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PREVALENCE OF ANTIBODY TO *TOXOPLASMA GONDII* AND *TRICHINELLA* SPP. IN FERAL PIGS (*SUS SCROFA*) OF EASTERN NORTH CAROLINA

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ABSTRACT: Feral pigs (*Sus scrofa*) survive in many climates, reproduce year-round, and are dietary generalists. In the United States, the size and range of the feral pig population has expanded, resulting in greater interaction with humans and domestic swine and increased potential for disease transmission. We conducted a serosurvey in feral pigs from eastern North Carolina to determine exposure to the zoonotic parasites, *Toxoplasma gondii* and *Trichinella* spp. Between September 2007 and March 2009, blood serum was collected from 83 feral pigs harvested at Howell Woods Environmental Learning Center, Four Oaks, North Carolina, USA. We used a modified agglutination test to test for *T. gondii* antibodies and an enzyme-linked immunosorbent assay to test for *Trichinella* spp. antibodies. The prevalences of antibodies to *T. gondii* and *Trichinella* spp. were 27.7% and 13.3%, respectively and 4% ($n=3$) had antibodies to both agents. We detected an increased risk of *T. gondii* antibodies with age, whereas the risk of exposure to *T. gondii* across years and between sexes was similar. In eastern North Carolina, feral pigs have been exposed to *T. gondii* and *Trichinella* spp. and may pose a health risk to domestic swine and humans.

Key words: Feral pigs, North Carolina, *Sus scrofa*, *Toxoplasma gondii*, *Trichinella* spp.

INTRODUCTION

Since their original introduction to the United States from Europe, in the mid-16th century, pigs (*Sus scrofa*) have been raised as domestic livestock and pursued as a game animal (Towne and Wentworth, 1950). However, because of their ability to adapt in many climates, reproduce year-round, and survive on a varied diet (Wilcox and Van Vuren, 2009), feral pigs have expanded their range and increased in numbers. Today, the feral pig population in the United States is estimated to be ~4 million animals across 39 states, with large populations in California, Texas, and the Southeast (Clay, 2007). The increasing feral pig population has resulted in more feral pig interactions with domestic swine and humans and increased risk of transmission of zoonotic disease agents, including the parasites *Toxoplasma gondii* (Dubey and Beattie, 1988) and *Trichinella spiralis* (Campbell, 1983).

Toxoplasma gondii is a protozoan parasite that infects domestic animals, wildlife, and humans through the uptake of an infective stage of the *T. gondii* life cycle (Dubey and Beattie, 1988). *Toxoplasma gondii* oocysts, the infective stage, are shed into the environment by the definitive host, members of the family Felidae. Oocysts can persist in the environment from 46 to 410 days (Yilmaz and Hopkins, 1972) and survive in water up to 54 mo (Benenson et al., 1982; Bowie et al., 1997; Dubey, 2004). If oocysts are ingested by a nonfelid host, including humans, the parasite will invade and encyst in muscle tissue and organs causing flu-like symptoms in humans with the possibility of more serious complications in the immunocompromised (Dubey and Beattie, 1988). Further, transmission of *T. gondii*

may occur by consumption of parasite stages encysted in muscle tissue, including improperly cooked meat (Dubey and Beattie, 1988). In feral pigs, it is unclear if infections primarily occur by ingestion of oocysts from the environment or from ingesting muscle cysts in prey or carrion.

There have been seven described species of nematodes within the genus *Trichinella* (*Trichinella britovi, Trichinella murrelli, Trichinella nativa, Trichinella nelson, Trichinella papuae, Trichinella pseudospiralis,* and *Trichinella spiralis*; Pozio et al., 1992, 1999; Nagano et al., 1999; La Rosa and Pozio, 2000; Pozio and La Rosa, 2000), two of which have been predicted to occur in eastern North Carolina, *T. spiralis* and *T. murrelli* (Pozio, 2000; Masuoka et al., 2009). *Trichinella spiralis* is a widely distributed nematode parasite that has a direct life cycle and can be transmitted interspecifically to mammals and humans (Campbell, 1983). Infection of *T. spiralis* in humans is commonly associated with ingestions of raw or undercooked game meat (Gamble et al., 1999) and may become clinical, potentially leading to human fatalities. Similarly, domestic pigs may become infected by ingesting *T. spiralis*–laden tissue of other omnivorous or carnivorous species (Zimmermann et al., 1962), by ingesting feces containing gravid intestinal worms (Hill, 1968), or by cannibalism (Leighty, 1983). *Trichinella murrelli* has been widely detected in wildlife within the United States, but the complete distribution is yet to be defined (Pozio and La Rosa, 2000).

