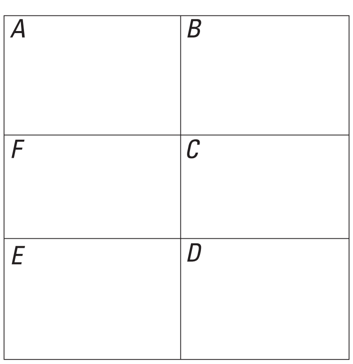
National Wildlife Health Center

Trichinosis

Circular 1388

U.S. Department of the Interior
U.S. Geological Survey



Cover. Background image, "Sharing frozen, aged walrus meat" by Ansgar Walk. *A*, male walrus by Bill Hickey, U.S. Fish and Wildlife Service. *B*, large blacks by Amanda Slater, Wikimedia Commons CC BY-SA-NC. *C*, coiled larvae in muscle, William Foreyt. *D*, U.S. Fish and Wildlife Service. *E*, courtesy of Joel Reale©. *F*, common, black bear family, Anan Interpretive Staff, U.S. Forest Service.

Trichinosis

By William J. Foreyt

Edited by Rachel C. Abbott and Charles van Riper, III

Prepared by the USGS National Wildlife Health Center

Circular 1388

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2013

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment, visit http://www.usgs.gov or call 1-888-ASK-USGS

For an overview of USGS information products, including maps, imagery, and publications, visit http://www.usgs.gov/pubprod

To order this and other USGS information products, visit http://store.usgs.gov

Suggested citation:
Foreyt, William J., 2013, Trichinosis: Reston, Va., U.S. Geological Survey Circular 1388, 60 p., 2 appendixes, *http://dx.doi.org/10.3133/cir1388*.

Library of Congress Cataloging-in-Publication Data

Foreyt, Bill, author.
Trichinosis / by William J. Foreyt ; edited by Rachel Abbott and Charles van Riper, III.
pages cm. -- (Circular ; 1388)
"Prepared by the USGS National Wildlife Health Center."
Includes bibliographical references.
ISBN 978-1-4113-3638-4
1. Trichinosis. 2. Trichinosis in animals. I. Abbott, Rachel, editor. II. Van Riper, Charles, editor. III. National Wildlife Health Center (U.S.) IV. Title.
RC186.T815F67 2013
616.9'654--dc23 2013024494

ISSN 1067–084X (print)
ISSN 2330–5703 (online)

Foreword

C. van Riper, III, R. C. Abbott, M. Friend, and C. Bunck

> *Let both sides seek to invoke the wonders of science instead of its terrors. Together let us explore the stars, conquer the deserts, eradicate disease, tap the ocean depths, and encourage the arts and commerce.*
> John F. Kennedy

Increasingly, society is recognizing that parasitic zoonoses are an important component of emerging global infectious diseases (Daszak and Cunningham, 2002), not only for wildlife but for human populations. Because over 50 percent of the pathogens involved with human disease have had their origins in wild animal populations (Daszak and others, 2000; World Health Organization, 2004), there is more recognition than ever before of the need to better integrate the disciplines of human and animal health to address the phenomenon of infectious disease emergence and resurgence. Trichinosis (*Trichinella* spp.), one of the better known and more widespread zoonotic diseases, originated in wildlife species and is now well established as a human malady.

Food- and waterborne zoonoses are receiving increasing attention as components of disease emergence and resurgence (Slifko and others, 2000; Tauxe, 2002; Cotrovo and others, 2004). Trichinosis is transmitted to humans via consumption of contaminated food, and the role of wildlife in this transmission process is becoming more clearly known and is outlined in this report. This zoonotic disease causes problems in wildlife species across the globe and is a major cause of concern for human health worldwide. Trichinosis is widely distributed, extending from the Arctic to the Tropics and even to oceanic islands (Dick and Pozio, 2001)

Disease emergence in wildlife since the late 1900s has been of unprecedented scope relative to geographic areas of occurrence, wildlife species affected, and the variety of pathogens involved (Friend, 2006; Daszak and others, 2000). The emergence of many new zoonotic diseases in humans in recent years is a result of our densely populated, highly mobilized, and environmentally disrupted world. As towns and cities expand, and wildlife populations increase in numbers, the wildland-urban interface broadens, and human associations with wildlife become increasingly frequent. With geographic distance and isolation no longer meaningful barriers, the opportunities for once isolated diseases to spread have never been greater. Future generations will continue to be jeopardized by trichinosis infections in addition to many of the other zoonotic diseases that have emerged during the past century. Dealing with emerging diseases requires the ability to recognize pathogens when they first appear and to act appropriately. Since outbreaks often are evident in the nonhuman components of the environment before humans are affected, understanding our environment and associated 'sentinel' wildlife is a prerequisite to protecting human health. Through monitoring trichinosis infection levels in wildlife populations, we will be better able to predict future human infection levels. This publication is the fifth in a series of U.S. Geological Survey Circulars on emerging zoonotic diseases.

> *In examining disease, we gain wisdom about anatomy and physiology and biology. In examining the person with disease, we gain wisdom about life.*
> Oliver Sacks

Cotrovo, J.A., Bartram, J., Carr, R., Cliver, D.O., Cotruvo, J., Craun, G.F., Dufour, A., and Rees, G., 2004, Waterborne zoonoses: Identification, causes and control: Geneva, World Health Organization, 523 p.

Daszak, P., and Cunningham, A.A., 2002, Emerging infectious diseases: A key role for conservation medicine, *in* Aguirre, A.A., Ostfeld, R.S., House, C.A., Tabor, G.M., and Pearl, M.C., eds, Conservation medicine: Ecological health in practice: New York, Oxford University Press, p. 40–61.

Daszak, P., Cunningham, A.A., and Hyatt, A.D., 2000, Emerging infectious diseases of wildlife—Threats to biodiversity and human health: Science, v. 287, p. 443–449.

Dick, T.A., and Pozio, E., 2001, *Trichinella* spp. and trichinellosis, *in* Samuel, W.M., Pybus, M.J., and Kocan, A.A., eds., Parasitic diseases of wild mammals: Ames, Iowa State University Press, p. 380–396.

Friend, M., 2006, Disease emergence and reemergence: The wildlife-human connection: Reston, Va., U.S. Geological Survey, Circular 1285, 388 p.

Slifko, T.R., Smith, H.V., and Rose, J.B., 2000, Emerging parasite zoonoses associated with water and food: International Journal for Parasitology, v. 30, p. 1379–1393.

Tauxe, R., 2002, Emerging foodborne pathogens: International Journal of Food Microbiology, v. 78, p. 31–41.

World Health Organization, 2004, Expert consensus, *in* Contruvo, J.A., Dufour, A., Rees, G., Bartram, J., Carr, R., Cliver, D.O., Craun, G.F., Fayer, R., and Gannon, V.P.J., eds., Waterborne zoonoses: Identification, causes and control: London, IWA Publishing, p 3–16.

Contents

Topic Highlight Boxes

Illustrations

Tables

Conversion Factors and Abbreviations

Multiply	By	To obtain
	Inch/Pound to SI	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
	SI to Inch/Pound	
millimeter (mm)	0.03937	inch (in.)
gram (g)	0.03527	ounce, avoirdupois (oz)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows: °C=(°F-32)/1.8

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows: °F=(1.8×°C)+32

ELISA Enzyme-linked immunosorbent assay

PCR Polymerase chain reaction

μm The micrometer, or micron, is a measurement unit of linear distance equal to one millionth (10^{-6}) of a meter.

kGy The gray (Gy) is a measurement unit of the absorbed dose by matter of ionizing radiation. A kilogray (kGy) is expressed as 10^3 Gy.

Words in **bold** type in the text, the topic highlight boxes, and the tables are defined in the Glossary.

Trichinosis

By William. J. Foreyt[1]

“Trichinellosis: the **zoonosis** that won’t go quietly.” (Murrell and Pozio 2000)

Synonyms

Trichinellosis, trichinelliasis, trichiniasis, Trichina worm infection

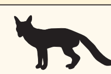
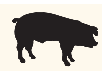
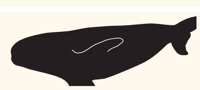
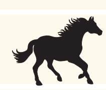
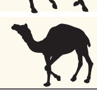
Overview

Trichinosis, or trichinellosis, is one of the most widespread global **parasitic** diseases of humans and animals. This ancient disease is caused by the **larval** stage of parasitic **roundworms** (**nematodes**) in the genus *Trichinella*. Often called the “trichina worm,” this **parasite** is considered to be the king of the parasite community, because it has adapted to an extremely wide range of **hosts** including **domestic** animals, wildlife, and humans (table 1). *Trichinella spiralis* is the usual cause of the disease in humans, but humans and many other **mammals**, **birds**, and **reptiles** also can be infected with other species or **strains** of *Trichinella*. Regardless of climate and environments, a wide variety of hosts on most continents are infected.

Trichinella is transmitted through the ingestion of infected meat, primarily through **predation** or **cannibalism** of raw meat, and this ensures survival of the parasite in a wide variety of hosts. Humans become infected only by eating improperly cooked meat that contains **infective larvae**. While most people have only mild **symptoms** after infection, when high numbers of larvae are ingested trichinosis can cause serious disease, as well as death. Although trichinosis has been historically associated with pork, it is now **emerging** as a more widespread food-borne zoonosis as the consumption of wild game meat increases.

Table 1. Minimum numbers of nonhuman species infected with *Trichinella* spp.

[Adapted from Campbell, 1983b]

Order		Minimum number of species infected
Carnivora		71
Rodentia		36
Primates		11
Insectivora		10
Artiodactyla		9
Lagomorpha		3
Cetacea		2
Marsupialia		2
Edentata		1
Chiroptera		1
Perissodactyla		1
Tylopoda		1

[1]Washington State University, Department of Veterinary Microbiology and Pathology.

