Toxoplasma gondii Infection in the United States: Seroprevalence and Risk Factors

Jeffrey L. Jones,[1] Deanna Kruszon-Moran,[2] Marianna Wilson,[1] Geraldine McQuillan,[2] Thomas Navin,[1] and James B. McAuley[1]

Infection with *Toxoplasma gondii* can cause severe illness when the organism is contracted congenitally or when it is reactivated in immune-suppressed persons. To determine the prevalence of *T. gondii* infection in a representative sample of the US population, the authors tested sera from participants in the Third National Health and Nutrition Examination Survey (1988–1994) for immunoglobulin G antibodies to *T. gondii*. Of 27,145 persons aged ≥12 years, 17,658 (65%) had sera tested. The overall age-adjusted seroprevalence was 22.5% (95% confidence interval (CI): 21.1, 23.9); among women aged 15–44 years, seroprevalence was 15.0% (95% CI: 13.2, 17.0). Age-adjusted seroprevalence was higher in the Northeast (29.2%) than in the South (22.8%), Midwest (20.5%), or West (17.5%) ($p < 0.05$). In multivariate analysis, risk for *T. gondii* infection increased with age and was higher among persons who were foreign-born, persons with a lower educational level, those who lived in crowded conditions, and those who worked in soil-related occupations, although in subset analyses risk categories varied by race/ethnicity. Nearly one quarter of adults and adolescents in the United States have been infected with *T. gondii*. Most women of childbearing age in the United States are susceptible to acute infection and should be educated about ways to minimize exposure to *T. gondii*. *Am J Epidemiol* 2001;154:357–65.

prevalence; seroepidemiologic studies; serology; *Toxoplasma*; toxoplasmosis

Toxoplasmosis is a disease caused by the protozoal parasite *Toxoplasma gondii*. Newly acquired *T. gondii* infection in a pregnant woman can be transmitted to the fetus and may cause mental retardation, blindness, epilepsy, and death. *T. gondii* can also cause severe encephalitis via acute infection or reactivation of latent infection among immune-suppressed persons, including those with acquired immunodeficiency syndrome, those with immunosuppressive cancer, and transplant recipients on immunosuppressive drugs. Toxoplasmosis is the most frequent severe neurologic infection among persons with acquired immunodeficiency syndrome (1). However, adults with normal immune function are usually asymptomatic or have symptoms such as fever, malaise, and lymphadenopathy that resolve spontaneously. Estimates of the incidence of congenital infection in the United States range from 400 per year to 4,000 per year (2), but because toxoplasmosis is not a nationally reportable disease, the true magnitude of disease is not known. The annual economic impact of toxoplasmosis in the United States is estimated to be $7.7 billion (3).

Most *T. gondii* infections among humans occur in one of three ways: 1) by eating raw or undercooked meat containing *T. gondii* tissue cysts or eating food that has been cross-contaminated with raw/undercooked meat; 2) by ingesting oocysts from soil (for example, through gardening, handling/eating unwashed vegetables, or changing a cat litter box); or 3) by acquiring congenital infection through the placenta. Of the estimated 750 deaths caused by toxoplasmosis in the United States each year, 375 are thought to occur from eating raw or undercooked meat; this makes toxoplasmosis the third-leading cause of US foodborne death (4).

Recent epidemiologic studies have identified the following risk factors for *T. gondii* infection: owning cats (5); being in proximity to seropositive cats in farming areas (6); cleaning the cat litter box (7); eating raw or undercooked pork, mutton, lamb, beef, or mincemeat products (5–8); gardening (6); having contact with soil (8); eating raw or unwashed vegetables or fruits (5); eating raw vegetables outside the home (5); washing kitchen knives infrequently (7); having poor hand hygiene (5); and traveling outside of Europe, the United States, and Canada (8). However, owning a cat was not shown to be a risk factor for *T. gondii* infection in two studies of pregnant women (8, 9) or in a study of persons infected with human immunodeficiency virus (10). Protective factors include adhering to a meat-free diet (11), living at a high altitude or in an arid climate (12, 13), and living in a climate with frequent freezing and thaw-

ing (14). Outbreaks of toxoplasmosis have been attributed to ingestion of raw or undercooked ground beef, lamb, pork, or venison (15–20); consumption of unpasteurized goat's milk (21); and exposure to contaminated water (22, 23), soil (24), or aerosolized soil (25).

High *T. gondii* seroprevalence has been found in countries (such as France) where undercooked meat is commonly eaten (26, 27) and in tropical areas of Latin America or sub-Saharan Africa where cats are abundant and the climate favors survival of oocysts (12, 28–34). For example, in France, a seroprevalence of 71 percent has been found among pregnant women (26, 27). In Panama, seroprevalence has been reported to be 13 percent by age 6 years (29) and 90 percent by age 60 years (30). Seroprevalence has been reported to be 78 percent among pregnant women in Ibadan, Nigeria (34), 44 percent among persons living in the drier regions of Somalia (12), and 83 percent in the population of the South Delta in Nigeria (12). Researchers working in Panama (where meat was well cooked) found that there was a rapid rise in seroprevalence during childhood that probably reflected soil exposure to *T. gondii* oocysts (30). On the other hand, extrapolation from a study of women of childbearing age in France showed that the risk of being infected with *T. gondii* was the same throughout life (35). Studies carried out in Scandinavian countries (36–38) and in England (39) have shown lower seroprevalence.

To our knowledge, the prevalence of *T. gondii* infection in the general US population has not been previously reported. We present here the results of *T. gondii* serologic testing done on a representative sample of the US general population selected in the Third National Health and Nutrition Examination Survey (NHANES III).

