Experimental Parasitology 124 (2010) 10–25

Contents lists available at ScienceDirect

Experimental Parasitology

journal homepage: www.elsevier.com/locate/yexpr

Minireview

Waterborne toxoplasmosis – Recent developments

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ARTICLE INFO

Article history:
Received 31 October 2008
Received in revised form 10 March 2009
Accepted 17 March 2009
Available online 24 March 2009

Keywords:
Toxoplasma gondii
Toxoplasmosis
Oocyst
Pathogenesis
Biology
Diagnosis
Epidemiology
Toxoplasma
Waterborne
Parasite
Protozoa

ABSTRACT

Humans become infected with *Toxoplasma gondii* mainly by ingesting uncooked meat containing viable tissue cysts or by ingesting food or water contaminated with oocysts from the feces of infected cats. Circumstantial evidence suggests that oocyst-induced infections in humans are clinically more severe than tissue cyst-acquired infections. Until recently, waterborne transmission of *T. gondii* was considered uncommon, but a large human outbreak linked to contamination of a municipal water reservoir in Canada by wild felids and the widespread infection of marine mammals in the USA provided reasons to question this view. The present paper examines the possible importance of *T. gondii* transmission by water.
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1. Introduction

Infection with the protozoan *Toxoplasma gondii* is one of the most common parasitic infections of man and other warm-blooded animals (Dubey and Beattie, 1988; Tenter et al., 2000; Hill et al., 2002). In most adults it does not cause serious illness, however, blindness and mental retardation can occur in congenitally infected children, severe disease occurs in those with depressed immunity, and ocular disease can occur from acute infection after birth. Toxoplasmosis, until recently, was not often considered a waterborne zoonosis. However, a major outbreak of toxoplasmosis in humans in Canada in 1994 (Bowie et al., 1997) was associated with *T. gondii* in municipal waters. Recently, *T. gondii* has been reported in many marine mammals, suggesting the possibility that the contamination of seawater with *T. gondii* may be more common than realized (Conrad et al., 2005; Dubey and Jones, 2008). This review focuses on the waterborne aspects of *T. gondii*.

2. Life cycle

Toxoplasma gondii is a coccidian parasite where felids are the definitive hosts and warm-blooded animals are intermediate hosts (Frenkel et al., 1970). It is among the most common of parasites of animals and *T. gondii* is the only known species. Coccidia in general have complex life cycles. Although most are host-specific, and only transmitted by a fecal-oral cycle, *T. gondii* can also be transmitted transplacentally and by carnivorism.

There are three stages of *T. gondii* that are infectious for all hosts: tachyzoites, bradyzoites, and oocysts. The tachyzoite is often crescent-shaped and 2×6 μm in size. It enters the host cell by active penetration of the cell membrane and becomes surrounded by a parasitophorous vacuole that protects it from host defense mechanisms. The tachyzoite multiplies asexually by repeated endodygeny until the host cell ruptures.

After an unknown numbers of divisions, *T. gondii* tachyzoites give rise to another stage called a tissue cyst. Tissue cysts grow and remain intracellular. They vary in size from 5 to 70 μm and contain a few to several hundred bradyzoites (Dubey et al.,

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0014-4894/$ - see front matter Published by Elsevier Inc.
doi:10.1016/j.exppara.2009.03.013

Table 1
Wild felids as definitive host for *T. gondii*.[a]

Definitive host	Oocyst shedding		Reference
	Expt.	Natural	
African wild cat (*Felis lybica*)	Yes[b]	No	Polomoshnov (1979)
Amur leopard cat (*Felis euptilurus*)	No	Yes[b]	Lukešová and Literák (1998)
Asian leopard (*Felis bengalensis*)	Yes	No	Janitschke and Werner (1972)
	Yes[b]	No	Miller et al. (1972)
Bobcat (*Lynx rufus*)	No	Yes[b]	Marchiondo et al. (1976)
	Yes[b]	No	Miller et al. (1972)
Cheetah (*Acinonyx jubatus*)	No	Yes[b]	Marchiondo et al. (1976)
	Yes[b]	No	Polomoshnov (1979)
Cougar (*Felis concolor*)	No	Yes[b]	Marchiondo et al. (1976)
	Yes[b]	No	Miller et al. (1972)
Cougar (*Felis concolor vancouverensis*)	No	Yes[b]	Aramini et al. (1998)
Geoffroy's cat (*Oncifelis geoffroyi*)	No	Yes[c]	Pizzi et al. (1978)
	No	Yes[b]	Lukešová and Literák (1998)
Iriomote cat (*Felis iriomotensis*)	No	Yes[b]	Akuzawa et al. (1987)
Jaguarundi (*Felis yagouaroundi*)	Yes[b]	No	Jewell et al. (1972)
Lion (*Panthera leo*)	No	Yes[d]	Ocholi et al. (1989)
	Yes[b]	No	Polomoshnov (1979)
Mountain lion (*Felis concolar*)	No	Yes[b]	Marchiondo et al. (1976)
Ocelot (*Felis pardalis*)	Yes[b]	No	Jewell et al. (1972)
	No	Yes	Patton et al. (1986)
Pallas cat (*Felis manul*)	No	Yes[b]	Basso et al. (2005)
	No	Yes[d]	(Dubey et al. 1988)
	Yes[b]	No	Polomoshnov (1979)
Pampas cat (*Oncifelis colocolo*)	No	Yes[c]	Pizzi et al. (1978)
Siberian tiger (*Panthera tigris altaica*)	No	Yes[b]	Dorny and Fransen (1989)
Wild cat (*Felis silvestris*)	No	Yes[b]	Lukešová and Literák (1998)