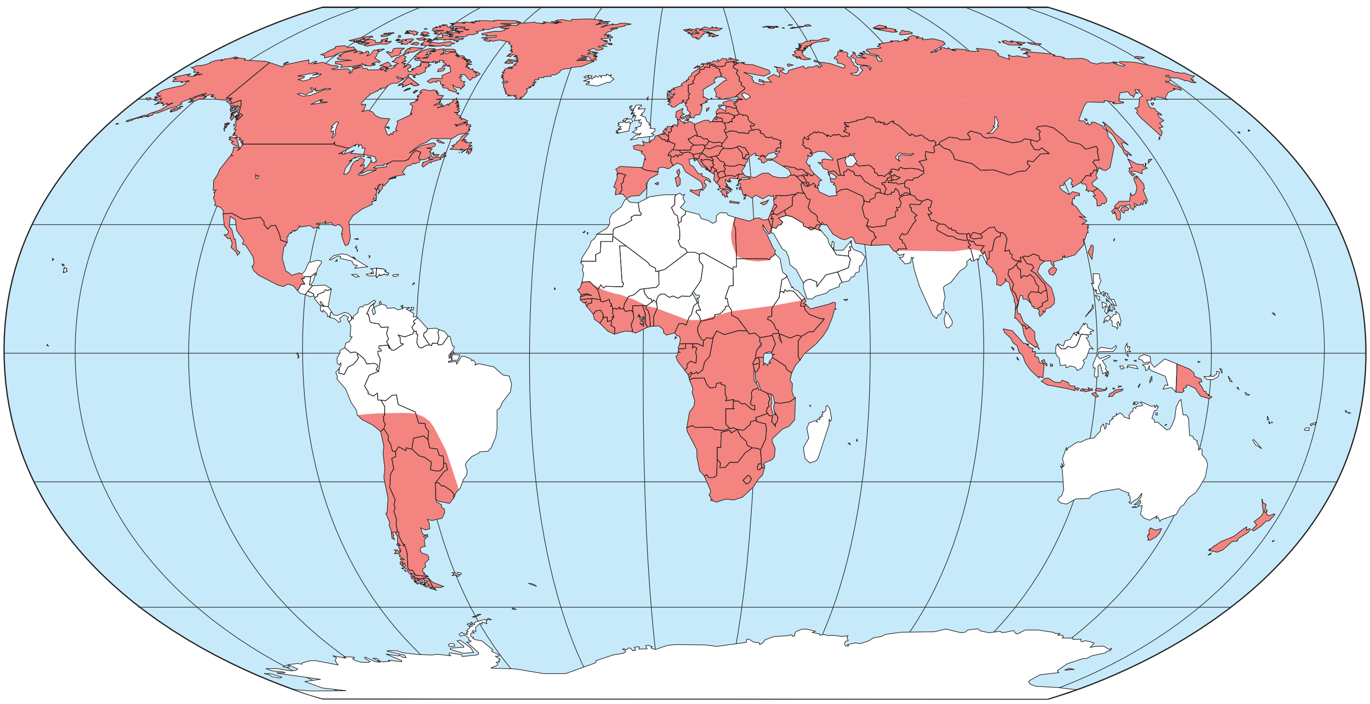


Figure 1. Distribution of *Trichinella* spp. throughout the world. (Modified from International Trichinella Reference Center)

Background

During the course of evolution, *Trichinella* spp. appear to have adjusted their life cycles in accord with the **carnivorous** feeding habits of their hosts, which allows ample opportunity for interspecies transmission. *Trichinella* likely was a parasite of northern regions and had its main center of distribution in the **Arctic** and **Subarctic**, where carnivorous animals are plentiful. *Trichinella* spp. is now found in almost every country of the world (fig. 1), but they are still more commonly associated with northern climates. In the course of development of civilization, pigs and humans became more intimately involved in the life cycle. Although most human infections in the world result from eating pork (Gottstein and others, 2009), infections can also result from eating meat of other domestic animals and wildlife species (table 2). **Domestication** of pigs over 10,000 years ago and adaptation of *Trichinella* spp. to a wide spectrum of wildlife species including mammals, birds, and reptiles apparently created a permanent **reservoir** of infection for humans.

Although trichinosis has been described as an ancient disease, it has only been during the last 150 years that the *Trichinella* parasite was first seen and determined to cause disease. With this knowledge, people could begin to implement control measures to mitigate the **public health** and economic impacts of trichinosis (Box 1). Worldwide, as many as 11 million people may be infected (Dupouy-Camet, 2000; Pozio, 2001). In the United States, the number of reported human cases has decreased dramatically since the 1940s, but repeated **cluster outbreaks** of disease in humans and a constant reservoir of infected wildlife indicate that this is a disease that will remain an important **zoonotic** disease in future years (Murrell, 2000).

In wildlife, predation, cannibalism, and **scavenging** are the main methods of transmission, but **fecal-oral transmission** can occur when **coprophagic** animals eat feces from animals that have recently fed on infected meat or when animals eat meat-eating **arthropods** that have recently fed on infected meat. Detailed reviews on the history and the worldwide status of *Trichinella* spp. are available (Gould, 1970; Campbell, 1983a; Dupouy-Camet, 2000; Dick and Pozio, 2001; Pozio and Zarlanga, 2005; Mitreva and Jasmer, 2006).

Causative Agent

The life cycle of *Trichinella* spp. is unique in that both adults and larvae develop within the same host, but two hosts are usually required to complete the life cycle (Box 2). The usual method of transmission of larvae from animal to animal is through predation, cannibalism, and scavenging, whereas transmission from domestic animals and wildlife to humans is through ingestion of improperly cooked meat containing infective larvae. Adult worms live in the intestine (Box 3). Larvae have a predilection for muscles with high oxygen concentration, such as the **diaphragm**, tongue, and **masseter**, but they can be found in many muscles, especially in heavy infections. Localization of larvae also differs among hosts.

Table 2. Animals naturally infected with *Trichinella* spp. and probability of human infection.

[Data from Ljungström and other, 1998; Murrell and Pozio, 2000; Centers for Disease Control, 2009]

Species	Relative frequency of infection	Source for human infection
Domestic animals		
Pig	Common	Frequent
Horse	Rare	Infrequent
Sheep	Rare	Rare
Goat	Rare	Rare
Cattle	Rare	Rare
Dog	Infrequent	Occasional
Cat	Infrequent	Infrequent
Poultry	Infrequent	Infrequent
Wild animals		
Boar	Common	Frequent
Bear	Common	Common
Felids	Occasional	Occasional
Canids	Occasional	Occasional
Marine mammals	Common	Common
Crocodile	Infrequent	Rare
Fish	Rare	Rare
Rodents	Occasional	Rare
Deer	Rare	Rare

For example, *T. spiralis* larvae concentrate in the tongue, diaphragm, and masseter muscles of horses, but larvae concentrate in the tongue and diaphragm of pigs.

The number of species or **genotypes** of *Trichinella* is a matter of considerable scientific controversy. For over 100 years, *T. spiralis* was thought to be the only species of the genus, but differences in the ability to withstand freezing, **DNA** patterns, geographic distribution, reproductive abilities, survival times, host preference, and presence or absence of a **nurse cell** are characteristics that justify separating the genus into several species or subtypes. Eight species of *Trichinella* (table 3) have been determined by polymerase chain reaction (**PCR**) testing (Murrell and others, 2000; Pozio and others, 2002; Pozio, 2005). An additional three related—but unclassified—genotypes, T6, T8, and T9, are of uncertain **taxonomic** status. Characteristics of the different species are listed in table 4. Of the eight *Trichinella* species, five have **encapsulated** larvae within muscle nurse cells and infect only mammals; *T. pseudospiralis, T. papuae*, and *T*. zimbabwensis have nonencapsulated larvae and can infect birds or reptiles as well as mammals (table 5).

In some cases, the encapsulation or nonencapsulation is a response of the host to the parasite (Worley and others, 1986). Both types of larvae are able to penetrate muscle cells and induce **dedifferentiation** of the cells, but only those species with encapsulated larvae induce the nurse cell to stimulate **collagen** production. The significance of the nurse cell is that encapsulated larvae survive significantly longer than nonencapsulated larvae under adverse environmental conditions, such as in **putrefied** meat. The existence of both encapsulated larvae within a nurse cell and nonencapsulated larvae provides evidence of two evolutionary lines in the genus *Trichinella*, and this may eventually be one criterion for reclassifying nonencapsulated species to another genus (Pozio, Zarlenga, and LaRosa, 2001b).

Table 3. **Taxonomy** of *Trichinella* spp.

Classification	Designation
Kingdom	Animalia
Phylum	Nematoda
Class	Enoplea
Order	Trichurida
Family	Trichinellidae
Genus	*Trichinella*
Species	*spiralis*
	nativa
	britovi
	pseudospiralis
	murrelli
	nelsoni
	papuae
	zimbabwensis

Box 1 From Dinosaurs to the 20th Century—the Path of Discovery

Humans and animals have been infected by *Trichinella* spp. for centuries. Larvae have been recovered from the body of an Egyptian mummified in approximately 1200 B.C. (Gould, 1970; Campbell, 1983a), and it has been suggested that *Trichinella* spp. could have been associated with carnivorous dinosaurs and ancient mammals (Dupouy-Camet, 2000). *Trichinella* larvae were first observed in a human cadaver in 1835 by James Paget, a first-year medical student at the London Hospital Medical School. After observing an **autopsy** on an Italian man who was thought to have died of tuberculosis, Paget became curious about what caused the "sandy diaphragm" in the man. He removed a piece of the diaphragm muscle, examined it with a microscope, and saw small worms coiled up inside each **nodule**. Richard Owen, the assistant conservator of the Museum of the Royal Society of Surgeons in London, also examined the muscle tissue. After seeing the coiled worms, he named them *Trichina spiralis* and presented his findings to the Royal Society (Owen, 1835). The worm was renamed *Trichinella* by Railliet in 1895 to avoid confusion with the genus of flies already known as *Trichina* (Gould, 1970).

In 1846, Joseph Leidy, an American **zoologist**, observed identical larval **cyst**s in pieces of pork he was eating, but his observations were largely ignored at that time. In 1850, Ernst Herbst fed meat scraps to his pet badger and later observed *Trichinella* larvae in the muscles of the badger after it died, suggesting that transmission was by the ingestion of meat. He continued the chain of transmission by then feeding the badger meat to dogs, thereby infecting them. Rudolph Virchow, a German **pathologist**, continued this method of experimentation in 1859 by feeding infected human muscle tissue to a dog. When he autopsied the dog, he observed tiny adult worms, distinct from ***Trichuris*** worms, in the **gastrointestinal tract** of the dog, thus demonstrating transmission of the parasite and contributing to the understanding of its life cycle. In addition, Virchow discovered that the cooking of infected meat inactivates the infectivity of the larvae. Virchow became a vocal advocate of the virtues of eating well-cooked pork products, much to the dismay of German veterinarians and smoke-cured ham enthusiasts. On at least two occasions, he challenged opponents to eat undercooked pork products, yet neither opponent dared to eat the meat, thus validating Virchow's position on the risks of eating undercooked pork (Despommier and Chen, 2004). Additional work by German zoologist Rudolph Leuckart provided scientific support to Virchow's campaign to create meat inspection laws in Germany. The American Joseph Leidy was also an early advocate of the thorough cooking of pork to kill the parasite and prevent infection, writing in 1853, "Cooking food is of advantage in destroying the germs of parasites, hence man, notwithstanding his liability to the latter, is less infested than most other mammalia." (Despommier and Chen, 2004)

In 1860, Friedrich Albert von Zenker, a German pathologist and physician, provided the first evidence of transmission of *Trichinella* to humans from pig meat when he travelled to

Geographic Distribution

Trichinella spp. are present throughout most of the world in over 150 different hosts (fig. 1; Kim, 1983; Dick and Pozio, 2001; Appendix 1). Because the parasite resides in so many different wildlife and **domestic** hosts, it is unlikely that it will ever be eliminated from the human food chain. Most human infections are associated with the ingestion of pork or meat from wildlife, but consumption of meat from horses and other animals can also be uncommon sources of human infection, depending on such factors as cultural practices, diet, changes in farm husbandry, and poverty. In China, for example, outbreaks of human trichinosis attributed to *T. nativa* have been caused by consumption of dog meat (Cui and Wang, 2001). Infection rates in dogs in different provinces in China ranged from 7 to 40 percent, indicating a very high environmental presence of *Trichinella*. In France and Italy, human infection has been linked to consumption of horsemeat (Dupouy-Camet, 2000).

