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Invited Review

Toxoplasma gondii infection in humans and animals in the United States

J.P. Dubey [a,*], J.L. Jones [b]

[a] *United States Department of Agriculture, Agricultural Research Service, Animal and Natural Resources Institute, Animal Parasitic Diseases Laboratory, Building 1001, Beltsville, MD 20705-2350, USA*
[b] *Division of Parasitic Diseases, National Center for Zoonotic, Vectorborne and Enteric Diseases, Coordinating Center for Infectious Diseases, Centers for Disease Control and Prevention, 4770 Buford Highway, MS: F22, Chamblee, GA 30341, USA*

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Abstract

This paper reviews clinical and asymptomatic *Toxoplasma gondii* infection in humans and other animals in the USA. Seroprevalence of *T. gondii* in humans and pigs is declining. Modes of transmission, epidemiology and environmental contamination with oocysts on land and sea are discussed.
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1. Introduction

Toxoplasma gondii infections are prevalent in humans and animals worldwide (Dubey and Beattie, 1988). Felids are the key animal species in the life cycle of this parasite because they are the hosts that can excrete the environmentally-resistant stage, the oocyst. Humans become infected post-natally by ingesting tissue cysts from undercooked meat, consuming food or drink contaminated with oocysts, or by accidentally ingesting oocysts from the environment. However, only a small percentage of exposed adult humans or other animals develop clinical signs of disease. It is unknown whether the severity of toxoplasmosis in immunocompetent hosts is due to the parasite strain, host variability or other factors. Recently, attention has been focused on genetic variability among *T. gondii* isolates from apparently healthy and sick hosts.

It has been 100 years since the discovery and naming of *T. gondii*. The parasite was first found in laboratory animals (for history see Dubey, 2007). Its medical importance remained unknown until 1939 when *T. gondii* was identified conclusively in tissues of a congenitally-infected infant in New York City, USA (Wolf et al., 1939), and its veterinary importance became known when it was found to cause abortion storms in sheep in 1957 in Australia (Hartley and Marshall, 1957). In the present paper, we summarize information on clinical and sub-clinical *T. gondii* infections in humans and animals in the USA, including transmission, epidemiology and control.

2. Clinical and asymptomatic *Toxoplasma gondii* infection in humans and animals

2.1. Infection in humans

2.1.1. Asymptomatic infection

Infection with *T. gondii* can occur pre- or post-natally. After birth, humans are usually infected with *T. gondii* by ingestion of oocysts in soil or water that have been contaminated with cat feces, or by ingestion of tissue cysts in undercooked meat (Dubey and Beattie, 1988; Bowie et al., 1997; Bahia-Oliveira et al., 2003; Dubey, 2004; Jones et al., 2005; de Moura et al., 2006). Transfusion or organ transplantation from an infected person can also transmit the organism (Shulman and Appleman, 1991; Schaffner,

* Corresponding author. Tel.: +1 301 504 8128; fax: +1 301 504 9222.
E-mail address: jitender.dubey@ars.usda.gov (J.P. Dubey).

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2001). Most persons infected after birth are asymptomatic (Montoya and Liesenfeld, 2004; Remington et al., 2006), however, some develop a mild disease or in rare cases, a more severe systemic illness (see Section 2.1.2). Once infected, humans are believed to remain infected for life. Unless immunosuppression occurs and the organism reactivates, people usually remain asymptomatic. However, there is ongoing research on whether chronic *T. gondii* infection has an effect on reaction time (Havlıček et al., 2001), tendency for accidents (Flegr et al., 2002), behavior (Flegr et al., 1996, 2000; Lafferty, 2005, 2006) and mental illness (Yolken et al., 2001; Flegr et al., 2003; Brachmann et al., 2005; Brown et al., 2005).

