tr>
<td>• Fruits and vegetables should be peeled or thoroughly washed before eaten.</td>
</tr>
<tr>
<td>• Cutting boards, dishes, counters, utensils, and hands should be washed with hot soapy water after they have been in contact with raw meat, poultry, seafood, or unwashed fruits and vegetables.</td>
</tr>
<tr>
<td>• Raw oysters, mussels, and clams should not be eaten.</td>
</tr>
<tr>
<td>• Unpasteurized goat’s milk should not be ingested.</td>
</tr>
<tr>
<td>• Viscera of hunted animals should be buried to prevent scavenging by animals, especially cats, leading to their infection and the spread of T. gondii in the ecosystem.</td>
</tr>
<tr>
<td>• Pregnant women and immunosuppressed persons should wear gloves when they are gardening or handling soil or sand because of the possible presence of cat feces. Afterwards, they should wash their hands thoroughly.</td>
</tr>
<tr>
<td>• Sandboxies should be covered when not in use.</td>
</tr>
<tr>
<td>• Untreated water should not be ingested (especially in developing countries).</td>
</tr>
<tr>
<td>• If possible, pregnant women and immunosuppressed persons should avoid changing cat litter pans. If no one else is available to change the cat litter, they should wear gloves for this task and then wash their hands thoroughly. The litter box should be changed daily because T. gondii oocysts require more than 1 day to become infectious. They should be encouraged to keep their cats inside and not to adopt or handle stray cats. Cats should be fed only canned or dried commercial cat food or well-cooked table food; cats should not be given raw or undercooked meat.</td>
</tr>
<tr>
<td>• Health education for women of childbearing age and immunosuppressed persons should include information about preventing T. gondii transmission. At the first prenatal visit, healthcare providers should educate pregnant women about food hygiene and avoiding exposure to cat feces.</td>
</tr>
<tr>
<td>• The meat industry should continue efforts to reduce the presence of T. gondii in meat by employing good production practices such as keeping cats and rodents out of food animal production areas and using clean or treated water sources for the animals.</td>
</tr>
<tr>
<td>• The government should help encourage and disseminate information about animal production practices to reduce T. gondii contamination of meat and should encourage research in methods that reduce T. gondii contamination of meat, methods to prevent human infection from contaminated meat (including education about hygiene and cooking, and development of optimal cooking temperatures, irradiation, high-pressure treatment, and other methods to inactivate T. gondii cysts in meat), and methods to reduce contamination of the environment with T. gondii oocysts.</td>
</tr>
</tbody>
</table>
by production measures to reduce *T. gondii* in meat; adequate cooking, freezing, or physical/chemical treatment of meat; prevention of cross contamination from raw meat; and measures that prevent *T. gondii* infection of cats, and therefore, decrease spreading of oocysts into the environment (eg, keeping cats indoors and not feeding raw meat to cats). The trend in production of organically raised meat is likely to increase the risk of acquiring *T. gondii* from undercooked meat. Areas for future research that could help reduce foodborne transmission of *T. gondii* include: vaccine development; improved methods to deactivate *T. gondii* cysts in meat and oocysts in cat feces, soil, and water, and on fruits and vegetables; improved methods to prevent *T. gondii* infection in food animals, including those in field-raised production systems; improved methods to reduce environmental contamination by outdoor cat populations; and improved methods to educate the public and health professionals about prevention of foodborne toxoplasmosis.

**Notes**

**Disclaimer.** The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the Department of Health and Human Services, the Centers for Disease Control and Prevention, or the United States Department of Agriculture.

**Potential conflicts of interest.** All authors: No reported conflicts.

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