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A Modern Understanding of a Historical Parasite: Food-Borne Risks of *Trichinella* from California Bear and Feral Pig Populations

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ABSTRACT: Trichinellosis is a zoonotic disease caused by one of the most widely distributed parasite groups in the world, *Trichinella*. Infection and illness in humans occurs following the consumption of undercooked meat containing larvae. Many cases of trichinellosis go unreported, but symptomatic disease can present with nausea, diarrhea, vomiting, fatigue, and in severe cases, death. Since the eradication of *Trichinella* from the commercial swine industry, wildlife meat, specifically black bear and feral pig, has become the main cause of human trichinellosis in the United States. California continues to be home to the majority of these cases. Despite this change in epidemiology, few studies have focused on importance of wildlife as a reservoir of human trichinellosis. The most recently reported prevalence estimate of *Trichinella* in California black bears was over 30 years ago, in 1977. To our knowledge, there have been no published reports on the prevalence of *Trichinella* in California feral pigs. Furthermore, human, black bear, and feral pig population growth, coupled with increased urban development, has created an expanding ecological niche for parasite transmission, thus increasing the risk of *Trichinella* infection for consumers of wildlife meat. Given the lack of contemporary data and knowledge, there is a need to generate estimates of the current burden of *Trichinella* in California wildlife in order to assess the foodborne risk this potentially lethal parasite poses to the public.

KEY WORDS: black bear, feral pig, food safety, parasites, *Sus scrofa*, *Trichinella*, *Ursus americanus*, zoonotic disease

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INTRODUCTION

Domestic animals and wildlife are important sources of food, clothing, companionship, and aesthetic enrichment, but they also carry an abundance of parasites that may cause human disease. Trichinosis, or trichinellosis, is a parasitic disease caused by numerous species of roundworms of the genus *Trichinella* (Fernandez 2003). Members of the genus *Trichinella* are able to infect a broad spectrum of mammalian hosts, making them one of the world's most widely-distributed groups of nematode infections (La Rosa et al. 2006). Currently, there are 7 recognized species within the genus: *Trichinella spiralis*, *T. nativa*, *T. britovi*, *T. nelsoni*, *T. murrelli*, *T. pseudospiralis*, and *T. papuae* (Fernandez 2003). Many of these species have wildlife hosts that serve as natural reservoirs of infection, which creates a highly diverse source of potential transmission to both humans and animals alike (Dupouy-Camet et al. 2007).

Infection and illness in humans occurs following the consumption of undercooked meat containing *Trichinella* larvae (Gottstein et al. 2009). Many cases of human trichinellosis go unreported, but symptomatic disease can present with nausea, diarrhea, vomiting, fatigue, and in severe cases, death (Capo and Despommier 1996). Worldwide approximately 10,000 incidental cases are reported each year, primarily in areas of high levels of poverty and poor sanitary conditions (CDC 2010). Since the 1980s, the United States has experienced a yearly average of 50 cases, down from 400 in the mid-20th century. The decrease in incidence can be attributed to increased regulations and health standards for commercial pig (*Sus scrofa*) production. Furthermore, at this time, the U.S. experienced a change in which the majority of cases were linked to wildlife meat rather than commercial pork products (CDC 2010).

BACKGROUND

Life Cycle of *Trichinella*

Infection is initiated by ingesting raw or under-cooked meats containing a nurse cell-larva complex (Campbell 1983). As a result of mastication and digestive enzymes in the stomach, larvae are released from muscle tissue, and proceed to the small intestine where larvae rapidly molt into adults and reproduce (Despommier and Turgeon 1975, Stewart et al. 1987). Live offspring are produced within 5 days (Despommier 1983). Final expulsion of worms from the host can take up to several weeks, during which multiple generations of larval worms are produced (Lawrence et al. 2000).