Little research has focused on evaluating feral pigs as potential reservoirs of *T. gondii* (Diderrich et al., 1996; Gresham et al., 2002; Blumenshine et al., 2009). However, the role of feral pigs as reservoirs of *T. spiralis* has been investigated as many countries attempt to demonstrate pathogen-free status for international pig production (Gamble et al., 2005; Antolova et al., 2006; Nockler et al., 2006). The objective of this study was to investigate prevalence of antibody to *Trichinella* spp. and *T. gondii* in feral pigs in eastern North Carolina, where domestic swine farms are concentrated.

MATERIALS AND METHODS

Study site and data collection

Research was conducted between September 2007 and March 2009 at Howell Woods Environmental Learning Center in eastern North Carolina (35°22′16″N, 78°18′23″W). Howell Woods encompassed 11 km^2 with elevations ranging from 32 m to 50 m. The climate is temperate with an average rainfall of 120.4 cm and average maximum temperatures in July and January of 32.0 C and 11.0 C, respectively (118 yr of data; Southeast Regional Climate Center, 2010). Howell Woods is primarily comprised of bottomland hardwood forest including red maple (*Acer rubrum*), willow oak (*Quercus phellos*), loblolly pine (*Pinus taeda*), and sweetgum (*Liquidambar styraciflua*). The understory consists of giant river cane (*Arundinaria gigantea*) and possumhaw (*Ilex decidua*). Howell Woods is located within 5 km^2 of ~13,320 domestic pigs.

Feral pigs were hunted at Howell Woods from September 2007 to March 2009. A total of 30 hunts were conducted consisting of ≤20 hunters for ≤4 consecutive days. All hunting was conducted from tree stands overlooking automated feeders programmed to dispense corn at 4:00 PM. Feral pig hunting did not occur from April to August in any year of the study; therefore, pigs were grouped into two time periods: Year 1 (September 2007–March 2008) or year 2 (September 2008–March 2009).

Feral pigs killed by hunters were transported to a central processing site for field dressing. Once at the processing site, pigs were weighed, sex and age were recorded, and blood was collected by heart puncture, cranial sinus puncture, or directly from the wound site. Age of pigs was estimated based upon dental characteristics (Matschke, 1967), and pigs were divided into three age-classes: juvenile (≤5 mo), subadult (5–8 mo), and adult (>8 mo). Blood was centrifuged (Vulcon Technologies Mobilespin Model 128 centrifuge, Grandview, Missouri, USA) at 1100 × G for 10–15 min and stored at −80 C until tested. Serum samples were tested for antibodies to *T. gondii* and *Trichinella* spp. by the Clinical Parasitology Diagnostic Service at the University of Tennessee, College of Veterinary Medicine.

Serology

Serum was screened for *Toxoplasma gondii* IgG using the modified agglutination test, (MAT; Toxo-Screen DA, Biomerieux SA, Marcy-l'Etoile, France), as previously described (Desmonts and Remington, 1980; Dubey et al., 1995). Dubey et al. (1995) concluded the sensitivity and specificity of the MAT for *T. gondii* antibodies in pigs were 82.9% and 90.2% respectively. Also, the MAT detected antibody at titers of at least 1:80 in all pigs recently infected as confirmed by bioassay (the gold standard) with low numbers of *T. gondii* (Dubey et al., 1995). Serum was screened for *T. gondii* IgG antibodies at 1:16, 1:32, and 1:512 dilutions, and any serum with an IgG titer ≥1:32 was considered positive for *T. gondii*.

Serum antibodies (IgG) to *Trichinella* species were determined using a validated commercial kit (Safepath Laboratory, Carlsbad, California, USA; now marketed by Bio-Rad) which is a US Department of Agriculture–licensed enzyme-linked immunosorbent assay (ELISA; Gamble, 1993; Davies et al., 1998) and the recommended test for swine (OIE, 2000; Gamble et al., 2004). Test serum was added to wells that came coated with excretory-secretory (ES) antigen derived from *Trichinella* in the muscle of infected pigs. Sera were tested at a 1:200 dilution as recommended by the manufacturer and positive and negative control sera were incubated on each plate. The ELISA values were considered positive if the optical density exceeded 0.300 after subtraction of the negative control well. The test was 98.4% sensitive and 100% specific.

Statistical analyses

Antibody prevalence of *T. gondii* was analyzed by age, sex, and year using a likelihood ratio test. A Fisher's exact test (two-tailed) was used to compare years for *Trichinella* spp. All statistical analyses were conducted using SAS's JMP version 7.0.2 (SAS Institute, Inc., Cary, North Carolina, USA) and alpha was set at 0.05.