Selected serological surveys in humans in the USA are summarized in Table 1. Previous serological surveys were summarized by Dubey and Beattie (1988). A recent serosurvey using samples from the population-based National Health and Examination Nutrition Study (NHANES) found a decrease in the age-adjusted *T. gondii* prevalence in USA-born persons 12–49 years old from 14.1% in 1988–1994 to 9% in 1999–2004, a seroprevalence of 11% in USA-born women 15–44 years old in 1999–2004, and a seroprevalence of 28.1% in foreign-born women 1999–2004 (Jones et al., 2007). The overall seroprevalence (USA and foreign-born combined) increased with age and was higher among non-Hispanic black persons and Mexican Americans than among non-Hispanic white persons; however, among USA-born persons Mexican Americans had a lower seroprevalence than non-Hispanic white or black persons (age 12–49, 5.1% versus 8.8% and 11.5%, respectively). An earlier study evaluating NHANES III (1988–1994) sera for all persons $\leqslant$12 years of age (USA and foreign-born combined) showed an overall age-adjusted seroprevalence of 22.5%, a relatively linear increase in *T. gondii* infection with age, and a higher age-adjusted seroprevalence in the northeastern USA (29.2%) compared with the South (22.8%), Midwest (20.5%) or West (17.5%) (Jones et al., 2001). In this study, the risk for *T. gondii* infection was higher among persons who were foreign-born, had a lower education level, lived in crowded conditions and worked in soil-related occupations. In a separate study using NHANES III sera, the rate of *T. gondii* seropositivity among persons seropositive for the soil-transmitted helminth *Toxocara* spp. was nearly double the rate of *T. gondii* seropositivity among persons who were not seropositive for *Toxocara* spp., suggesting that sufficient soil exposure to lead to *Toxocara* spp. infection doubles the risk of *T. gondii* infection (Jones et al., 2008).

Prior studies have also shown a decrease in *T. gondii* seroprevalence in the USA 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 (Feldman, 1965; Smith et al., 1996). Although not a complete sampling of the USA regional populations, the studies in military recruits (Feldman, 1965; Smith et al., 1996) and an earlier study (Feldman and Miller, 1956) found lower rates of *T. gondii* infection in the West. The western region of the USA is generally drier and oocysts may not survive as well in the soil in this climate. However, due to variations in weather, cat populations and human behavior, there is likely to be a wide variation in *T. gondii* prevalence within regions of the USA.

2.1.2. Symptomatic infection

A minority of healthy persons infected with *T. gondii* after birth develop symptoms, which are usually mild and include manifestations such as fever, malaise and lymphadenopathy (Montoya and Liesenfeld, 2004; Remington et al., 2006). However, in rare cases, humans who were previously healthy have developed severe and even fatal disease, including pulmonary and multivisceral involvement, possibly from more virulent types of the organism (Carme et al., 2002; Demar et al., 2007). In addition, up to 2% of healthy persons in the USA infected with *T. gondii* develop ocular disease (Holland, 2003), usually retinochoroiditis. A higher percentage of infected persons have been documented to develop ocular disease in other parts of the world, for example, one region of Southern Brazil (17.7% with ocular lesions) (Glasner et al., 1992). Retinochoroiditis can be due to congenital or post-natally acquired disease and can be associated with acute infection or reactivation (Montoya and Remington, 1996; Holland, 1999). Current thinking is that the majority of ocular toxoplasmosis comes from post-natally acquired disease (Holland, 1999, 2003). Acute toxoplasmic retinochoroiditis results in pain, photophobia, tearing and loss of vision.

Table 1
Selected USA human *Toxoplasma gondii* antibody prevalence studies

Year sampled	Age group	Source of sera	No. tested	% Positive	Reference
1962	U.S. young adult	Military recruits	2680	14	Feldman (1965)
1987	$\geqslant$18 years old	Maryland community	251	31	Roghmann et al. (1999)
1989	U.S. young adult	Military recruits	2862	9.5	Smith et al. (1996)
1992–1993	$\geqslant$18 years old	Illinois swine farm workers	174	31	Weigel et al. (1999)
1988–1994	U.S. age-adjusted $\geqslant$12 years old	NHANES[a]	17,658	22.5	Jones et al. (2001)
1999–2000	U.S. age-adjusted 12–49 years Women 12–49 years	NHANES	4234	15.8 14.9	Jones et al. (2003)
1999–2004	U.S. age-adjusted 12–49 years Women 15–44 years	NHANES	15,960	10.8 11.0	Jones et al. (2007)

[a] NHANES, National Health and Nutrition Examination Study.