MATERIALS AND METHODS

NHANES III was a cross-sectional survey conducted by the National Center for Health Statistics of the Centers for Disease Control and Prevention between 1988 and 1994. It was designed to obtain nationally representative statistics on a variety of health measures and conditions through household interviews, standardized physical examinations, and collection of blood samples in mobile examination centers (40). NHANES III was based on a stratified, multistage, probability cluster design from which a sample representative of the civilian, noninstitutionalized US population aged 2 months or older was drawn. Persons aged ≥60 years, children aged 2 months through 5 years, Mexican Americans, and Blacks were sampled at higher rates than other persons to assure an adequate sample size for these age, racial, and ethnic groups. Detailed descriptions of the design of the survey and the sample have been published elsewhere (40).

Surplus sera from a representative sample of persons aged ≥12 years were available for testing for antibodies to *T. gondii*. Sera were also tested for a limited number of children aged 1–5 and 6–11 years for whom sera were available. Because of the limited availability of sera from children, these groups represent convenience samples rather than random subsets of children aged <12 years; therefore, we cannot assume that they are representative of

the US population. Nevertheless, for completeness, we present the data for children aged <12 years in a figure showing seroprevalence by age and sex.

Race/ethnicity was defined by self-report as non-Hispanic White, non-Hispanic Black, or Mexican-American. Persons who did not self-select into one of these three groups were classified as "other" and were analyzed only within the total population. Multivariate analyses were conducted for persons aged 20 years or older, because some important predictor variables (education and occupation) were only applicable to this age range. Age was grouped as 20–29, 30–39, 40–49, 50–59, 60–69, and ≥70 years and was entered into logistic regression models using these categories. A separate logistic regression analysis was carried out for persons aged 12–19 years, excluding education and occupation. A poverty index was calculated by dividing total family income by the US poverty threshold, adjusted for family size. A crowding index was calculated by dividing the total number of rooms in a household (excluding bathrooms) by the number of household residents; it was expressed as number of persons per room, and the variable was categorized as <0.5, 0.5–0.99, and ≥1.0 persons per room. Education was measured as the last year of schooling completed and was grouped into four levels (no high school, some high school, high school completion, some college) for entry into all logistic regression models. Residence in a central county with a population of ≥1 million was defined as metropolitan residence; residence in all other counties (including rural areas) was defined as nonmetropolitan residence.

Working in a soil-related occupation was defined by the longest-held job and included farm workers, farm operators, farm managers, and related agricultural occupations. Because NHANES III was not specifically designed to study *T. gondii* seroprevalence, no other data on soil exposure variables were collected. Meat consumption was determined from average consumption over the past month and included bacon, sausage, luncheon meat, liver and other organ meat, beef, pork, chicken, and turkey. Average meat consumption was grouped into categories of none, 1–15 servings per month, 15–30 servings per month, and >30 servings per month.

Laboratory testing

All specimens were analyzed during the years 1991–1995 using the Platelia Toxo-G immunoglobulin G enzyme immunoassay test (Sanofi Diagnostics Pasteur, BioRad, Hercules, California), according to the manufacturer's instructions. Results were reported in International Units (IU); samples with >6 IU were considered positive for *T. gondii* immunoglobulin G antibodies. Prior to initiation of the study, the Platelia Toxo-G kit was evaluated using a battery of 90 sera (23 negative and 67 positive) with various titers in the Centers for Disease Control and Prevention's *Toxoplasma* immunofluorescence assay–immunoglobulin G test. Specificity was 100 percent; sensitivity was 95.5 percent. The three specimens with discrepant results (immunofluorescence assay-positive, Platelia-negative) were analyzed by means of the dye test (Dr. Jack Remington, Palo Alto, California) and

found to be dye test-negative; thus, the sensitivity of the Platelia Toxo-G kit was actually 100 percent in this group of specimens.

Statistical analysis

All estimates were weighted to represent the total US population and to account for oversampling and nonresponse to the household interview and physical examination (41, 42). Statistical analyses were conducted using SUDAAN, a family of statistical procedures for analysis of data from complex sample surveys (43). Prevalence estimates were age-adjusted by the direct method to the 1980 US population when seroprevalence was compared across population subgroups.

To screen for possible predictors of *T. gondii* seropositivity, we evaluated differences in seroprevalence without correcting for multiple comparisons, by examining the 95 percent confidence intervals for the seroprevalence values generated by SUDAAN. We determined *p* values from a general linear contrast procedure in SUDAAN, using a univariate *t* statistic. Independent predictors were further determined by means of multivariate logistic regression. For persons aged ≥20 years, modeling was conducted for the combined population and for each racial/ethnic group (non-Hispanic White, non-Hispanic Black, and Mexican-American). Subset analyses were conducted in persons aged 12–19 years (all three racial/ethnic groups) and, for Mexican Americans, persons aged 20–59 and ≥60 years. Variables that had a Satterthwaite-adjusted *F* statistic with a *p* value ≤ 0.05 were considered significant. A reduced model containing only those cofactors that were considered independent predictors of *T. gondii* seropositivity for at least one of the three racial/ethnic groups is presented individually for each racial/ethnic group.

RESULTS

Of the 27,145 persons aged 12 years or older who were selected for NHANES III, 75 percent (*n* = 20,241) were interviewed and underwent a physical examination, and 65 percent (*n* = 17,658) had sera tested for *T. gondii* antibodies. The availability of a specimen for antibody testing among those interviewed did not vary by age, race/ethnicity, sex, poverty index, educational level, crowding, or other characteristics included in our analysis (range, 77–83 percent), except that it was somewhat lower (69 percent) among persons aged ≥70 years. Previous analysis of NHANES III data found that no apparent bias was introduced by nonresponse (41).

As we noted above, the availability of sera for children aged <12 years was limited. The availability of specimens for all children under 12 with completed interviews ranged from 30 percent to 35 percent when data were stratified according to all important demographic cofactors, except that availability was somewhat lower among non-Hispanic Whites (27 percent) and higher among the foreign-born (45 percent) and those from the northeastern United States (43 percent).

