IMMUNOLOGY AND HOST-PARASITE INTERACTIONS - ORIGINAL PAPER

Suburban white-tailed deer seropositive for *Toxoplasma gondii* from Chicago, Illinois

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Abstract

The presence and abundance of vertebrates influences the circulation of zoonotic diseases. White-tailed deer (*Odocoileus virginianus*) are widely distributed in North America and deer densities are frequently high in unhunted areas, including most major metropolitan regions. This study investigated the seroprevalence for *Toxoplasma gondii* from live-captured and culled deer sampled in two suburban forest preserves around Chicago, Illinois, from 1995 to 1999. Seroprevalence for *T. gondii* was 55.9% ($n = 443$) and was significantly higher at the northern study site, Des Plaines. Seroprevalence for *T. gondii* varied by year and month. Multivariate logistic regression (LR) screened main effect variables (age, sex, site, year, and month) by backward stepwise elimination. The final LR model for *T. gondii* contained all main effect variables. This study provides baseline data for future *T. gondii* suburban deer studies and information to public health and wildlife officials regarding the prevalence a parasitic pathogen present in two public forest preserves in Chicago, Illinois.

Keywords Prevalence · Suburban · *Toxoplasma gondii* · White-tailed deer · Illinois

Introduction

A dynamic change globally in wildlife biology is the emergence and reemergence of wildlife diseases. Greater than 60% of emerging infectious diseases (EID) are caused by zoonotic pathogens and more than 70% are of wildlife origin (Jones et al. 2008). Serological surveys of white-tailed deer (*Odocoileus virginianus*) have examined the presence of antibodies for various zoonotic agents (Acha and Szyfres 1994; Adrian and Keiss 1977; Dawson et al. 1994; Hoff et al. 1973; Thomas and Trainer

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1970). Deer can be pathogenic hosts, reservoirs, or amplifiers and are considered a link in zoonotic disease emergence (Daszak et al. 2001). Deer have direct contact with the environment and are exposed to pathogens because of wide distribution, abundance, and sedentary behavior (Trainer and Hanson 1960).

Toxoplasma gondii is a zoonotic, protozoan parasite that globally infects humans and over 200 warm-blooded vertebrates (Acha and Szyfres 1994; Dubey 2010). Definitive hosts, domestic and wild felids, eliminate *T. gondii* oocysts (Acha and Szyfres 1994). The parasite is transmitted via fecal-oral ingestion of oocysts in vegetation, water, and feces (i.e., in soil, gardens, litter boxes, and sand pits) or by ingestion of infected meat (Dubey 2010). Barriga (1997) reported *Toxoplasma* antibodies ranging from 16 to 80% in the USA, Great Britain, European, and Latin American human populations. Small epidemics of toxoplasmosis due to the consumption of infected meat (Choi et al. 1997) or contaminated water (Mullens 1996) have been reported. In the USA, approximately 375 human deaths occur annually due to consuming food contaminated with oocysts (Mead et al. 1999). In 1979, an outbreak of toxoplasmosis in Panama affected 39 of 98 soldiers because a water resource was contaminated with wild feline feces (Benenson 1995). Ross et al. (2001) reported five human cases of ocular toxoplasmosis in the USA because hunters consumed undercooked venison.

White-tailed deer have been examined for *T. gondii* in several regions of the Midwest, but no studies have been conducted in suburban Chicago, Illinois where intensive public use of forest preserves may increase human exposures to the parasite. We investigated seroprevalence levels for *T. gondii* in white-tailed deer (live and culled) in suburban Des Plaines (DP) and Palos forest preserves in Cook County, Illinois, from 1995 to 1999. The results will serve as baseline comparison data for future *T. gondii* suburban deer studies and provide information to public health departments, wildlife managers, and researchers.