In the United States, *T. spiralis* is the predominant species, but *T. pseudospiralis* and *T. murrelli* have also been identified (fig. 2). In addition, a freeze-resistant **isolate** of *Trichinella* T6 that likely represents a different species or genotype was a farm where several people were suffering from signs of trichinosis to determine the source of infection. He linked the infection to pork by finding numerous larvae in the ham and pork sausage the affected humans had eaten (Campbell, 1983a). He carefully documented a set of clinical signs (fatigue, fever, **edema**, muscle and joint pain) attributed to the infection found in the patients, particularly in one who died. This association of a defined **pathogen** with a defined disease was a milestone in the elucidation of *Trichinella* as a human pathogen and is considered by many to be the most significant **helminthological** contribution of the 19th century.

Von Zenker, Leuckart, and Virchow all contributed to an understanding of the epidemiology of *Trichinella* through their discoveries, which included recovery of the tiny adult parasites in the gut and larvae in the muscles of animals fed infected meat, early maturation of the adults in the gut, migration of larvae in the **lymphatics**, and finding larvae in the **uterus** of mature worms. It was now clear that infection was from ingestion of meat and that adult worms and larvae developed in the same host.

Following the definition of trichinosis as a disease of humans with a known cause, numerous outbreaks in Europe and the United States were reported. In 1863, 158 people in Germany were infected with *Trichinella* by eating infected pork, and 28 of those people died (Foster, 1965). In 1864, trichinosis was reported in the United States, and, in 1871, in England. By the 1870s, inspection of pig meat by **trichinoscopy** became mandatory in many parts of Germany thanks to the work of Virchow, Leuckart, and von Zenker. By the late 1800s, *Trichinella* infection in pigs was recognized as a major problem in the United States, and this caused many European countries to ban the import of American pork products. To protect this market, in 1894 the United States passed the Federal Meat Inspection Program for pork, which required trichinoscopy of export pork.

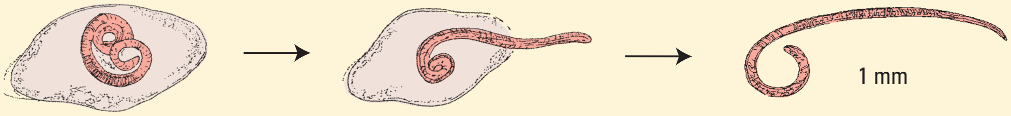
Additional legislation requiring the cooking of garbage to be fed to pigs was passed in the United States in 1953 to combat another disease, **vesicular exanthema**, but the law had a considerable impact on reducing *Trichinella* infections in pigs in the United States. At about the same time, recommendations for replacing garbage dumps with sanitary landfills were published, thus discouraging the practice of allowing pigs to scavenge through garbage dumps (American Public Works Association and U.S. Public Health Service Joint Committee, 1953). Improvements in biosecurity and hygiene on pig farms also contributed to decreasing trichinosis in pigs. These control measures have successfully decreased the **prevalence** of *Trichinella* infection in pigs in the United States from 1.41 percent in 1900 (Ransom, 1915) to 0.013 percent in 1995 (Gamble and Bush, 1999).

isolated from a cougar in Idaho that was eaten by several people as home-cured jerky, resulting in clinical illness (Dworkin and others, 1996). Freeze-resistant isolates, *T. nativa*, are found commonly in black bears, and these isolates are more likely causes of human infections than non-freeze resistant isolates (Worley and others, 1986).

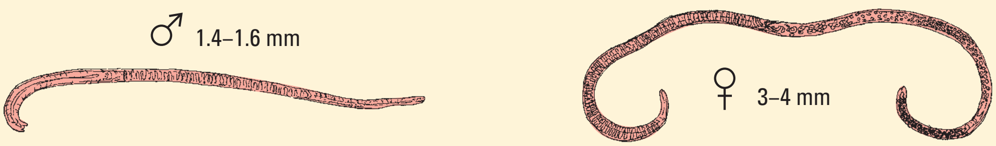
Trichinella species can be found in a wide range of ecological habitats from frigid **circumpolar** climates to hot equatorial climates (fig. 3). In the arctic and subarctic regions, *T. nativa* is commonly associated with carnivores (foxes, wolves, polar bears, seals, walrus, etc.), whereas in southern Africa *T. nelsoni* is in carnivores and wart hogs, and *T. zimbabwensis* is in crocodiles and monitor lizards (Appendix 1). It is a well-accepted concept that the natural distribution of the **sylvatic** species of *Trichinella* in wildlife is strongly influenced by climatic zones. However, *T. spiralis* is a **cosmopolitan** parasite and is found in most areas where pigs are present.

Box 2 Life Cycle of *Trichinella* spp.

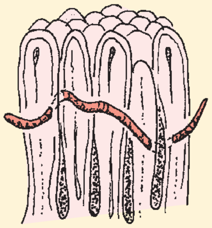
1.
Within hours after an animal ingests meat that contains the larvae of *Trichinella* spp., they are freed from their muscle cysts in the animal's stomach during the digestive process. Larvae then migrate to the small intestine and penetrate the intestinal **mucosa** to reside within **epithelial cells**.



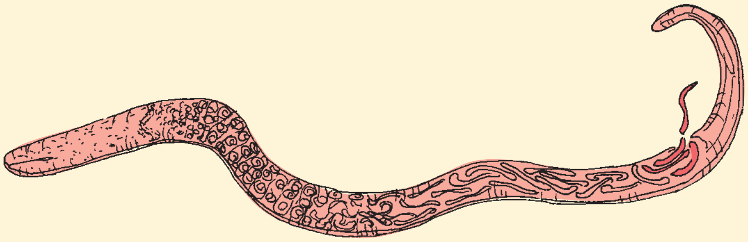
2.
The larva undergoes four **molts** within the next 30 hours to become an immature adult worm, either male or female.



3.
Adult worms thread their way through epithelial cells in the small intestine and mate within the mucosa.
Adult worms can live and reproduce for approximately 10 days to several weeks, depending on the host.

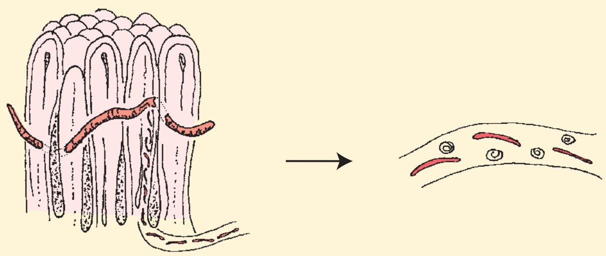


4.
Fertilized eggs develop within female worms, and larvae are deposited within the wall of the intestine 4 to 7 days after initial infection. A female worm may produce between hundreds to thousands of larvae for days to weeks before dying and passing out of the host.



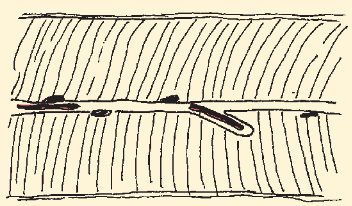
5.

Larvae, 100 µm long and 6 µm diameter, migrate from the intestine, through the **mucosal** lymphatics and regional **lymph nodes** to the **thoracic duct**, and then enter the **venous circulation**. They become distributed throughout the body by the **peripheral circulation**.



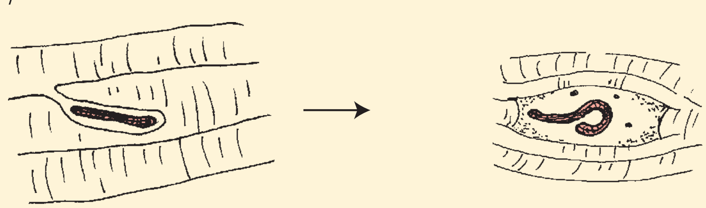
6.

Upon reaching skeletal muscle, most commonly the diaphragm, tongue, and masseter muscles, larvae penetrate the membranes covering the muscle fibers to enter the muscle cells, as early as 5 days after infection. They induce changes in the host cell to enhance their own survival.



7.

Within the muscle cell, the larvae coil up and, in most *Trichinella* species, the host muscle cell is transformed into a nurse cell to surround and encapsulate the larva by collagen and layers of connective tissue. Larval coiling and **encystment** usually take 3 weeks or more.



8.

Encapsulated larvae absorb nutrients from the host muscle **sarcoplasm** and grow to become infective in about 4 to 8 weeks. They remain inactive until they are eaten by another host. In some cases, the host may wall off the larvae, causing theirt death.

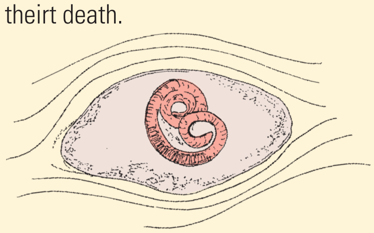


Table 4. Distribution, characteristics, and major hosts of eight currently recognized species of *Trichinella*.[1]

[Modified from Murrell and Pozio, 2000; Capó and Despommier, 1996. D, domestic; S, sylvatic]

Species	Genotype	Distribution	Cycle	Resistance to freezing	Pathogenicity to humans	Major hosts
T. spiralis	T1	Found on most continents as a cosmopolitan parasite	D, S	No	High	Primarily associated with pigs, humans, and **synanthropic** mammals. Wide host spectrum including pigs, rats, dogs, wild carnivores, **omnivores**, **herbivores**, and humans.
T. nativa	T2	Arctic and subarctic regions of Europe and Asia	S	High	High	Wild carnivores, dogs. Rare in pigs.
T. britovi	T3	Primarily in **temperate** areas of South Africa, Namibia, Japan	S	Yes	High	Carnivorous mammals (bears, canids, felids), horses, humans. Rare in domestic pigs and rats.
T. pseudospiralis	T4	Australia, New Zealand, Thailand, **nearctic** and **palearctic** regions	S	No	High	Broad host range, including **marsupials** and birds. Humans.
T. murrelli	T5	Temperate areas of North America, including the United States	S	Moderate	Moderate	Wild carnivores (fox, **mustelids**, felids, walrus, seals), horses, humans.
T. nelsoni	T7	Southern one-half of Africa	S	No	Low	Carnivores in wildlife areas. Occasionally in pigs and humans.
T. papuae	T10	Papua New Guinea	D, S	Moderate	Moderate	Pigs, carnivores, saltwater crocodiles.
T. zimbabwensis	None	Zimbabwe	S	No	Unknown	Farmed crocodiles and monitor lizards.