The overall age-adjusted *T. gondii* seroprevalence for persons aged ≥12 years was 22.5 percent (95 percent confidence interval (CI): 21.1, 23.9). Among women of childbearing age (15–44 years), seroprevalence was 15.0 percent (95 percent CI: 13.2, 17.0). For children aged 1–5 years, 21 percent (*n* = 1,359) had sera available for testing and 3.7 percent were seropositive for *T. gondii* immunoglobulin G. For children aged 6–11 years, 48 percent (*n* = 1,819) had sera available for testing, and 5.2 percent were seropositive for *T. gondii* immunoglobulin G. Because the proportion of children aged <12 years who had sera available for testing was low, there is a greater potential for these estimates to be biased. Regardless, these estimates will be useful "benchmarks" with which to compare results of future studies in this age group.

The age-adjusted seroprevalence of *T. gondii* was higher in the Northeast (29.2 percent) than in the South (22.8 percent), Midwest (20.5 percent), or West (17.5 percent) (*p* < 0.05; table 1). Seroprevalence was similar for males and females by age group, except among persons aged 30–39 years, where it was somewhat higher for males (*p* = 0.02) (figure 1). Age-adjusted seroprevalence did not differ significantly by racial/ethnic group; however, seroprevalence did vary by race/ethnicity within specific age groups (figure 2). Age-adjusted seroprevalence differed significantly by education (in the combined population, among non-Hispanic Whites, and among Mexican Americans) and by birth outside of the United States (all groups except non-Hispanic Whites). Age-adjusted seroprevalence also differed significantly by household crowding (combined population and Mexican Americans), poverty (combined population and non-Hispanic Whites), soil-exposed occupation (all groups except non-Hispanic Blacks), and cat ownership (Mexican Americans only). Age-adjusted seroprevalence did not differ significantly by sex, residence in a metropolitan area, or consumption of meat in the past 30 days (table 1).

In the overall multivariate model for persons aged 20 years or older, *T. gondii* seroprevalence was significantly lower among Mexican Americans (compared with non-Hispanic Whites) and among persons living in the West, Midwest, and South (compared with the Northeast) (table 2). Seroprevalence was significantly higher among those in the age groups 40–49 years and above, those who had not been born in the United States, those living in more crowded conditions (≥1 persons per room vs. <0.5 persons per room), those with less than some college education, and those who worked in soil-related occupations (table 2). In the overall multivariate model, seroprevalence did not vary significantly by sex, socioeconomic level, metropolitan area, current amount of meat in the diet, or cat ownership (table 2).

There were significant interactions between race/ethnicity and age, education, country of birth, occupation, cat ownership, and metropolitan residence; therefore, we present results from reduced models for each of the three racial/ethnic groups that contain only those variables that were significant predictors of *T. gondii* seropositivity for at least one of the racial/ethnic groups (table 3). Among non-Hispanic Whites, four age categories, less education at all three levels, birth outside of the United States, and history of

TABLE 1. Stratified age-adjusted seroprevalence of *Toxoplasma gondii* in the civilian noninstitutionalized US population aged ≥12 years, Third National Health and Nutrition Examination Survey, 1988–1994

Characteristic	Total no.*	Entire study population (n = 17,658)		Race/ethnicity					
				Non-Hispanic White (n = 6,995)		Non-Hispanic Black (n = 5,002)		Mexican-American (n = 4,944)	
		%	95% CI†	%	95% CI	%	95% CI	%	95% CI
Race	17,658	22.5	21.1, 23.9	21.2	19.5, 23.0	23.6	21.8, 25.5	22.5	20.2, 25.0
Sex									
Male	8,273	23.3	21.6, 25.0	21.9	19.9, 24.1	25.5	23.4, 27.8	23.5	20.2, 27.4
Female	9,385	21.8	20.1, 23.7	20.6	18.5, 22.9	22.0	19.7, 24.6	21.4	19.5, 23.5
Poverty level									
Below	4,116	27.8	24.8, 31.2‡	26.8	22.9, 31.5‡	24.7	21.8, 28.1	24.5	21.4, 28.1
At or above	11,910	21.5	20.0, 23.1	20.7	19.0, 22.5	23.0	21.3, 24.9	20.4	17.6, 23.7
Crowding index (persons per room)									
<0.5 (referent)	6,102	20.1	18.3, 22.1	19.9	18.0, 22.1	23.4	21.6, 25.3	15.2	12.0, 19.2
0.50–0.99	7,111	23.3	21.6, 25.0	22.9	20.8, 25.1	22.2	19.7, 25.1	18.2	15.8, 20.9
≥1	4,397	29.0	26.0, 32.5‡	25.1	20.0, 31.5	28.4	24.5, 32.9	29.9	25.8, 34.8‡
Education§									
None or elementary school	3,580	38.5	34.7, 42.6‡	33.4	26.1, 42.6‡	35.8	28.5, 44.9	30.2	26.7, 34.1‡
Some high school	2,442	31.9	29.6, 34.3‡	31.7	28.7, 35.0‡	28.3	24.6, 32.7	25.4	20.8, 30.9
High school graduation	4,546	25.0	23.0, 27.1	24.4	22.1, 27.1	24.5	21.8, 27.6	21.1	17.2, 25.7
Some college (referent)	4,244	20.7	18.7, 23.0	20.1	18.0, 22.3	25.4	22.7, 28.6	16.8	12.1, 23.2
Employment in an occupation involving soil exposure§									
Yes	1,041	37.2	31.8, 43.6‡	37.0	29.4, 46.5‡	31.5	23.6, 41.9	34.3	28.6, 41.2‡
No	13,487	25.0	23.6, 26.6	23.7	22.1, 25.4	26.0	24.1, 28.2	23.8	21.6, 26.3
Residence in a metropolitan area									
Population of ≥1 million	8,463	22.3	20.4, 24.3	19.6	17.7, 21.8	22.6	20.7, 24.8	24.0	21.6, 26.6
Population of <1 million or rural	9,195	22.8	20.4, 25.3	22.4	19.9, 25.3	24.9	21.8, 28.5	20.3	16.4, 25.1
Place of birth									
Non-United States	3,433	34.1	30.7, 37.8‡	25.9	22.6, 29.8	44.6	37.5, 53.0‡	30.3	27.5, 33.5‡
United States	14,167	20.7	19.3, 22.2	20.8	19.1, 22.7	22.0	20.2, 24.0	15.1	13.3, 17.2
Current cat ownership									
Yes	2,473	22.3	19.5, 25.5	22.6	19.5, 26.0	25.1	20.4, 30.9	15.1	12.2, 18.7‡
No	15,170	22.5	21.1, 23.9	20.6	19.0, 22.4	23.5	21.6, 25.6	23.3	21.0, 25.8
No. of servings of meat in past month¶									
0	89	16.7	9.1, 30.5						
1–15	2,883	22.6	20.1, 25.4						
16–30	6,236	23.0	20.9, 25.3						
>30 (referent)	8,326	22.1	20.5, 23.8						
Region¶,#									
West	4,034	17.5	15.5, 19.7‡						
South	7,831	22.8	20.4, 25.4						
Midwest	3,527	20.5	18.1, 23.0‡						
Northeast (referent)	2,266	29.2	25.1, 33.9						