Materials and methods

Deer capture and culling

The study areas included Des Plaines (DP; 1168 ha) and Palos (1178 ha) public lands and green spaces within the Forest Preserve District of Cook County (FPDCC) in suburban Chicago, Illinois (41°85′ N, 87°65′ W; Fig. 1). Habitat for the study sites was described by Piccolo et al. (2010). We live-captured deer with drop-nets (Wildlife Materials Inc., Carbondale, Illinois, USA; Ramsey 1968) or remote dart gun (Pneu-Dart Inc., Williamsport, Pennsylvania, USA; Kilpatrick et al. 1997) from December to March (1995–1998). Deer were sexed then aged by tooth replacement and wear as fawn (< 1 year old), yearling (1–2 years old), or adult (≥ 2 years old; Severinghaus 1949). Blood was obtained from the jugular vein of live deer (25–40 cc). As part of a management program, additional deer were culled from November to April (1995–1999) by state-certified sharp shooters at baited sites approved by the Illinois Department of Natural Resources (IDNR). Morphological information (including age and sex) was recorded for culled deer. Age was determined to year, and age groups were confirmed by cementum annuli (Matson's Laboratory, Milltown, Montana, USA; Gilbert 1966). Blood was collected (≤ 45 cc) from the chest cavity or available blood vessel of culled deer. Processed meat was donated to local food depositories (Good Samaritan Act, House Bill 3412, 1991–1992). Blood samples were centrifuged to separate sera from whole blood, stored at − 60 °C, and batch shipped annually for serological analyses.

The University of Illinois Champaign-Urbana Laboratory Animal Care Advisory Committee reviewed and approved all methods (Protocol V5R246 and V5R246/8340). Deer were captured and culled under Illinois Department of Natural Resources (IDNR) and FPDCC ecological permits.

Serology

Samples were tested for *T. gondii* by Dr. JP Dubey at the United States Department of Agricultural (USDA) Research Center in Beltsville, Maryland, USA. Samples were tested by modified serum agglutination tests (MAT) described by Dubey and Desmonts (1987). Samples were classified as positive if the titer was ≥ 1:25.

Statistical analyses

Univariate analyses were used to detect differences in prevalence by serological outcome for age, sex, site, and collection period (year, month; Crosstabs in SPSS® 23.0, IBM Corporation, Armonk, NY, USA; Rothman 1986). Pearson chi-square statistics ($p \leq 0.05$) and Cochran-Mantel-Haenszel (CMH) odds ratios (OR) were used to examine significant relationships (Fleiss 1981). Biological parameters (site, year, month) were controlled by age and sex during statistical analyses. Multivariate logistic regression (LR) was used to evaluate deer parameters for each serological outcome (Nash et al. 1995). The initial models included age, sex, site, and collection period (year, month). The variables were screened by backward stepwise elimination to remove main effect variables ($p \leq 0.20$) which did not significantly affect the likelihood statistics or the magnitude of remaining variables (Hosmer and Lemeshow 1989; Kleinbaum 1994). Hosmer and Lemeshow goodness of fit (GOF) statistic was used to determine model fit (Hosmer and Lemeshow 1989). Biologically relevant interactions of main effect variables were also evaluated.

Results

Two hundred thirty-four samples were collected from DP which included 185 culled and 49 live-captured deer (collared and tagged; Table 1). We collected 209 samples from 181 culled and 28 live-captured deer from Palos (Table 1). Due to other research objectives, females were prioritized for capture and adult females were targeted for lethal removal to reduce deer overabundance. Overall seroprevalence for *T. gondii* was 55.9% ($n = 443$) and prevalence increased with age ($\chi^2 = 40.86$, 2 df, $p < 0.001$; Table 2). There was a higher prevalence (68%) by site for DP (OR = 2.97, CI = 2.02–4.39, $\chi^2 = 30.97$, $p < 0.001$; Table 2). Seroprevalence differed by year ($\chi^2 = 11.26$, 3 df, $p = 0.01$) with higher prevalence detected in 1996–1997 and 1997–1998 (Table 2). Seroprevalence also differed by month ($\chi^2 = 11.52$, 3 df, $p = 0.009$; Table 2) with higher prevalence detected in November through January. Positive deer titers ranged from 25 ($N = 47$), 50 ($N = 107$), to > 500 ($N = 71$). The final LR model included age (beta = −0.830, SE = 0.134), sex (beta = 0.455, SE = 0.238), site (beta = 0.70, SE = 0.014), year (beta = −0.201, SE = 0.105), and month (beta = −0.080, SE = 0.037; $R^2 = 0.214$, GOF = 0.544, 5 df, $p < 0.001$).