RESULTS

Forty-three feral pigs were tested during year 1 (2007–2008) and 40 during year 2 (2008–2009) for *Trichinella* spp. and *T. gondii* antibodies. In year 1, 13 of 43 (30%) feral pigs had detectable antibodies to *T. gondii* and eight of 43 (19%) feral pigs had antibodies to *Trichinella* spp. In year 2, 10 of 40 (25%) feral pigs had antibodies to *T. gondii* and three of 40 (8%) feral pigs had antibodies to *Trichinella* spp. When combined across years, the antibody prevalence was 28% for *T. gondii* and 13% for *Trichinella* spp. In year 1, three feral pigs (7%) had antibodies to both parasites.

We detected an increased risk of *T. gondii* antibodies with age ($\chi^2[2]=6.89$, $P=0.032$); older feral pigs were more likely to be infected than younger. No effect of year ($\chi^2[1]=1.79$, $P=0.181$) or sex ($\chi^2[1]=0.001$, $P=0.939$) was detected on the presence of *T. gondii* or *Trichinella* spp. antibodies. Further, the probabilities of feral pigs being infected in years 1 and 2 were similar ($P=0.198$).

DISCUSSION

The antibody prevalence (28%) to *T. gondii* in feral pigs at Howell Woods was similar to other studies (0.5–38%; Dubey et al. 1991, 1997; Diderrich et al., 1996; Davies et al., 1998; Gauss et al., 2005). The prevalence of *T. gondii* in domestic swine in the USA is reportedly zero, which has been reduced from previous levels by the implementation of modern biosecurity on commercial production farms (Lubroth et al., 1983; Dubey and Weigel, 1996). Nevertheless, there has not been a corresponding decrease in human exposure to *T. gondii* based upon antibody prevalence, which remains around 15.8% of the adult population (Jones et al., 2003). Hence, it is believed that human exposure is being maintained from an underestimated or increasing oocyst presence in the environment and not from domestic pork consumption (Conrad et al., 2005).

Feral cats have been trapped and removed from Howell Woods but none have been tested for *T. gondii* antibodies. Nutter et al. (2004) detected antibodies in 63% of feral cats in a central North Carolina county. Surveys of domestic cats in the USA have shown *T. gondii* antibody prevalences from 8% to 74% (Conrad et

al., 2005). Further, up to 2% of feral cats may be shedding oocysts at any time (Dubey, 1973; Christie et al., 1976; Guterbock and Levine, 1977) and an infected cat can shed more than 100 million oocysts in its feces (Dubey et al., 1970; Dubey and Frenkel, 1972; Tenter et al., 2000). Although only felids shed oocysts, several native wildlife species are known to have antibodies to *T. gondii* and may serve as potential intermediate hosts, including raccoons (*Procyon lotor*; Smith et al., 1992), white-tailed deer (*Odocoileus virginianus*; Humphreys et al., 1995), several species of rodents and insectivores (Kijlstra et al., 2008), striped skunk (*Mephitis mephitis*; Smith et al., 1992), opossum (*Didelphis virginianus*; Smith et al., 1992), and numerous species of birds (Dubey, 2002). Notably, feral pigs may consume all of these species as prey or carrion, thus ingesting infective *T. gondii* cysts.

We detected a 13% prevalence of antibodies to *Trichinella* spp. in feral pigs in eastern North Carolina. As the ELISA is not species-specific, these pigs could have been infected by any of the three species of *Trichinella* predicted to occur within eastern North Carolina (*T. murrelli*, *T. pseudospiralis*, and *T. spiralis*). Although previous research within North Carolina has detected *T. spiralis* infection within domestic swine (Davies et al., 1998), feral pigs have a slightly higher prevalence of antibodies to *T. spiralis* (1.3%) than do domestic pigs (0.4%; Gamble et al., 1999).

Modern market farm production practices have nearly eliminated *T. gondii* and *T. spiralis* infection (Davies et al., 1998); however, the recent trend toward "organic" and free-ranging pig production has increased domestic pig exposure to infection and the possibility of human infection through pork consumption (Kijlstra et al., 2004; Schulzig and Fehlhaber, 2006; van der Giessen et al., 2007; Gebreyes et al., 2008). Further, the importance of feral pigs as sources of infection to humans and domestic swine has increased (Nelson et al., 1961; Schultz, 1970; Bessonov, 1979; Dubey and Jones, 2008). As feral pig range and population size expands, either naturally or with human assistance, the opportunity for feral pig hunting increases. We recommend education programs be conducted for hunters to understand the risk of exposure to zoonotic diseases during the cleaning process and meat consumption.

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