* The total for each category may not equal the overall sample size because of nonresponse.
† CI, confidence interval.
‡ 95% confidence limits do not overlap those of the referent group in this category (read vertically).
§ Data on persons aged ≥20 years were used for this factor.
¶ The sample size was not sufficient to assess this factor by racial/ethnic group.
# West: Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming; South: Alabama, Arkansas, Delaware, District of Columbia, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, and West Virginia; Midwest: Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin; Northeast: Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont.
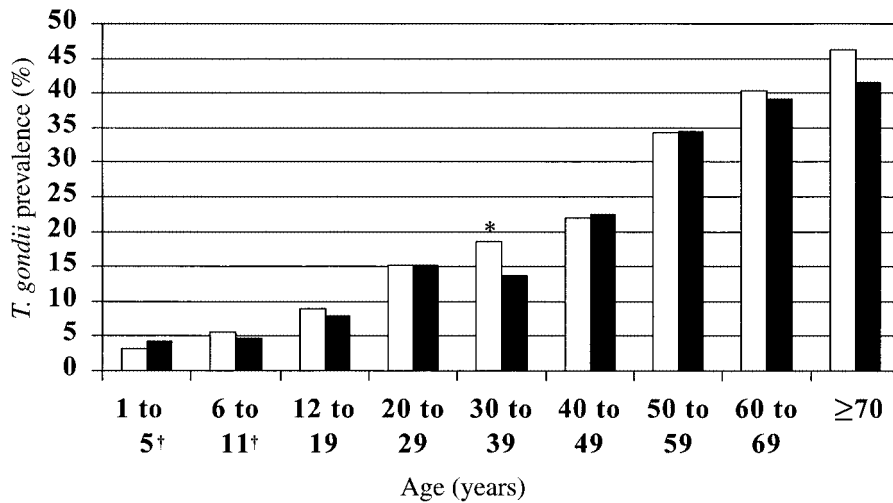
FIGURE 1. Seroprevalence of *Toxoplasma gondii*, by age and sex, Third National Health and Nutrition Examination Survey, 1988–1994. □, men; ■, women. In the age group 30–39 years (*), seroprevalence was higher in males than in females ($p = 0.02$). Among children under 12 years of age (†), seroprevalence estimates are unstable because of low sample representation in these categories.

employment in an occupation involving soil exposure were all associated with increased risk for *T. gondii* seropositivity (table 3). Among non-Hispanic Blacks, significantly higher risk for *T. gondii* seropositivity was associated with four age categories, with having no education/elementary education or some high school education as compared with some college, and with birth outside of the United States. In addition, among non-Hispanic Black persons, lower seropositivity for *T. gondii* was associated with living in a metropolitan area. Among Mexican Americans, the two highest age categories, no education/elementary education or some high school education as compared with some college, birth outside of the United States, and employment in an occupation involving heavy soil exposure were associated with increased risk of *T. gondii* seropositivity. Current cat ownership was asso-

ciated with a reduced risk for *T. gondii* seropositivity among Mexican Americans.

Subset multivariate analysis was carried out for persons aged 12–19 years, excluding the occupation and education variables. In this analysis, none of the risk factors for White or Black persons reached statistical significance. Results for Mexican Americans are described below.

Because the age curve for Mexican Americans had a different shape than the curve for the other two racial/ethnic groups, with a flatting from ages 20–29 years through ages 50–59 years (figure 2), we conducted a subset analysis comparing the age groups 12–19 years (without education and occupation), 20–59 years, and ≥60 years to examine how *T. gondii* seropositivity risk factors might vary between these groups. Among Mexican Americans aged 12–19 years, risk
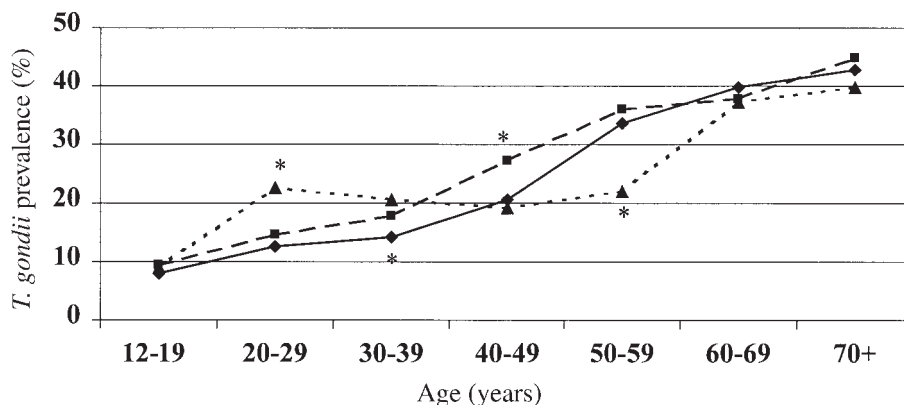

FIGURE 2. Seroprevalence of *Toxoplasma gondii*, by age and race/ethnicity, Third National Health and Nutrition Examination Survey, 1988–1994. ◆, non-Hispanic Whites; ■, non-Hispanic Blacks; ▲, Mexican Americans. An asterisk (*) beside a symbol indicates that seroprevalence in that racial/ethnic group differed significantly ($p < 0.05$) from that in the other two racial/ethnic groups in the same age range.