Fig. 1 Location of Des Plaines and Palos study sites, Forest Preserve District of Cook County, Chicago, Illinois, USA
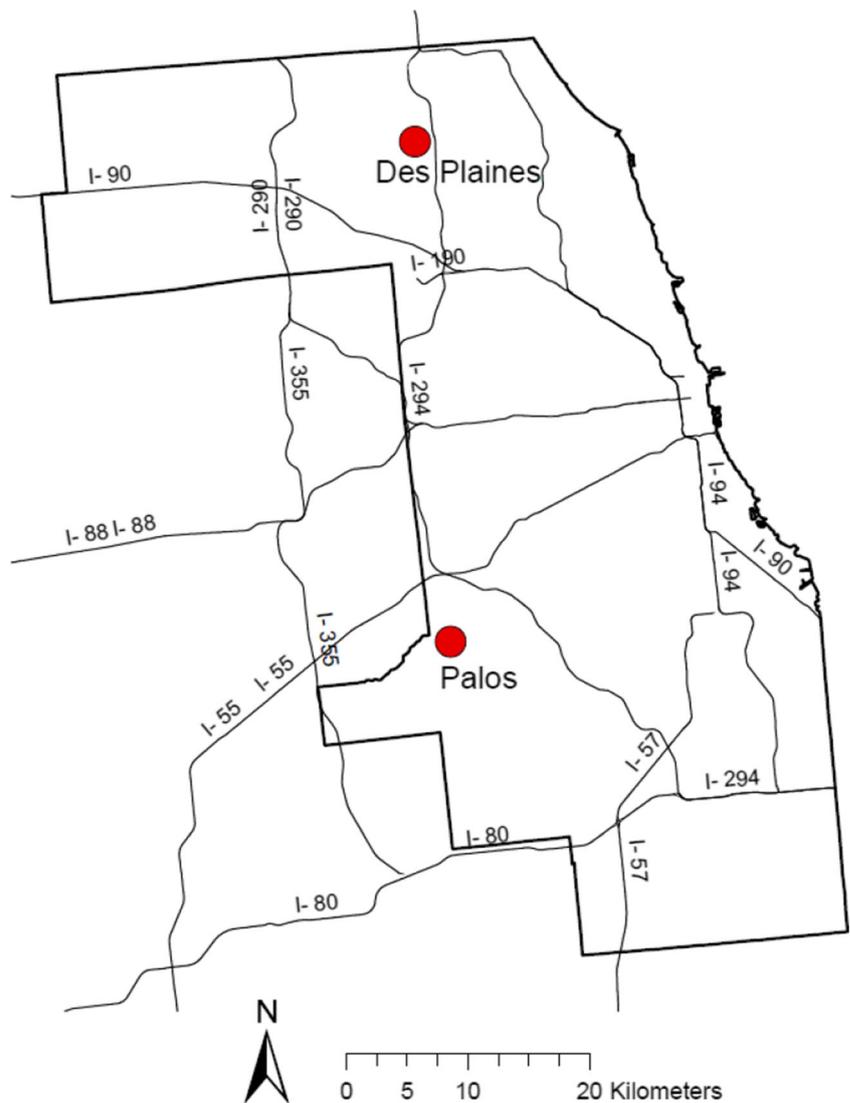
Discussion

White-tailed deer are herbivores and may become exposed and/or infected with *T. gondii* oocysts by ingesting plants, soil, or contaminated water. Seroprevalence for *T. gondii* (55.9%) in deer from our study is similar to that reported in the hunter-killed deer from Pennsylvania (60.2%; Humphreys et al. 1995) and deer culled from Cleveland Metroparks in Ohio (58.8%; Ballash et al. 2015). However, *T. gondii* seroprevalence was lower in hunter-harvested deer from New Jersey (28.7%; Dubey et al. 2013) and New York (38.5%; Schaefer et al. 2013).