The newborn larvae enter the lymph or bloodstream and migrate throughout the body. Using a sword-like stylet, they create an entry hole in potential host cells (Despommier 1983). Not only do the parasites remain inside skeletal muscle cells after invasion, but they also initiate a series of changes, causing the host muscle cell to transform into one that supports the growth and development of the larva (Despommier 1998). This is known as the 'nurse cell-parasite complex' and can live for as long as the host remains alive (Stewart et al. 1987). In order for the life cycle to continue, an infected host must die and be eaten by another mammal. Scavenging is a common behavior among most wild mammals, and this helps to ensure the maintenance of *Trichinella* and its relatives in their respective host species (Kennedy et al. 2009).

Transmission Cycles

Trichinosis was first discovered as an infection of humans and domestic animals in 1835 (Pozio 2000). For more than 100 years following this discovery, the parasite was considered to be transmitted only through pork con-

sumption. Therefore, most studies focused on *Trichinella* infection in domestic pigs and synanthropic rats (*Rattus* spp.) (Campbell 1988). In the last century, new and different transmission patterns have been documented with increased importance. The epidemiology of *Trichinella* can be broken down into two distinct cycles: domestic, and sylvatic. The domestic cycle refers to the cycle of transmission involving human settlements, most specifically in association with pigs and rats through the pork industry. The sylvatic cycle consists of the transmission of *Trichinella* among wildlife, either by ingestion of infected flesh of an animal that has been devoured as prey, or by ingestion of flesh from a carcass. It was generally recognized that the sylvatic cycle, or wildlife cycle, operated independently from the domestic cycle; however, recent studies have demonstrated the flow between them (Campbell 1983, Dame et al. 1987).

In the wild, the vast majority of all carcasses are consumed by scavengers, and this infection is widespread within a given biome. In the U.S., Murrell et al. (1987) showed that rats (*Rattus norvegicus*), skunks (*Mephitis mephitis nigra*), opossums (*Didelphis virginiana*), and raccoons (*Procyon lotor*) harbored the same parasitic species of *Trichinella* found in their habitat, and that their synanthropic behavior is responsible for the transmission between the domestic and sylvatic cycles. *Trichinella* larvae have been found to be infective for up to 4 months in extremely decayed meat (Madsen 1974). Thus, the life cycle of *Trichinella* can include a free-living stage when species-dispersing populations of larvae are present in rotten carcasses of synanthropic species. Consequently, mammals that demonstrate scavenging and cannibalistic behaviors have a higher risk of obtaining *Trichinella* spp. from their environment (Pozio 2000). Animals that are most commonly infected include those at the top of the food chain with carnivorous and/or omnivorous behavior, such as bear (*Ursus* spp.), wolf (*Canis lupus*), fox (*Vulpes vulpes* and *Urocyon cinereoargenteus*), raccoon, and wild boar (Kim 1983).

TRICHINELLA TODAY

***Trichinella* in the United States**

Kennedy et al. (2009) published a detailed report on trichinellosis surveillance in the U.S., and a summary of their findings is provided below. Over the last 70 years, reports of trichinellosis cases in the U.S. have drastically decreased. During the late 1940s when the U.S. Public Health Service began counting and recording cases of trichinellosis, 400 cases in the U.S. were reported each year, on average. During 2002-2007, 11 cases were reported to the Centers for Disease Control and Prevention (CDC) each year, on average (Kennedy et al. 2009). The overall number of cases reported has decreased because of improved pig-raising practices in the pork industry, commercial and home freezing of pork, and public awareness of the danger of eating raw or undercooked meat products (Moorehead et al. 1999). In contrast, the number of cases associated with raw or undercooked wild game meats has increased over time. Despite the overall decrease in incidence, *Trichinella* still remains a public safety issue, especially for people consuming wild game, particularly bear (Kennedy et al. 2009). Furthermore, indicator animals such as bears provide an estimation of the prevalence of

Trichinella in the environment (Nöckler et al. 2000).

Prior to 1968, only two reported outbreaks of human trichinosis were attributable to bear meat. Since that time, trichinosis acquired from bears has become increasingly important. From 1968 to 1974, 9 outbreaks of human trichinosis were related to ingestion of bear meat (Zimmermann 1977). By the late 1990s, meats other than pork were the most common source of infection (Roy et al. 2003). From 2002 to 2007, a total of 54 cases and 16 outbreaks of trichinosis were reported in the U.S.; 49% of those cases were related to the consumption of bear meat. Of those 54 cases, 10 were reported in California including two outbreaks, both associated with the consumption of undercooked bear meat (Kennedy et al. 2009).