TABLE 2. Risk of *Toxoplasma gondii* seropositivity, as estimated with a full logistic regression model, for persons aged ≥20 years (*n* = 12,566), Third National Health and Nutrition Examination Survey, 1988–1994

Factor	OR*	95% CI*
Age group (years)		
20–29	1.00†	
30–39	1.23	0.89, 1.70
40–49	1.94‡	1.44, 2.63
50–59	3.52‡	2.46, 5.04
60–69	4.26‡	3.12, 5.81
≥70	4.78‡	3.46, 6.61
Race/ethnicity		
Mexican-American	0.78‡	0.63, 0.96
Non-Hispanic Black	0.99	0.85, 1.16
Non-Hispanic White	1.00†	
Sex		
Male	1.14	0.95, 1.36
Female	1.00†	
Poverty level		
Below	1.14	0.96, 1.34
At or above	1.00†	
Crowding index (persons per room)		
≥1	1.27‡	1.02, 1.59
0.50–0.99	0.98	0.81, 1.19
<0.5	1.00†	
Education		
No school/elementary	1.61‡	1.30, 1.99
Some high school	1.68‡	1.42, 1.98
High school	1.31‡	1.10, 1.57
Some college/graduate school	1.00†	
Residence in a metropolitan area		
Population of ≥1 million	0.92	0.79, 1.08
Population of <1 million or rural	1.00†	
Place of birth		
Non-United States	1.93‡	1.62, 2.30
United States	1.00†	
Employment in an occupation involving soil exposure		
Yes	1.40‡	1.06, 1.85
No	1.00†	
Current cat ownership		
Yes	1.11	0.92, 1.35
No	1.00†	
No. of servings of meat in past month		
0	0.84	0.35, 2.00
1–15	1.11	0.87, 1.42
16–30	1.09	0.93, 1.27
>30	1.00†	
Region§		
West	0.51‡	0.39, 0.67
South	0.72‡	0.53, 0.98
Midwest	0.69‡	0.50, 0.94
Northeast	1.00†	

* OR, odds ratio; CI, confidence interval.
† Referent.
‡ 95% confidence interval does not include 1.
§ See table 1 for a list of states included in each region.

was significantly increased only for foreign birth (relative risk (RR) = 8.20, 95 percent CI: 4.52, 14.86). Among Mexican Americans aged 20–59 years, risk was increased for foreign birth (RR = 2.16, 95 percent CI: 1.77, 2.64) and for some high school education compared with some college education (RR = 1.46, 95 percent CI: 1.01, 2.11); risk was decreased for cat ownership (RR = 0.58, 95 percent CI: 0.38, 0.87). In the 20- to 59-year age range, none of the 10-year age categories were significantly associated with risk (for ages 30–39 years, RR = 0.89; for ages 40–49 years, RR = 0.88; and for ages 50–59 years, RR = 0.99, in comparison with ages 20–29 years). Among Mexican Americans in the age group ≥60 years, foreign birth (RR = 1.69, 95 percent CI: 1.15, 2.48) and crowding (≥1 persons per room as compared with <0.5 persons per room) (RR = 1.84, 95 percent CI: 1.04, 3.27) were the only two factors associated with risk for *T. gondii* seropositivity.

DISCUSSION

We found an overall age-adjusted *T. gondii* seroprevalence of 22.5 percent, and among women of childbearing age we found a seroprevalence of 15.0 percent. These results indicate that the United States is a country with low *T. gondii* seroprevalence in comparison with other nations such as France (26, 27) and many countries in Latin America or sub-Saharan Africa (12, 28–34). The relatively gradual increase in seroprevalence associated with age suggests that soil exposure, which is greatest during the childhood years, may not be the principal mechanism by which persons are exposed to *T. gondii* in the United States. Therefore, a significant proportion of toxoplasmosis in this country may be due to ingestion of raw or undercooked infected meat or cross-contamination from such meat. However, we cannot rule out a cohort effect, with there being a higher risk for *T. gondii* infection in the past, as an explanation for the age trends. Risk for *T. gondii* infection is likely to have been higher in the past, because freezing of meat was formerly less common and because improved livestock rearing practices have led to a decline in toxoplasmosis (which has been documented in pork (44)).

These data suggest that 85 percent of women in the United States are susceptible to acute *Toxoplasma* infection during the childbearing years, and therefore their infants are susceptible to congenital toxoplasmosis. For this reason, it is important that women of childbearing age, especially pregnant women, be educated about not eating raw or undercooked meat and using good cat feces- and soil-related hygiene. Recommendations for preventing congenital toxoplasmosis among pregnant women have been published (2). It is also important that persons infected with human immunodeficiency virus and other immunosuppressed individuals be made aware of toxoplasmosis prevention guidelines. Recommendations for prevention of toxoplasmosis among persons with human immunodeficiency virus have also been published (45).