The trend of increasing *T. gondii* with age in deer is common among studies (Schaefer et al. 2013; Vanek et al. 1996) because increased prevalence in adult deer indicates parasite presence and long-term and/or repeated exposures. Female deer from non-hunted populations in the Chicago suburbs have high survival rates and live longer than deer from hunted populations (Etter 2001; Etter et al. 2002), increasing the likelihood for continued

oocyte exposures. *T. gondii* seropositivity in deer sampled from Minnesota and Iowa varied by age; 37%, 55.6%, and 67% for fawns, yearlings, and adults, respectively (Dubey et al. 2009). Seroprevalence of *T. gondii* in deer fawns from Cleveland Metroparks in Ohio was 35.8% (54/151), 71.3% (72/101) in yearlings, and 70.3% (135/192) in adults (Dubey et al. 2014). In the Ohio study, 66.1% (150 of 227) deer < 1 year old were seropositive, indicating infection was acquired early in life. In our study, increased prevalence (68%) in adults is likely due to new and/or repeated exposures to the parasitic oocysts. In the Cleveland Metroparks, greater than half the yearlings were seropositive and prevalence increased with age reaching 83% in 4-year-old deer (Dubey et al. 2014). Although *T. gondii* can be transmitted congenitally in deer, the prevalence of transplacental transmission is unknown (Dubey et al., 2008).

Yearlings from Palos had substantially lower *Toxoplasma* seroprevalence (39.5%) compared with those from DP (59.5%). This could in part be due to differences in deer ecology and

Table 1 *Toxoplasma gondii* prevalence by site, age, and sex in suburban white-tailed deer ($n = 443$) from Chicago, Illinois, USA, 1995–1999

Variables	Seropositive	Seronegative	N	Prevalence (%)
Des Plaines ($n = 234$)				
Age ($p = 0.01$)				
Fawn	22	27	49	44.9
Yearling	25	17	42	59.5
Adult	112	31	143	78.3
Sex ($p = 0.21$)				
Female	122	51	173	74.8
Male	37	24	61	60.7
PALOS ($n = 209$)				
Age ($p < 0.001$)				
Fawn	14	48	62	22.6
Yearling	17	26	43	39.5
Adult	56	48	104	53.9
Sex ($p = 0.14$)				
Female	49	82	131	37.4
Male	38	40	78	48.7

parasitic prevalence between preserves. The increased female yearling seroprevalence at DP (16 of 28; 57%) compared with that at Palos (5 of 19; 26%) suggests site-specific differences in parasitic exposure. Nine of fourteen (64%) yearling males from DP were positive for *Toxoplasma* compared with 12 of 24 (50%) from Palos. Etter et al. (2002) determined that dispersal of deer in the Chicago region was low ($\leq$ 7%) for all sex and ages except 50% of male yearlings dispersed in the spring. Piccolo et al. (2010) reported neonate fawn mortality for 56 radio-tagged fawns from 1999 to 2001 and neonate mortality at DP (72%) was nearly three times higher than mortality at Palos (27%) with the primary cause of death being coyote predation. Therefore, the

Table 2 Prevalence for *Toxoplasma gondii* in suburban white-tailed deer ($n = 443$) from Chicago, Illinois, USA, 1995–1999

Variables	Seropositive	Seronegative	N	Prevalence (%)
Age ($p < 0.001$)				
Fawn	36	75	111	32.4
Yearling	42	43	85	49.4
Adult	168	79	247	68.0
Sex ($p = 0.73$)				
Female	171	133	304	56.3
Male	75	64	139	54.0
Study site ($p < 0.001$)				
Des Plaines	159	75	234	68.0
Palos	87	122	209	41.6
Year ($p = 0.01$)				
1995–1996	48	57	105	45.7
1996–1997	76	47	123	61.8
1997–1998	84	50	134	62.3
1998–1999	38	43	81	47.0
Month ($p = 0.009$)				
November–December	36	13	49	73.5
January	61	37	98	62.2
February	56	58	114	49.1
March–April	93	89	182	51.1

high mortality of neonatal fawns at DP may have contributed to lower numbers of resident yearlings exposed to localized *T. gondii* oocysts and up to 50% of the yearling males sampled at DP may have originated from adjacent preserves or green spaces where *T. gondii* exposure was not examined for this study.