[1]In addition to the identified species, the taxonomic status of genotype T6 (related to *T. nativa*) and genotypes T8 and T9 (related to *T. britovi*) remain uncertain.

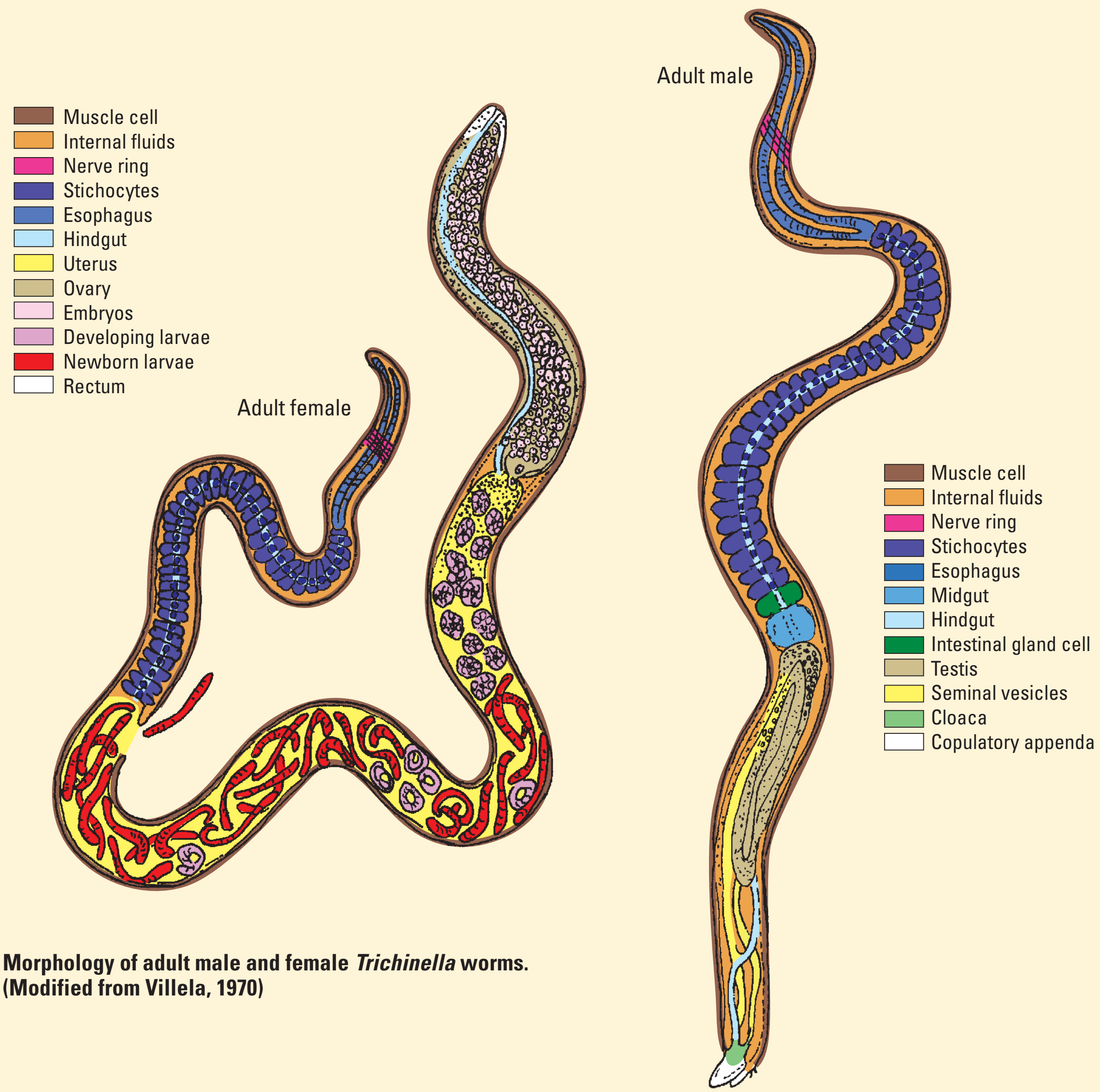
Table 5. Relation between larval forms and host **susceptibility** of *Trichinella* spp.

[Adapted from Pozio, 2005. °C, temperature in degrees Celsius]

Trichinella species	Larval form	Host susceptibility and body temperature range		
		Mammals (37.5–40°C)	Birds (40.5–42.5°C)	Reptiles (25–32°C)
T. spiralis	Encapsulated	Susceptible	Not susceptible	Not susceptible
T. nativa	Encapsulated	Susceptible	Not susceptible	Not susceptible
T. britovi	Encapsulated	Susceptible	Not susceptible	Not susceptible
T. murrelli	Encapsulated	Susceptible	Not susceptible	Not susceptible
T. nelsoni	Encapsulated	Susceptible	Not susceptible	Not susceptible
T. pseudospiralis	Nonencapsulated	Susceptible	Susceptible	Not susceptible
T. papuae	Nonencapsulated	Susceptible	Not susceptible	Susceptible
T. zimbabwensis	Nonencapsulated	Susceptible	Not susceptible	Susceptible

Box 3 Anatomy of the Parasite

Although *Trichinella* worms are the smallest nematode parasite of humans, they are the largest **intracellular** parasite and have been described as "the worm that would be virus" (Despommier, 1990). Adult worms are **intramulticellular** parasites in the intestinal epithelium, where they reside in mucosal cells at the base of the **villi**, the deep pits between intestinal villi, and occasionally the tips of the villi. The **morphology** of the parasite's **esophagus** is characteristic of the Trichinellidae family, and it occupies approximately one-third of the body length and is surrounded by large cells (Anderson, 1992). Adult males are 1.4 to 1.6 mm in length and do not have **spicules**, but a pair of lateral flaps is found on each side of the **cloacal opening** and two pairs of **papillae** are between them. Females are 3 to 4 mm in length, and the **vulva** opens in the middle of the esophageal region. Females are **viviparous** (produce live young rather than eggs), and the viable larvae develop within the adult female 4 to 7 days after infection (Anderson, 1992). Adult worms usually live for less than 4 weeks, but longevity varies among hosts.



Morphology of adult male and female *Trichinella* worms. (Modified from Villela, 1970)

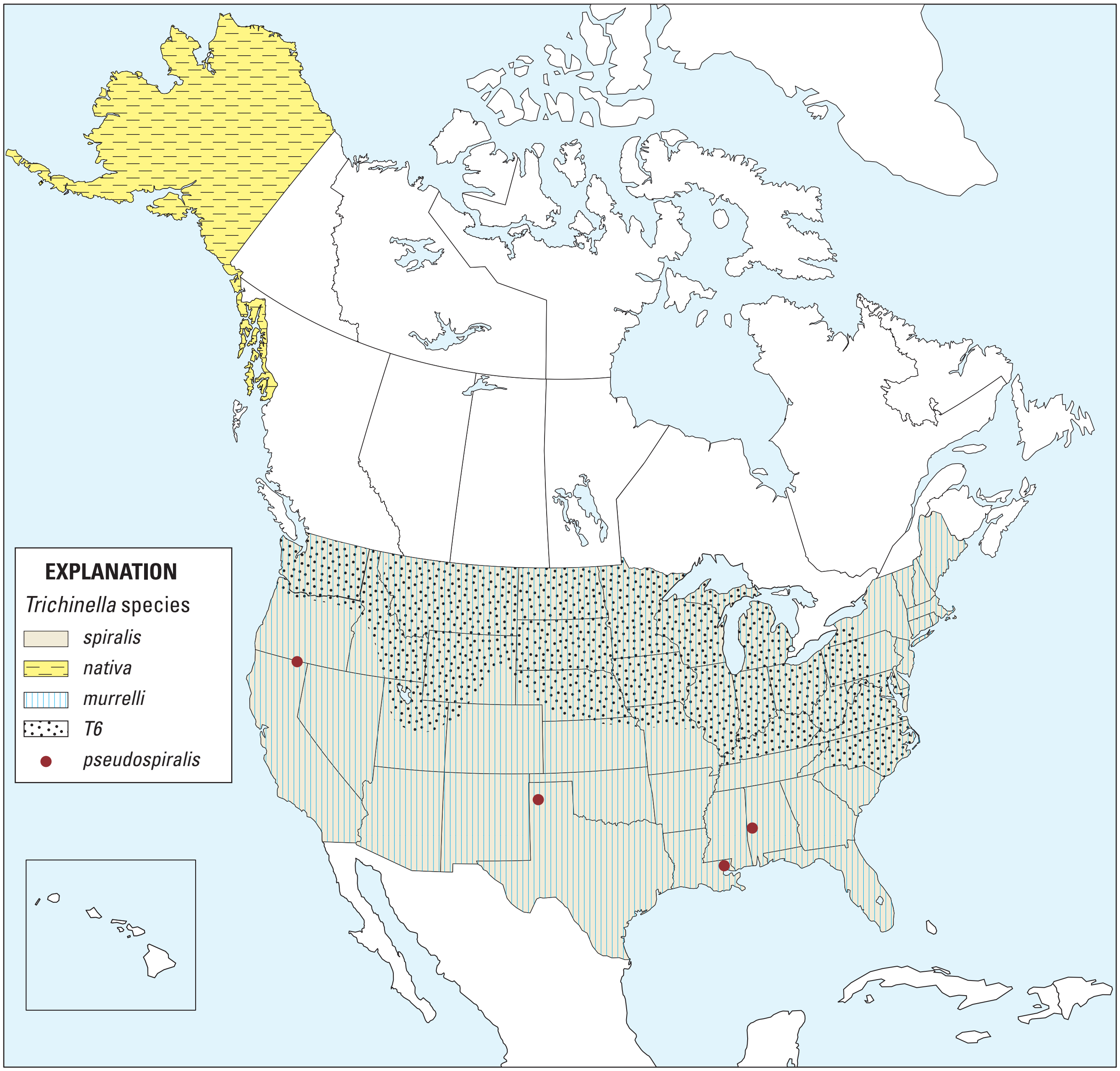


Figure 2. Distribution of *Trichinella* species found in the United States. (Modified from International Trichinella Reference Center)