In 1962 and 1989, the prevalence of *T. gondii* infection was examined among military recruits, with results of 14.4 percent and 9.5 percent, respectively (46, 47). Approximately 80

TABLE 3. Risk factors for *Toxoplasma gondii* seropositivity among non-Hispanic Whites, non-Hispanic Blacks, and Mexican Americans aged ≥20 years, Third National Health and Nutrition Examination Survey, 1988–1994*

Factor	Race/ethnicity					
	Non-Hispanic White (*n* = 6,129)		Non-Hispanic Black (*n* = 3,858)		Mexican-American (*n* = 3,874)	
	Odds ratio	95% confidence interval	Odds ratio	95% confidence interval	Odds ratio	95% confidence interval
Age group (years)						
20–29	1.00†		1.00†		1.00†	
30–39	1.19	0.81, 1.74	1.29	0.95, 1.75	0.89	0.69, 1.14
40–49	1.91‡	1.33, 2.73	2.43‡	1.62, 3.63	0.90	0.69, 1.18
50–59	3.44‡	2.29, 5.19	3.53‡	2.50, 4.97	1.05	0.71, 1.55
60–69	4.29‡	3.08, 5.98	3.63‡	2.53, 5.22	2.45‡	1.84, 3.26
≥70	4.55‡	3.19, 6.49	4.64‡	3.21, 6.69	2.32‡	1.38, 3.90
Education						
No school/elementary	1.86‡	1.47, 2.36	1.36‡	1.03, 1.80	1.49‡	1.06, 2.09
Some high school	1.82‡	1.51, 2.20	1.33‡	1.03, 1.70	1.62‡	1.15, 2.29
High school	1.33‡	1.08, 1.63	0.99	0.82, 1.20	1.20	0.84, 1.72
Some college/graduate school	1.00†		1.00†		1.00†	
Place of birth						
Non-United States	1.66‡	1.32, 2.07	3.10‡	2.36, 4.07	2.08‡	1.73, 2.51
United States	1.00†		1.00†		1.00†	
Employment in an occupation involving soil exposure						
Yes	1.60‡	1.12, 2.30	0.91	0.65, 1.27	1.30‡	1.03, 1.66
No	1.00†		1.00†		1.00†	
Current cat ownership						
Yes	1.17	0.96, 1.43	0.98	0.68, 1.41	0.65‡	0.46, 0.91
No	1.00†		1.00†		1.00†	
Residence in a metropolitan area						
Population of ≥1 million	0.92	0.76, 1.11	0.74‡	0.59, 0.93	1.22	0.99, 1.51
Population of <1 million or rural	1.00†		1.00†		1.00†	

* Estimated with logistic regression analysis (reduced model showing only significant predictors in at least one racial/ethnic category).
† Referent.
‡ 95% confidence interval does not include 1.

percent of the recruits in the 1989 study (47) were men aged 17–20 years. For comparison, we examined men aged 17–20 years from our study population and found a *T. gondii* seroprevalence of 11.9 percent. This is consistent with the previous studies, although different types of serologic tests were used for each of these studies.

We found the lowest *T. gondii* seropositivity among persons residing in the western region of the United States. This finding is consistent with the studies of military recruits (46, 47) and with the lower seropositivity previously found in western cities (48). Previous studies have found a lower incidence of *T. gondii* in hot, dry climates and at high altitudes (12, 13). Although local rainfall varies, the western region of the United States is generally drier than the East, and it has many areas with higher altitudes (49). Therefore, the climatic and topographic characteristics of the West may explain the lower *T. gondii* seroprevalence found there. We do not know why the Northeast had the highest seroprevalence in our population; it may be a consequence of food preparation and eating practices. Regardless of the overall seroprevalence for a region, there is likely to be wide varia-

tion within regions. However, the NHANES III sample was not designed to obtain estimates for geographic areas smaller than the four major regions of the United States.

Lower levels of education were associated with an increased risk for toxoplasmosis in the overall and race/ethnicity-specific logistic regression models. Lower levels of education are associated with lower socioeconomic status and may be related to employment in jobs with greater soil exposure. In our analysis, soil-related occupations were also independently associated with *T. gondii* seropositivity among non-Hispanic Whites and Mexican Americans (table 3). There is some preliminary evidence from a population-based survey done in seven states indicating that persons with less education are not more likely to eat undercooked hamburger, steak, roast, or pork (50). However, this same survey found that persons with less education may be less likely to wash cutting boards with soap or bleach after cutting raw meat.

In the overall multivariate analysis, the risk for *T. gondii* seropositivity was lower among Mexican Americans (table 2). In the race/ethnicity-specific analysis, risk for *T. gondii*

seropositivity among Mexican Americans was not increased in the age groups 30–39, 40–49, and 50–59 years as it was among non-Hispanic Whites and non-Hispanic Blacks (table 3). We do not know why risk was not increased in these age groups for Mexican Americans.

It is also notable that among Mexican Americans (and no other group), current cat ownership was associated with reduced risk for *T. gondii* seropositivity. Although in most previous studies cat ownership has been associated with either increased risk for toxoplasmosis/*T. gondii* seropositivity or no change in risk, one previous study found that possession of cats decreased the risk for seropositivity (51). In our overall multivariate results, current cat ownership did not significantly change the risk for *T. gondii* seropositivity. There are several possible reasons for this finding. The NHANES III interview only inquired about current ownership of cats. Persons who did not own cats at the time of the interview may have owned them in the past. In addition, risk of *T. gondii* infection in humans derives from exposure to the feces of a cat that is shedding oocysts. Cats generally shed oocysts for only a few weeks during their lives. Cats that are kept indoors, do not hunt, and are not fed raw meat are not likely to acquire *T. gondii* infection and therefore pose little risk to humans. In addition, neighborhood or feral cats that defecate in gardens or sandboxes may pose the greatest risk of *T. gondii* infection for some people, regardless of whether they own a cat.

Higher seroprevalence of *T. gondii* infection was found among foreign-born persons in all three major racial/ethnic groups in multivariate analysis. Reasons for high *T. gondii* seroprevalence vary in different countries and are related to the amount of *T. gondii* in meat, food-preparation and eating habits, and exposure to soil and cat feces. We did not have a sufficient number of cases to examine risk associated with birth in individual countries or regions outside of the United States. It is notable that in London, Gilbert et al. (52) found a higher incidence of acute symptomatic *Toxoplasma* chorioretinitis among Blacks born in West Africa than among people born in Britain.