***Trichinella* in California**

In California, black bear (*Ursus americanus*) hunting is a popular form of recreation. Each year, the California Department of Fish and Game sells an average of 25,000 bear hunting permits to residents. The hunting season runs from the second Saturday in October to the last Sunday in December, or when the number of kills reaches 1,700 (CDFG 2011). Hunters use their kills for the pelts, but primarily for their meat. Once collected, the bear is usually skinned, quartered, and the meat is frozen (Nutter et al. 1998). Many hunters think that by freezing their meat they are killing any potential infectious parasites. However, in contrast to the *Trichinella* species found in pork (*T. spiralis*), the species primarily found in bear meat (*T. nativa*) is freeze-resistant; therefore, cooking meat thoroughly is the only effective way to prevent infection (Bailey and Schantz 1990). Bear hunters are at increased risk of experiencing trichinosis outbreaks due to 1) the parasites' resistance to freezing, and 2) the nature in which meat is shared at family gatherings or parties (Pozio 2000).

The black bear population in California has grown both in distribution and abundance over the last 25 years. Population estimates generated from statewide harvest data indicate that bear numbers have climbed from approximately 10,000 - 15,000 bears in 1982 to 25,000 - 30,000 bears in 2007. As a result, bears have expanded their range and are now being observed in areas where they were not seen 50 years ago along the Central Coast and Transverse Mountain Ranges of Southern California (CDFG 2008). Given this information, it is important to understand the burden of disease within the bear community, in order to best protect both the health of the animals and the humans who eat them.

From 1970 to 1975, Zimmermann (1977) examined 454 bear samples from 10 states for infection with *Trichinella*. Trichinae were found in 14 of those individuals, for a prevalence of 3.1%. In California, 7 of 54 bears examined (13.2%) tested positive for trichinae. Furthermore, the bears from California reported the highest burdens of disease. Six of the bears had more than one trichina per gram, a level considered capable of inducing trichinosis in man. Two of those samples had over 500 trichinae per gram. Since 1975, the direct prevalence of *Trichinella* has not been examined in California black bears.

Although bears seem to be linked with the greatest number of human cases of trichinellosis in California, feral pigs have also been known to cause human infection.

Feral pigs display similar scavenging behaviors as bears and are experiencing extremely rapid population growth and expansion in California. To our knowledge, there have been no published reports on prevalence in feral pigs in California; however, a recent study found that 13.3% of pigs tested in North Carolina had been exposed to *Trichinella* spp. (Sandfoss et al. 2011).

FUTURE DIRECTIONS

Human behavior is an important factor influencing the transmission patterns of *Trichinella* genotypes in the domestic and wild habitat. The human impact on the natural ecosystem can either favor or impede the sylvatic cycle. When hunters fail to properly dispose of game carcasses or use carcasses of sylvatic carnivores as bait for other carnivores, the prevalence of *Trichinella* infection increases (Casulli et al. 2001). Humans have created new ecological niches, where some species of sylvatic animals (mainly carnivores and rodents) have developed synanthropic behavior, thus amplifying the flow of *Trichinella* among wildlife and from the sylvatic cycle to the domestic habitat (Poizio 2000). The incidence of trichinellosis associated with commercial pork was drastically decreased with the introduction of effective control programs and public awareness. It has become increasingly important to understand the transmission and maintenance of *Trichinella* in nature, although minimal efforts have been made to accomplish this goal. Up-to-date prevalence information in key wildlife species is necessary to reassess traditional trichinellosis surveillance and control approaches and prevent a resurgence of human disease.

As a result of both domestic and wild hosts as reservoir species, eradication and control of *Trichinella* is very difficult. However, by surveying indicator animals such as bears, in addition outreach education, we can monitor and control the public health aspects of *Trichinella* spp. in the environment (Nöckler et al. 2000, Poizio 2000).

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