Difference in *T. gondii* prevalence by site may be due to differences in definitive host abundance, felids. Bobcats (*Lynx rufus*) are rare or absent in the Chicago region (Gehrt et al. 2013); however, domestic cats were observed in DP and Palos forest preserves during the study. The role of domestic cats as a host shedding fecal *T. gondii* oocysts is well documented (Dubey 2010; Jessup 2004). The parasitic oocysts have the ability to persist and remain infective in water or moist soil and can survive heat, humidity, and freezing for up to 18 months (Frenkel et al. 1975). Ballash et al. (2015) sampled domestic cats from Ohio and 45/200 (23%) near suburban sites and 155/200 (77%) near urban sites were seropositive for *T. gondii*. The difference between urban and suburban domestic cat densities in Cleveland was described as the likely reason for an increased *T. gondii* seroprevalence in urban deer (Ballash et al. 2015). For our study areas, Graser et al. (2012) characterized the dominant land use adjacent to DP as urbanized consisting of > 75% medium- to high-density urban development, and Palos as urban-open with < 3% medium- to high-density urban development. This information supports the hypothesis that higher domestic cat densities present at DP could have contributed to higher prevalence of *T. gondii* seroprevalence in deer from this preserve. However, during our study, neither domestic feral, nor wild felids were directly sampled.

Additional factors contributing to overall differences in prevalence by age and site may include variations in deer densities and habitat between sites. Piccolo et al. (2010) reported high-densities of deer at DP and Palos as estimated by aerial counts from 1985 to 1999 (> 23 deer/km^2), reflecting populations potentially at carrying capacity. Differences in land cover and habitat are evident between DP and Palos. Des Plaines was characterized by a sparse understory dominated by non-native forbs and shrubs, and flooding from the DP River during rain events was common (Piccolo et al. 2010) which removed overlying leaves and detritus exposing soil. By comparison, Palos consisted of rolling forested uplands with a dense understory of mixed native and non-native shrubs and forbs. Because soil contaminated with oocysts is a mode of *T. gondii* infection for animals (Torgerson and Macpherson 2011), we would expect that deer from DP would have a greater likelihood of exposure to oocyst-contaminated soil and a higher prevalence of *T. gondii* compared with those from Palos.

Variation in *T. gondii* prevalence differed by year and month. Deer culled from Minnesota also had variations in seroprevalence by year. In 2008, prevalence was lower (14.8%, 26/175) compared with 2009 (27.7%, 59/213) and 2010 (25.2%, 25/99; Dubey et al. 2014). The authors assumed these differences were related to weather and oocysts

presence. We concur that weather patterns may influence parasite presence and abundance. Our data also reflects a higher prevalence of *T. gondii* in deer sampled from November through January. We hypothesize that recent deer exposure(s) and/or reexposure(s) to oocysts may occur prior to winter sampling, especially during seasonal months when foliage and soil are more accessible to deer. This is an important consideration if future studies are conducted to evaluate for *T. gondii*.

The multivariate model for *T. gondii* also included sex. Female deer during our study maintained smaller home ranges (Etter et al. 2002), potentially increasing repeated exposures to foci of oocysts in contaminated soil, vegetation, and water sources. Seroprevalence was also higher in females (60.9%) versus males (55.5%) from deer collected in urban/suburban Ohio; however, no association between seropositivity and gender was observed after adjusting for age and site (Ballash et al. 2015).

This study provides baseline data for future suburban deer studies and to public health and wildlife officials regarding the prevalence of *T. gondii* in two public forest preserves in Chicago, Illinois. Emerging and reemerging infectious diseases continue to increase worldwide and it is important to monitor for zoonotic pathogens that persist in the environment before outbreaks become endemic. Animals, such as deer from suburban culling programs, can be a cost-effective means to infer prevalence in host or reservoir populations when direct estimation is difficult (VerCauteren et al. 2008). It is critical in urban/suburban locations to test for zoonotic diseases because wildlife populations may occur at higher densities, domestic pets are present, and proximity of humans and recreational activities can increase potential pathogen exposure.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical statement All procedures performed during this research involving animals were in accordance with the ethical standards of the institution and state where the study was conducted.

Data availability The datasets generated for the current study are available from the corresponding author on reasonable request.

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