Meat consumption in the past 30 days was also not a significant predictor for *T. gondii* seropositivity in our analysis. However, very few persons in our study population ate no meat ($n = 89$), so our power to examine meat consumption was limited. Because NHANES III was not designed as a study of *T. gondii* seroprevalence, there were no questions asked in the survey about how thoroughly meat was cooked. In addition, the NHANES III questionnaire only inquired about meat consumption within the 30 days prior to the interview, not about meat consumption prior to that time.

Residence in a metropolitan area with less than 1 million persons was significantly associated with *T. gondii* seropositivity only among non-Hispanic Blacks (table 3). We attempted to examine seropositivity further in persons from areas with populations under 250,000, but the limited number of strata and primary sampling units in the NHANES III sample limited our power to detect differences associated with smaller metropolitan areas or with rural residence. One previous study showed higher *T. gondii* seropositivity among persons who grew up in rural areas in the United

States (47), but another study failed to show a difference between rural and urban seroprevalence (46). NHANES III only collected information about current residence, not about past living locations.

There are a number of limitations involved in using data from the NHANES III survey to evaluate *T. gondii* seroprevalence. NHANES III was designed to collect information on a wide variety of risk factors for chronic diseases; it was not designed to evaluate *T. gondii* risk factors and seroprevalence. Surplus serum samples were examined for *T. gondii* antibodies. As we noted above, only a limited number of surplus samples were available for children under age 12, so it cannot be assumed that these samples are representative of the US population. NHANES III data were also limited in terms of the information provided about soil exposure and pet exposure. It would be helpful for *T. gondii*-related studies if future NHANES surveys contained additional questions about cat- and soil-related risk factors.

Despite these drawbacks, NHANES III has provided us with a way to assess the prevalence of *T. gondii* infection and has enhanced our understanding of the seroepidemiology of this organism in the United States. We plan to continue monitoring *T. gondii* seropositivity in future NHANES surveys.

REFERENCES

1. Jones JL, Hanson DL, Dworkin MS, et al. Surveillance for AIDS-defining opportunistic illnesses, 1992–1997. Mor Mortal Wkly Rep CDC Surveill Summ 1999;48(no. SS-2):1–22.
2. Centers for Disease Control and Prevention. CDC recommendations regarding selected conditions affecting women's health. MMWR Morb Mortal Wkly Rep 2000;49(no. RR-2): 57–75.
3. Buzby JC, Roberts T. ERS updates US foodborne disease costs for seven pathogens. Food Rev 1996;19:20–5.
4. Mead PS, Slutsker L, Dietz V, et al. Food-related illness and death in the United States. Emerg Infect Dis 1999;5:607–24.
5. Baril L, Ancelle T, Goulet V, et al. Risk factors for *Toxoplasma* infection in pregnancy: a case-control study in France. Scand J Infect Dis 1999;31:305–9.
6. Weigel RM, Dubey JP, Dyer D, et al. Risk factors for infection with *Toxoplasma gondii* for residents and workers on swine farms in Illinois. Am J Trop Med Hyg 1999;60:793–8.
7. Kapperud G, Jenum PA, Stray-Pedersen B, et al. Risk factors for *Toxoplasma gondii* infection in pregnancy: results of a prospective case-control study in Norway. Am J Epidemiol 1996;144:405–12.
8. Cook AJ, Gilbert RE, Buffolano W. Sources of *Toxoplasma* infection in pregnant women: European multicentre case-control study. European Research Network on Congenital

Toxoplasmosis. BMJ 2000;321:142–7.
9. Stray-Pedersen B, Lorentzen-Styr AM. Epidemiological aspects of *Toxoplasma* infections among women in Norway. Acta Obstet Gynecol Scand 1980;59:323–6.
10. Wallace MR, Rossetti RJ, Olson PE. Cats and toxoplasmosis risk in HIV-infected adults. JAMA 1993;269:76–7.
11. Roghmann MC, Faulkner CT, Lefkowitz A, et al. Decreased seroprevalence for *Toxoplasma gondii* in Seventh Day Adventists in Maryland. Am J Trop Med Hyg 1999;60:790–2.
12. Dubey JP, Beattie CP. Toxoplasmosis in man (*Homo sapiens*). In: Toxoplasmosis of animals and man. Boca Raton, FL: CRC Press, Inc, 1988:41–60.
13. Walton BC, Arjona I, Benchoff BM. Relationship of *Toxoplasma* antibodies to altitude. Am J Trop Med Hyg 1966; 15:492–5.
14. Dubey JP. Effect of freezing on the infectivity of *Toxoplasma* cysts to cats. J Am Vet Med Assoc 1974;165:534–6.
15. Kean BH, Kimball AC, Christenson WN. An epidemic of acute toxoplasmosis. JAMA 1969;208:1002–4.
16. Toxoplasmosis—Pennsylvania. MMWR Morb Mortal Wkly Rep 1975;24:285–6.
17. Masur H, Jones TC, Lempert JA, et al. Outbreak of toxoplasmosis in a family and documentation of acquired retinochoroiditis. Am J Med 1978;64:396–402.
18. Fertig A, Selwyn S, Tibble MJ. Tetracycline treatment in a food-borne outbreak of toxoplasmosis. Br Med J 1977;2:192.
19. Choi WY, Nam HW, Kwak NH, et al. Foodborne outbreaks of human toxoplasmosis. J Infect Dis 1997;175:1280–2.
20. Sacks JJ, Delgato DG, Lobel HO, et al. Toxoplasmosis infection associated with eating undercooked venison. Am J Epidemiol 1983;118:832–8.
21. Sacks JJ, Roberto RR, Brooks NF. Toxoplasmosis infection associated with raw goat's milk. JAMA 1982;248:1728–32.
22. Benenson MW, Takafuji ET, Lemon SM, et al. Oocyst-transmitted toxoplasmosis associated with ingestion of contaminated water. N Engl J Med 1982;307:666–9.
23. Bowie WR, King AS, Werker DH, et al. Outbreak of toxoplasmosis associated with municipal drinking water. Lancet 1997; 350:173–7.
24. Stago S, Dykes AC, Amos CS, et al. An outbreak of toxoplasmosis linked to cats. Pediatrics 1980;65:706–12.
25. Teutsch SM, Juranek DD, Sulzer A, et al. Epidemic toxoplasmosis associated with infected cats. N Engl J Med 1979;300: 695–9.
26. Jeannel D, Niel G, Costagliola D, et al. Epidemiology of toxoplasmosis among pregnant women in the Paris area. Int J Epidemiol 1988;17:595–602.
27. Ancelle T, Goulet V, Tirard-Fleury V, et al. La toxoplasmose chez la femme enceinte en France en 1995: resultats d'une enquite nationale perinatale. (In French). Bull Epidemiol Hebdomadaire 1996;51:227–8.
28. Schwartzman JD, Maguire JH. Systemic coccidia (toxoplasmosis). In: Guerrant RC, Walker DH, Weller PF, eds. Tropical infectious diseases: principles, pathogens, and practice. Philadelphia, PA: Churchill Livingstone, 1999:829–39.
29. Frenkel JK, Hassanein KM, Hassanein RS, et al. Transmission of *Toxoplasma gondii* in Panama City, Panama: a five-year prospective cohort study of children, cats, rodents, birds, and soil. Am J Trop Med Hyg 1995;53:458–68.
30. Sousa OE, Sanez RE, Frenkel JK. Toxoplasmosis in Panama: a 10-year study. Am J Trop Med Hyg 1988;38:315–22.
31. Gomez-Martin JE, Montoya-de-Londono MT, Castano-Osorio JC. A maternal screening program for congenital toxoplasmosis in Quindio, Colombia and application of mathematical models to estimate incidences using age-stratified data. Am J Trop Med Hyg 1997;57:180–6.
32. Doehring E, Reiter-Owana I, Bauer O, et al. *Toxoplasma*