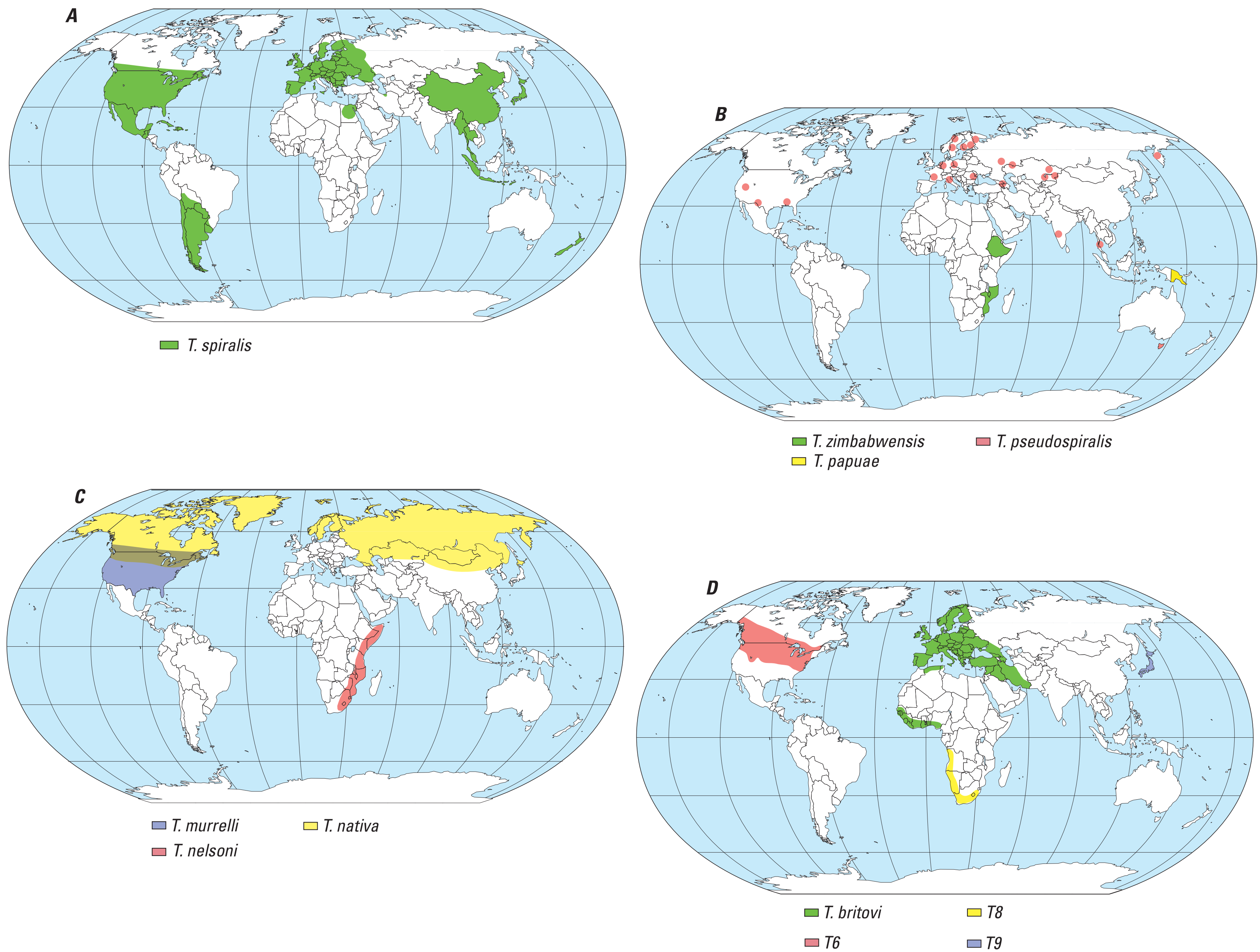


Figure 3. Geographic distribution of *A, T. spiralis*; *B, T. pseudospiralis, T. papuae*, and *T. zimbabwensis*; *C, T. murrelli, T. nelsoni*, and *T. nativa*; *D, T. britovi* and genotypes T6, T8, and T9. (Modified from International Trichinella Reference Center)

Patterns and Trends

Trichinosis has been a known public health threat for over 150 years and continues to be an important human disease throughout the world. Worldwide, as many as 11 million humans may be infected (Dupouy-Camet, 2000). In many countries, such as the United States, the number of reported cases has decreased significantly during the last 50 years (fig. 4), largely because of improvements in **surveillance**, public education, animal husbandry systems, and hygiene. A survey of 12,000 human **cadaver**s in the 1940s in the United States indicated that one in six was infected (Stoll, 1947). In the 1970s and 1980s, the number of cases in the United States was less than 300 per year, and between 1990 and 2006, the number of reported cases was less than 30 per year. However, trichinosis is an emerging and re-emerging disease in many countries, especially in Eastern Europe (Box 4). In the 1990s, an increased prevalence of up to 50 percent in **swine** herds in Byelorussia, Croatia, Latvia, Romania, Russia and Ukraine was reported (Pozio, 2001). In Argentina, Bolivia, Chile, and Mexico, trichinosis is still **endemic** and **prevalent**, primarily because of an increase in the number of small farms that often lack good management practices, lack of sanitary regulations, lack of regulations for home slaughter, and the misconception that trichinosis is no longer a disease concern (Gajadhar and Gamble, 2000). Major reasons for the dramatic increase in prevalence in many other countries include lack of veterinary control, poor diagnostics, war, political turmoil, changes in animal husbandry, changes in food marketing and distribution systems, manipulation of ecosystems, human practices, complacency, and an increase in wildlife reservoirs (Pozio, 2001).

For more than 100 years after the discovery of *T. spiralis*, it was believed that transmission to humans occurred only through the consumption of pork, but in the last 50 years new transmission patterns have been discovered as a result of in-depth **epidemiological** investigations and advanced techniques in biotechnology (Pozio, 2000a; 2001). The new patterns in the epidemiology and transmission of trichinosis are related to several factors, including dramatic changes in the interaction between animals and humans and the discovery of three nonencapsulated species of *Trichinella*: *T. pseudospiralis,* which infects a wide variety of mammals and birds; *T. papuae,* which was discovered in New Guinea, a new geographical location (Pozio and LaRosa, 2000); and *T. zimbabwensis,* which infects **cold-blooded** vertebrates, the crocodile, and the monitor lizard (Pozio and others, 2002; Pozio, 2005). These new patterns were previously unknown because of the difficulty in detecting nonencapsulated larvae in muscles. Advanced techniques in biotechnology have been used to identify new parasites, to trace infections to their source, and to identify the location of transmission (Murrell and others, 2000). With this improved knowledge

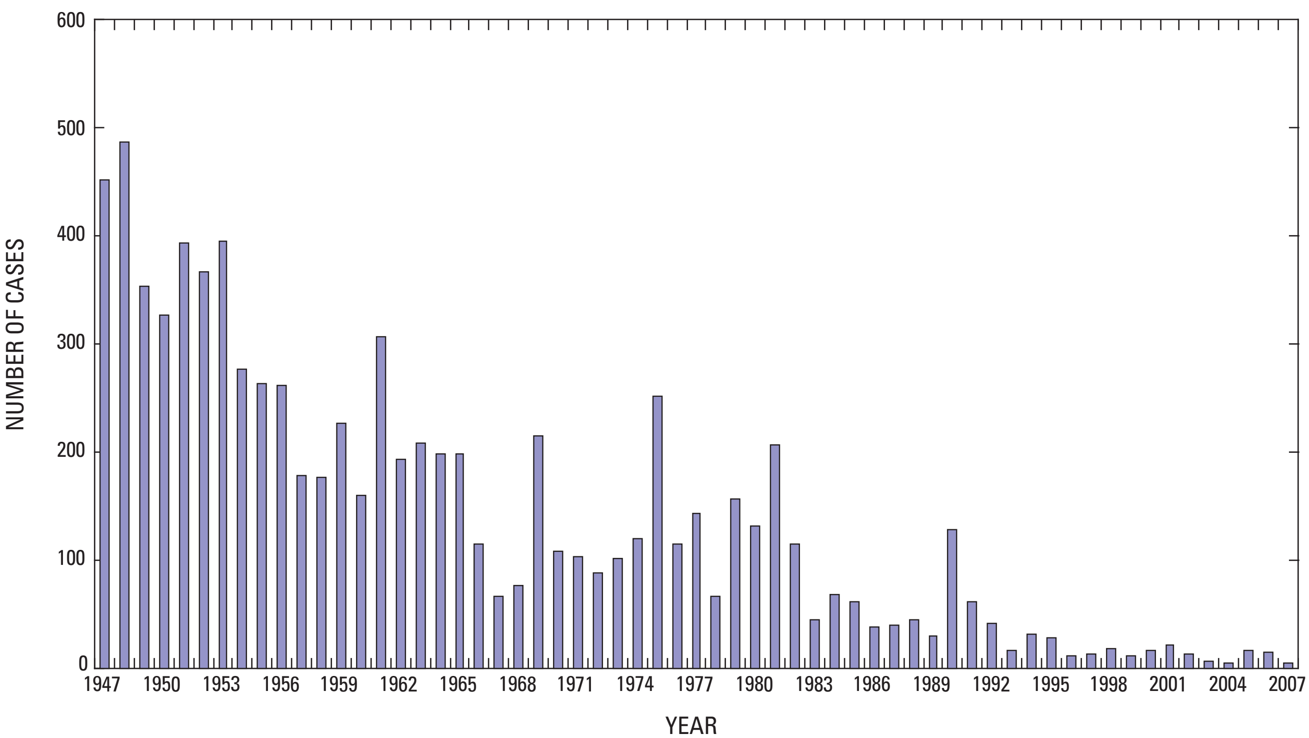


Figure 4. Number of human cases of trichinosis in the United States, 1947–2007. (Data from Centers for Disease Control and Prevention, 2007; Centers for Disease Control and Prevention, 1994)

and the development of new techniques for the isolation and identification of these parasites, it is likely that identification of new species and new patterns of transmission will follow.

Species Susceptibility

Trichinosis is primarily a disease of pigs, humans, rats, and carnivorous wildlife. Pigs and wild carnivores are the two animal groups of hosts that are most frequently infected with one or more species of *Trichinella*. After humans and animals ingest meat infected with *Trichinella* larvae, most infections are **subclinical** and remain undetected. However, when infections are moderate to heavy, symptoms can be severe and death can result. All mammals are likely **susceptible** to *Trichinella* infections, and many of these animal species are **susceptible** to infection with more than one *Trichinella* species (Appendix 1).

Human Infections

In humans, trichinosis is an important food-borne disease that can cause **acute** and **chronic** illness. Humans are only infected with *Trichinella* larvae through the ingestion of meat that has not been properly cooked. All species of *Trichinella*, except for the nonencapsulated species (*T. pseudospiralis*, *T. papuae*, and *T. zimbabwensis*), can be highly **pathogenic** in humans (Jongwutiwes and others, 1998; Kociecka, 2000). *T. spiralis* is apparently more pathogenic in humans than other species because more larvae are produced by the female worms (Pozio and others, 1992). In the Arctic, two distinct human disease **syndromes** associated with eating walrus meat infected with *T. nativa* have been observed (Box 5) (MacLean and others, 1992). Recently, *T. papuae* has been implicated in outbreaks of human trichinosis (Khumjui and others, 2008; Lo and others, 2009). Twenty-eight people in Thailand became sick after eating wild boar and suffered symptoms of trichinosis, and *T. papuae* was identified in a muscle **biopsy** from one of the patients (Khumjui and others, 2008). *T. papuae* was also suspected as the cause of an outbreak of trichinosis in eight people who had eaten raw soft-shelled turtles in Taiwan (Lo and others, 2009).