[a] From Dubey (2009a).
[b] Confirmed by bioassay in mice.
[c] Confirmed by bioassay in pigs.
[d] Immunohistochemical post mortem examination.

1998). Although tissue cysts may develop in visceral organs, including lungs, liver, and kidneys, they are more prevalent in muscular and neural tissues, including the brain, eye, skeletal, and cardiac muscle. The tissue cyst wall is elastic, thin (<0.5 μm), and may enclose hundreds of crescent-shaped slender bradyzoites each measuring 7 × 1.5 μm. Intact tissue cysts are probably harmless and can persist for the life of the host (Dubey et al., 1998).

Upon ingestion by cats, the wall of the tissue cyst is digested by the proteolytic enzymes in the stomach and small intestine, and bradyzoites are released. Some penetrate the lamina propria of the intestine and multiply as tachyzoites. Within a few hours, *T. gondii* may disseminate to extra-intestinal tissues. The bradyzoites that remain in the epithelial cells of the small intestine initiate the development of numerous generations of *T. gondii* (Dubey and Frenkel, 1972). Five morphologically distinct asexual types of *T. gondii* develop in intestinal epithelial cells before the sexual cycle begins. These stages are designated types A–E instead of generations because there are several generations within each *T. gondii* type. These asexual stages in the feline intestine are structurally distinct from tachyzoites that also develop in the lamina propria. The entroepithelial stages (types A–E, gamonts) are formed in the intestinal epithelium. Occasionally, type B and C schizonts develop within enterocytes that are displaced beneath the epithelium into the lamina propria. Types C, D, and E schizonts multiply by schizogony. In schizogony, the nucleus divides two or more times without cytoplasmic division. The sexual cycle starts 2 days after ingestion of tissue cysts by the cat. The origin of gamonts has not been determined, but the merozoites released from schizont types D and E probably initiate gamete formation. Gamonts occur throughout the small intestine but most commonly in the ileum, 3–15 days after inoculation. The male gamete has two flagellae and swims to and enters the female gamete. After the female gamete is fertilized by the male gamete, oocyst wall formation begins around the fertilized gamete. When oocysts are mature, they are discharged into the intestinal lumen by the rupture of intestinal epithelial cells. *Toxoplasma gondii* persists in intestinal and extra-intestinal tissue of cats for at least several months, and possibly for the life of the cat.

Oocysts of *T. gondii* are formed only in cats, including both domestic and wild felids (Table 1). Cats shed oocysts after ingesting tachyzoites, bradzyoites, or oocysts. However, less than 50% of cats shed oocysts after ingesting tachyzoites or oocysts whereas nearly all shed oocysts after ingesting tissue cysts.

Oocysts in freshly passed feces are unsporulated (non-infective), subspherical to spherical in shape, and 10 × 12 μm in diameter. Sporulation occurs outside the cat and within 1–5 days, depending upon aeration and temperature. Sporulated oocysts contain two ellipsoidal sporocysts. Each sporocyst contains four sporozoites. The sporozoites are 2 × 6–8 μm in size (Dubey et al., 1998).

Hosts, including felids can acquire *T. gondii* by ingesting either tissues of infected animals, food and drink contaminated with sporulated oocysts, or by transplacental transmission. After ingestion, bradyzoites released from tissue cysts or sporozoites from oocysts penetrate intestinal tissues, transform to tachyzoites, multiply locally, and are disseminated in the body via blood or lymph. After a few multiplication cycles, tachyzoites give rise to bradyzoites in a variety of tissues. *Toxoplasma gondii* infection during pregnancy can lead to infection of the fetus. Congenital toxoplasmosis in humans, sheep, and goats can kill the fetus.

3. Estimating oocyst contamination in the environment

3.1. Oocyst shedding during primary and secondary infections

Under laboratory conditions domestic cats shed millions of oocysts after feeding on one *T. gondii*-infected mouse (Dubey and Frenkel, 1972). In one study, cats fed as few as one bradyzoite shed