gondii antibodies in pregnant women and their newborns in Dar es Salaam, Tanzania. Am J Trop Med Hyg 1995;52:546–8.
33. Bowry TR, Camargo ME, Kinyanjui M. Sero-epidemiology of *Toxoplasma gondii* infection in young children in Nairobi, Kenya. Trans R Soc Trop Med Hyg 1986;80:439–41.
34. Onadeko MO, Joynson DH, Payne RA. The prevalence of *Toxoplasma* infection among pregnant women in Ibadan, Nigeria. J Trop Med Hyg 1992;95:143–5.
35. Papoz L, Simondon F, Saurin W, et al. A simple model relevant to toxoplasmosis applied to epidemiologic results in France. Am J Epidemiol 1986;123:154–61.
36. Stray-Pedersen B, Jenum P. Current status of toxoplasmosis in pregnancy in Norway. Scand J Infect Dis Suppl 1992;84:80–3.
37. Koskiniemi M, Lappalainen M, Koskela P, et al. The programme for antenatal screening of toxoplasmosis in Finland: a prospective cohort study. Scand J Infect Dis Suppl 1992;84:70–4.
38. Ljungstrom I, Gille E, Nokes J, et al. Seroepidemiology of *Toxoplasma gondii* among pregnant women in different parts of Sweden. Eur J Epidemiol 1995;11:149–56.
39. Joynson DH. Epidemiology of toxoplasmosis in the U.K. Scand J Infect Dis Suppl 1992;84:65–9.
40. National Center for Health Statistics. Sample design: Third National Health and Nutrition Examination Survey, 1988–94. (Vital and health statistics, series 2, no. 113). Washington, DC: US GPO, 1992. (DHHS publication no. (PHS) 92-1387).
41. Ezzati T, Khare M. Nonresponse adjustment in a national health survey. In: 1992 proceedings of the Section on Survey Research Methods. Alexandria, VA: American Statistical Association, 1993:339–44.
42. Mohadjer LM, Waksberg J. National Health and Nutrition Examination Survey III: weighting and estimation methodology. Hyattsville, MD: National Center for Health Statistics, 1996.
43. Shah BV, Barnwell BG, Hurt PN, et al. SUDAAN user's manual, release 5.50. Research Triangle Park, NC: Research Triangle Institute, 1996.
44. Dubey JP. Toxoplasmosis. J Am Vet Med Assoc 1994;205: 1593–8.
45. 1999 USPHS/IDSA guidelines for the prevention of opportunistic infections in persons infected with human immunodeficiency virus. US Public Health Service (USPHS) and Infectious Diseases Society of America (IDSA). MMWR Morb Mortal Wkly Rep 1999;48(no. RR-10):7–9.
46. Feldman HA. A nationwide serum survey of United States military recruits, 1962. VI. *Toxoplasma* antibodies. Am J Epidemiol 1965;81:385–91.
47. Smith KL, Wilson M, Hightower AW, et al. Prevalence of *Toxoplasma gondii* antibodies in US military recruits in 1989: comparison with data published in 1965. Clin Infect Dis 1996; 23:1182–3.
48. Feldman HA, Miller LT. Serological study of toxoplasmosis prevalence. Am J Hyg 1956;64:320–35.
49. Daly C. Annual average precipitation, United States of America. 1961–1990 normals from NOAA cooperative stations and NRCS SNOTEL sites. Portland, OR: Western Regional Climate Center, Natural Resources Conservation Service, US Department of Agriculture, May 22, 2000. (http://www.wrcc.dri.edu/pcpn/us_precip.gif).
50. Centers for Disease Control and Prevention. Foodborne Diseases Active Surveillance Network (FoodNet): Population Survey Atlas of Exposures: 1998–1999. Atlanta, GA: Centers for Disease Control and Prevention, 1999:1–331.
51. Ganley JP, Comstock GW. Association of cats and toxoplasmosis. Am J Epidemiol 1980;111:238–46.
52. Gilbert RE, Stanford MR, Jackson H, et al. Incidence of acute symptomatic *Toxoplasma* retinochoroiditis in south London according to country of birth. BMJ 1995;310:1037–40.