Clinical manifestations are often complex, and they depend on the age of the human host, the state of **resistance**, and the numbers of larvae ingested. Most clinical symptoms are present between 1 and 6 weeks after infection (Capó and Despommier, 1996), and the psychological effects of affected humans further complicate the physical symptoms of the disease. Three stages of disease in humans have been described: the **enteral** or intestinal phase, the migratory or mucosal invasion phase, and the **parenteral** or **convalescence** phase (Box 6) (Gould, 1983).

Animal Infections

Domestic animals and wildlife seem to tolerate high levels of infection with very few or no **clinical signs** of infection, even though many wild carnivores are highly susceptible. Domestic pigs and rats are resistant to infection with several of the sylvatic species of *Trichinella*. Malnourished, stressed, **immunocompromised**, or debilitated hosts appear to be more susceptible than healthy hosts to infections that normally cause lower infections in a particular host species.

Domestic Animals

Pigs

Pigs are the usual host for *T. spiralis*, but they rarely show signs of infection. Pigs are naturally resistant to most species of sylvatic *Trichinella*, except for *T. pseudospiralis*. Only experimental doses of 100,000 *T. spiralis* larvae in young pigs induced severe **pathological** changes and death (Dick and Pozio, 2001). Young pigs appear to be more susceptible than older pigs to infection. If pigs are infected by sylvatic species, few adult worms develop and few larvae survive (Kapel and others, 1998).

Horses

Trichinella spiralis, *T. britovi*, and *T. murrelli* have occasionally been found in horses (Boireau and others, 2000), suggesting that horses may be infected in areas where many infected meat scraps are available in the environment. Horses likely become infected by inadvertently consuming meat scraps with vegetation. Horses are uncommon hosts for *Trichinella* spp. because they are not meat-eating animals, but over 3,000 human infections have been traced to ingestion of raw or improperly cooked horsemeat. Horses are important in the transmission of *T. spiralis* to humans in Italy and France, where horsemeat is eaten raw or undercooked. Since 1975, more than 3,000 human cases of trichinosis in Italy and France have been linked to the consumption of horsemeat (Dupouy-Camet, 2000).

In Canada, *Trichinella* larvae were not detected in over 200,000 horses that were examined between 1995 and 1999 (Polley and others, 2000), indicating the limited role of horses in the maintenance of the parasite. Experimental infections of horses with 5,000 to 50,000 *T. spiralis* larvae resulted in no major clinical signs, but two horses infected with 50,000 larvae had stiff hind legs, and one horse had an elevated rectal temperature (Soule and others, 1989). Naturally infected horses with heavy infections of 600 larvae per gram of muscle showed no apparent clinical signs.

Box 4 Trichinosis as an Emerging Disease

Trichinosis has been regarded as a public health threat for more than 150 years. During this time, government agencies implemented regulatory measures in efforts to control and **eradicate** the disease in pigs and humans. Although the infection has not been eradicated, people in the United States and other areas of the world may tend to believe their risk of contracting trichinosis is very small. However, in the past 10–20 years, numerous outbreaks around the world and recent epidemiological findings have demonstrated that trichinosis is, indeed, a re-emerging disease in both developed and developing countries (Murrell and Pozio, 2000; Dupouy-Camet, 2000; Pozio, 2001). Many factors have contributed to the increasing prevalence of *Trichinella* spp. infections, from both domestic and sylvatic cycles.

Countries where trichinosis was emerging or declining, 1965–99.

[Data from Dupouy-Camet, 2000]

Country	Number of outbreaks[1] 1965–1989	1990–1999
Countries where trichinosis was emerging		
Russia	10	9
China	2	13
European Union	17	16
Yugoslavia	2	71
Countries where trichinosis was declining		
United States	18	3
Canada	11	1
Slovakia	6	0

[1]Number of outbreaks reported in journals indexed in MEDLINE.

Improved technology has resulted in detection of significantly more cases of trichinosis in both humans and animals than was expected (Murrell and Pozio, 2000) by enabling the detection of low numbers of larvae in animals and antibodies in infected people. Cases of trichinosis that would previously have been misdiagnosed as influenza are now being correctly classified and reported. In addition, advanced technologies have enabled researchers to identify the particular species of *Trichinella* involved in outbreaks and individual infections, demonstrating the increasing importance of sylvatic species in causing human infections.

Changes in animal husbandry can result in decreases or increases in trichinosis. Since World War II, no *Trichinella* infections have been reported in pigs on industrialized pig farms in Western Europe because of control measures put in place to limit their contact with rodents and to prevent feeding pigs uncooked animal protein (Pozio, 2001). However, as the numbers of small backyard farming operations increase in many countries and as more pigs are raised in open pastures for humane reasons, pigs are being exposed to more sources of *Trichinella*, for example, in their feed and by contact with wild reservoirs of infection. Pigs raised on these "ecological" farms for personal or local consumption are not always required to be tested for *Trichinella* infection, thus the meat from these animals poses a risk to the people who eat it.

Lack of veterinary **surveillance** controls in many countries where it is not required and of most backyard pigs raised by local inhabitants has also contributed to the increase in *Trichinella* infections. Outbreaks of trichinosis from ingestion of infected horsemeat in France and Italy have been attributed to inadequate or nonexistent testing of horsemeat. As a result, mandatory testing for *Trichinella* in horsemeat was implemented in Europe in 1985 and has been periodically strengthened to decrease the risks of eating horsemeat.

Political turmoil and war may result in a decrease in biosecurity and government quality control of the meat processing industry, as well as a reduction in hygiene practices and the decreased availability of protein sources (Murrell and Pozio, 2000). Eastern Europe has been especially impacted by the increase in trichinellosis for these reasons. In Serbia, during the 1990s, *Trichinella* infection of pigs spread from four restricted areas to almost one-third of the country (Cuperlovic, 2001).

Changes in food marketing and distribution systems have resulted in worldwide distribution of potentially contaminated meats from **enzootic** countries. The horsemeat involved in outbreaks of trichinosis in France and Italy was imported from eastern Europe and Mexico, where the domestic cycle of *Trichinella* is enzootic (Pozio, 2000b). Increased international travel of more visitors to enzootic countries has resulted in increased exposure of those travelers to local foods that may be contaminated with *Trichinella* larvae. These infections may be spread when travelers bring back local delicacies to share with their families and friends.

Manipulation of ecosystems may provide for increased exposure to a variety of reservoir animals. An increase in forested area in Europe has led to an increase in the numbers of wild boars and bears, contributing to the **maintenance** of sylvatic trichinosis (Dupouy-Camet, 2000; Saunders, 2008). An increase in these wildlife reservoirs of trichinosis provides a continual source of infections for humans who eat wild game meat, as well as an increase in the risk of the infection spilling over into domestic animals that humans may eventually eat.

Human practices can increase the risk for infections in wildlife and domestic animals, as well as people. Allowing access of wildlife to **viscera** from slaughtered animals can dramatically increase the prevalence of *Trichinella* in reservoir animals. The use of wild game as food and consumption of meats that have not been properly cooked can be responsible for localized outbreaks (Margolis and others, 1979; Dworkin and others, 1996; Moorhead and others, 1999; Forbes, 2000; Centers for Disease Control and Prevention, 1996, 2004, 2009; Ancelle and others, 2005; Wang and others, 2006). Horses, which are herbivores, may become infected with *Trichinella* by inadvertently eating feed contaminated with infected rodents or by being deliberately fed animal protein supplements for fattening prior to slaughter (Pozio, 2000a; Murrell and others, 2004).

Complacency is the result of many humans believing the food they eat in the form presented to them is completely safe. Appropriate testing and surveillance of meat products are key to the prevention of food-borne infections. As people become more interested in eating local food, they may increase their risk of becoming infected with *Trichinella*. Backyard butchering, which bypasses inspection for *Trichinella*, has led to numerous cases of the infection in several countries (Murrell and Pozio, 2000; Pozio, 2000; Gottstein and others, 2009). In the United States, while trichinosis from commercial pork has decreased, the proportion of cases associated with consumption of wild game has increased (Moorhead and others, 1999; Centers for Disease Control and Prevention, 1996, 2009). Vigilance concerning proper food preparation is always needed to ensure the safety of what is eaten. Just because food is "fresh" doesn't mean it can safely be eaten raw or undercooked.

Recent increases in the **incidence** of human cases of trichinosis in three countries.

Country	Time period	Increase in incidence	Reference
Romania	1983–1997	17 times	Olteanu, 1997
Argentina	1993–2000	7 times	Bolpe and Bofi, 2001
Lithuania	1989–1994	9 times	Rockiene and Rocka, 1997

Box 5 Trichinosis among Native Arctic Subsistence Hunters

Approximately one-tenth of the roughly 4 million people living in the Arctic region, which contains the Arctic Ocean as well as parts of Canada, Greenland, Russia, Alaska, Iceland, Norway, Sweden, and Finland, are **indigenous** (Larsen, 2004). These people, sometimes known as Eskimo ("eaters of raw meat") or **Inuit** ("real people"), have adapted to life on the ice-covered ocean and treeless frozen ground and depend largely upon **subsistence hunting** for their food supply. Traditional food includes seal, whale, caribou, walrus, polar bear, Arctic hare, fish, and birds eaten fresh or frozen, raw, boiled, or fermented.

Trichinosis has been specifically named as "a direct threat to human health in communities that rely on wildlife as a source of food" (Parkinson, 2008) by the current 4th International Polar Year (IPY, 2007–2008), which featured human health as a research theme with the ultimate goal of improving the health and well being of Arctic peoples. Surveys for *Trichinella* in human cadavers in the 1940s and 1950s found a substantially higher prevalence in northern Canada (22–46 percent) compared with other areas (1.5–7.3 percent) (Appleyard and Gajadhar, 2000). The rate of human cases of trichinosis in the Northwest Territories and Quebec has been reported to be 200 times the national rate in Canada (Appleyard and Gajadhar, 2000), indicating a high risk of acquiring the infection from consuming Arctic wildlife. In the United States, Alaska has the highest rate of trichinosis (MacLean and others, 1989).

The prevalence of *Trichinella* infection in polar bears and walruses has been shown to range from 24 to 61 percent and 2 to 9 percent, respectively. In northern Quebec, up to 11 percent of the walruses are infected with *T. nativa* larvae, resulting in periodic outbreaks of trichinosis in the Inuit who consume the meat either raw or insufficiently cooked. In general, Inuit of the Canadian Arctic prefer to eat polar bear meat well-cooked and walrus meat raw, making walrus meat a more common source of trichinosis. Although cases of trichinosis caused by eating polar bear meat have occurred in Inuit (Davies and Cameron, 1961), large outbreaks of the disease have resulted from consumption of infected walrus meat that has been widely distributed in a community according to the local tradition of sharing meat (Serhir and others, 2001).

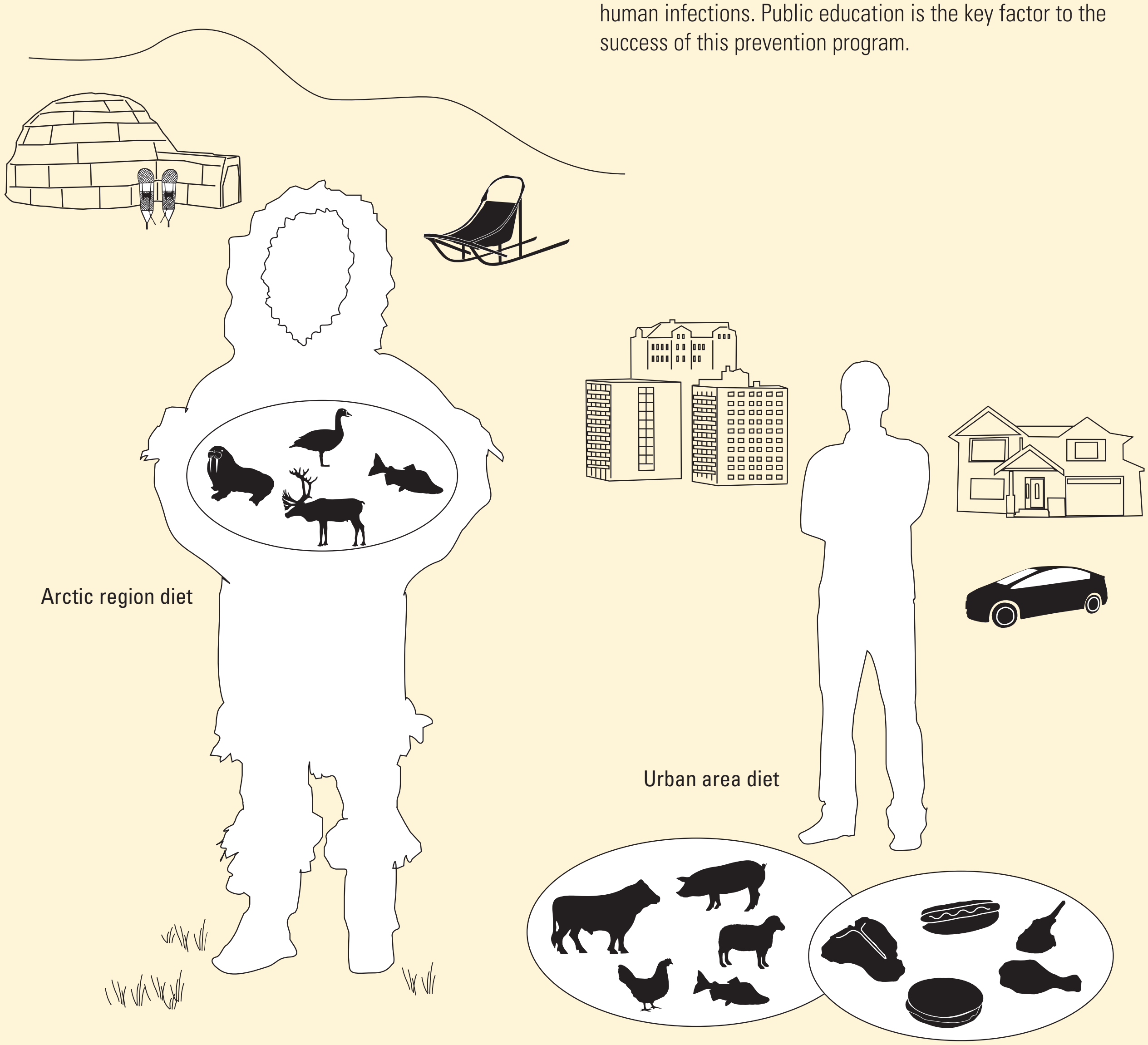
Photo courtesy of the U.S. Fish and Wildlife Service.

Outbreaks of trichinosis in North American Native Arctic peoples from eating walrus meat.

Date	Location	Number of cases	Reference
1975	Alaska	26	Margolis and others, 1979
1976	Alaska	4	Margolis and others, 1979
1982	Canada	10	Viallet and others, 1986
1983	Canada	40	MacLean and others, 1989
1984	Canada	9	MacLean and others, 1989
1984	Canada	15	MacLean and others, 1989
1987	Canada	42	MacLean and others, 1992
1999	Canada	62	Serhir and others, 2001

In the Arctic, two distinct human disease syndromes associated with eating walrus meat infected with *T. nativa* (MacLean and others, 1992) have been observed. The first syndrome is the classical muscular infection characterized by edema, fever, muscle pain, and rash. The second is thought to represent reinfection in previously infected humans, and it is characterized by persistent diarrhea that may last for several weeks.

A novel prevention program for human trichinosis has been instituted recently for Inuit peoples in northern Quebec (Proulx and others, 2002). When walrus are harvested, samples of tongue, **digastricus**, and intercostal and **pectoral** muscles are sent to a regional laboratory where the meat is tested with digestion methods and polymerase chain reaction (PCR) technology. When positive samples are identified, the meat from infected carcasses is destroyed rather than being eaten. This procedure has been accepted by the Inuit, and it has significantly reduced the number of human infections. Public education is the key factor to the success of this prevention program.

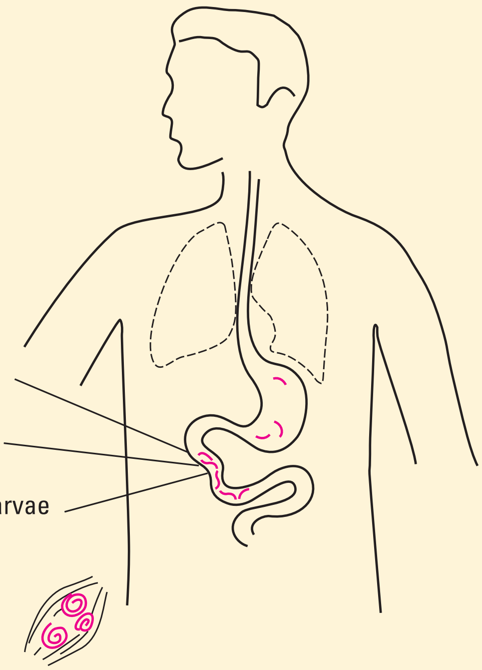


Box 6 Stages of Trichinosis in Humans

The clinical presentation of trichinosis in people varies and is influenced by the number of infective larvae ingested, the strain of *Trichinella* involved, and individual host factors such as age, sex, and **immune status** (Pawlowski, 1983; Ljungström and others, 1998).

Phase 1: Enteral Phase—penetration of larvae into intestinal mucosa and development to adults

Twelve hours to 2 days after the ingestion of infected meat, symptoms appear as worms are released from ingested muscle tissue and migrate through the intestinal epithelium. Symptoms may include diarrhea, nausea, abdominal pain, vomiting, and **malaise**. Most people who become infected suffer only mild transient diarrhea and nausea; people who have ingested low numbers of larvae may not experience any illness during this phase. Clinical signs mimic other intestinal disorders, such as food poisoning, and can cause the disease to be misdiagnosed if medical attention is sought after the onset of symptoms.



Signs and symptoms in mild to moderate trichinosis infection in humans.

[Capó and Despommier, 1996]

Sign/symptom[1]	Number of people affected, in percent
Diffuse muscle pain	30–100
Periorbital and/or facial edema	15–-90
Conjunctivitis	55
Fever	30–90
Headache	75
Skin rash	15–65
Paralysis-like state	10–35
Difficulties in swallowing	35
Bronchitis	5–40
Hoarseness	5–20

[1]Infected people may also experience **insomnia**, **anorexia**, weight loss, peripheral nerve sensations, hot flashes, profuse nasal discharge, **splinter hemorrhages** of the nail beds or the **retina** or both, visual disturbances, and paralysis of the ocular muscles.

Phase 2: Migratory Phase

Two to 6 weeks after infection, newborn larvae enter the **venous circulation** and migrate through tissues, causing mechanical damage to tissues as well as eliciting allergic responses from the host that lead to signs and symptoms that differ from those of the enteral phase. High numbers of white blood cells (**eosinophils**) appear about 2 weeks after infection. Damage to blood vessels may lead to localized edema in the face and hands. It is often during this phase that infected people first seek medical attention, especially if they have not experienced any symptoms during the initial phase of infection. During the migratory phase of infection, humans often have trouble walking, breathing, chewing, and swallowing because the muscles most heavily infected are masseters, muscles of the tongue, diaphragm, **larynx** and neck, the **intercostals**, and the **muscular insertions** of tendons and joint capsules.

Above: Clinical appearance of the conjunctivitis caused by trichinosis.
Left: Splinter hemorrhages under the finger nails caused by trichinosis.
Both photos courtesy of the Centers for Disease Control and Prevention; photos by Dr. Thomas F. Sellers

In extremely heavy infections, signs and symptoms, such as high fever and severe muscle pain and swelling, are more prominent. Larvae may invade cardiac muscle or neural tissue, resulting in **myocarditis**, **neuritis**, and other **central nervous system** disorders. Common neurologic signs include headache, **vertigo**, **tinnitus**, loss of the ability to speak or write, and convulsions (Capó and Despommier, 1996). Death in humans is usually associated with damage to the heart muscle and may occur between the third to fifth weeks after infection.

Phase 3: Parenteral Phase—penetration of muscle fibers by juveniles and nurse cell formation

In phase 3, patients may have few signs or symptoms because convalescence begins between 5 to 6 weeks after ingestion of infected meat. Some patients may continue to lose weight and feel tired. Patients who ingested large numbers of larvae may suffer the effects of the infection for up to 10 years after recovery (Harms and others, 1993). Infectious larvae can remain encysted in nurse cells months to years after recovery from clinical illness (Pawlowski, 1983). Some patients may suffer protracted recoveries with depression and fatigue due to psychological effects of infection. Proper mental therapy is important to reassure patients that they can function normally in spite of the presence of encysted larvae in their muscles (Pawlowski, 1983).

Long-term effects in humans after severe trichinosis infection.

[Harms and others, 1993; Feldmeier and others, 1991]

Effect	Number of people affected, in percent
Generalized myalgia	84–90
Ocular symptoms[1]	59–63
Abnormalities of the nervous system	35–52

[1]Conjunctivitis, difficulty in focusing, burning sensation

Ruminants

Trichinella larvae are rare in **ruminants**, although sheep, goats, and cattle are susceptible to experimental infections (Murrell, 1994; Theodoropoulous and others, 2000). Human infections in China have been traced to eating domestic sheep (Wang and others, 1998; Takahashi and others, 2000).

Wildlife

A wide variety of wildlife hosts are the principal reservoirs for the sylvatic species of *Trichinella*, and some wildlife species also harbor *T. spiralis* (table 2 and Appendix 1). All species of wildlife, but especially carnivores, are more than likely susceptible to at least one of the species of *Trichinella*, and many wildlife species are hosts for more than one species. Numerous wildlife surveys have been conducted throughout much of the world and have been summarized (Kim 1983; Murrell and Pozio, 2000; Dick and Pozio, 2001). The data presently available clearly indicate that most mammals, some birds, and some reptiles (crocodiles and monitor lizards) are susceptible to infection.

Bears

Trichinella larvae have been detected in many areas of North America where black bears have been evaluated (fig. 5) (Zimmerman, 1977; Kim, 1983; Schad and others, 1986; Stromberg and Prouty, 1987; Butler and Khan, 1992; Dick and Pozio, 2001; Pozio, Pence, and others, 2001). In North America, the black bear is one host that is a major potential source of human infection because bears are hunted and eaten. Bears are ubiquitous hosts for *Trichinella*, and, therefore, the meat should always be cooked well before it is eaten.

Arctic Mammals

In the Arctic and Subarctic, marine mammals and carnivores are hosts of *T. nativa,* which has a circumpolar distribution (table 6). Polar bears and walrus are two mammals commonly infected with *T. nativa*, and they serve as the usual sources for human infection (Forbes, 2000). High prevalence of infection in polar bears throughout the Arctic region has been reported (Thorshaug and Rosted, 1956; Fay, 1960; Madsen, 1961; Larsen and Kjos-vHanssen, 1983; Born and Henriksen, 1990; Weyermann and others, 1993); infection is less prevalent in walrus populations (Forbes, 2000). Other marine mammals that have occasionally been infected include Beluga whales, bearded seals, and ringed seals. Reports of *Trichinella* in Greenland seals, harbor seals, and narwhals are not well documented (Forbes, 2000). Arctic fox, sled dogs, and other carnivores, such as lynx, likely contribute to the life cycle of *Trichinella* in marine mammals by feeding on the infected carcasses of marine mammals (Kapel and others, 1996). In turn, carcasses of these land-based carnivores can also serve as sources of infection for marine mammals, either directly through **carrion** feeding or indirectly through ingestion of **amphipods** or fish that have fed recently on infected carcasses that have been deposited in the ocean (Forbes, 2000).

Birds

Birds from several countries, including the United States (Wheeldon and others, 1983), are occasionally infected with *T. pseudospiralis*, but they are generally resistant to natural infections with other *Trichinella* species. Therefore, birds appear to be of limited importance in the maintenance and transmission of the parasite.

Cold-Blooded Wildlife

Reptiles and fish have limited importance in the maintenance or transmission of *Trichinella* infections, but *T. zimbabwensis* has recently been detected in crocodiles and monitor lizards in Africa (Mukaratirwa and Foggin, 1999; Pozio and others, 2002). *T. papuae* has been detected in salt-water crocodiles in Papua New Guinea (Pozio and others, 2004). Among the fish that have been tested, carp retained infective larvae of *T. britovi* in the gut, body cavity, or muscle for up to 7 days after infection, indicating that carp are a potential source of transmission to other animals (Moretti and others, 1997).

Invertebrates

Experimental infection of various arthropods and arthropod larvae indicated that some arthropods can maintain infections for up to several days, suggesting that the role of **invertebrates** in the transmission of *Trichinella* is limited (Pozio, 2000a).

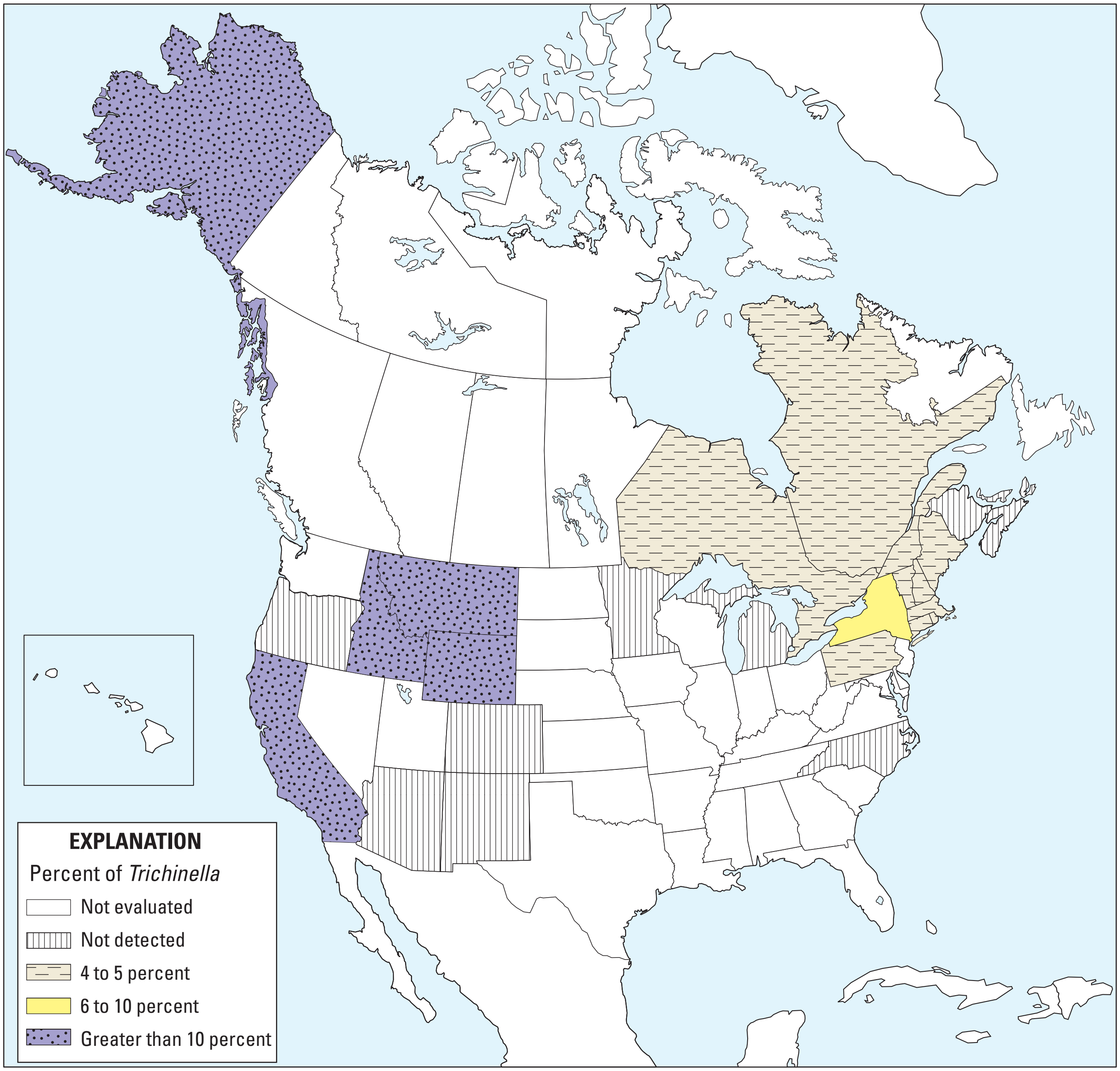
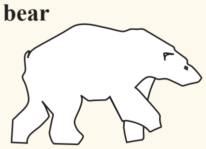
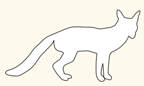
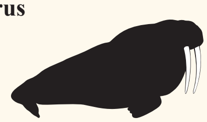
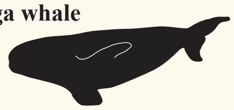
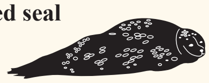


Figure 5. Prevalence of *Trichinella* spp. in black bears in North America. (Data from Zimmerman, 1977; Kim, 1983; Schad and others, 1986; Stromberg and Prouty, 1987; Butler and Khan, 1992; Nutter and others, 1998; Dick and Pozio, 2001; Pozio, Pence, and others, 2001)

Table 6. Prevalence of *Trichinella* spp. in arctic mammals.

[<, less than]

Species	Location	Number of animals tested positive per number tested	Animals tested positive, in percent	Reference
		Carnivores		
Polar bear 	Alaska	57/104	55	Fay, 1960.
		56/92	60.9	Weyermann and others, 1993.
	Greenland	56/231	24.2	Madsen, 1961.
		12/38	32	Born and Henriksen, 1990.
	Norway	118/376	31.4	Larsen and Kjos-Hanssen, 1983.
	Barents and Norwegian Seas	163/278	59	Thorshaug and Rosted, 1956.
Arctic fox 	Greenland	16/266	6	Kapel and others, 1999.
	Svalbard	8/53	15	Kapel and others, 1999.
	Victoria Island	Data not given	30	Dick and Pozio, 2001.
European lynx 	Finland	132/327	40	Oksanen and others, 1998.
		Marine mammals		
Walrus 	Russia	1/89	1	Forbes, 2000[1].
	Greenland	7/615	1	Forbes, 2000[1].
	Canada	21/600	3.5	Forbes, 2000[1].
	Barents and Greenland Seas	7/74	9	Forbes, 2000[1].
	Alaska	1/104	9.6	Forbes, 2000[1].
Beluga whale 	Alaska, Canada, Greenland, Norway	1/482	<1	Brandly and Rausch, 1950.
Bearded seal 	Alaska, Canada, Greenland, Norway, Russia	3/876	<1	Forbes, 2000[1].
Ringed seal 	Alaska, Canada, Greenland, Norway, Russia	3/2,743	<1	Forbes, 2000[1].

[1]Individual studies cited in Forbes, 2000.

Obtaining a Diagnosis

Methods for diagnosing trichinosis are similar for both humans and other animals. Over the last 100 years, the standard method for diagnosis of *Trichinella* larvae from muscles is trichinoscopy, which is the process of compressing small pieces of **striated muscle**, obtained by biopsy or after death, between two plates of glass and then viewing the pieces of muscle under a **dissecting or compound microscope**. Magnified larvae can be seen coiled in the compressed muscles (fig. 6). The preferred muscles for evaluation are the diaphragm, tongue, masseter, or intercostal. A second preferred method of diagnosis is the digestion method; muscle tissue is placed in a 1-percent hydrochloric acid-pepsin solution at 37°C for several hours, and then the digest is filtered through a screen with a grid of 80 meshes per inch. Larvae can then be observed and counted under a dissecting microscope, and data can be quantified as number of larvae recovered per gram of tissue. **Histopathologic** evaluation of preferred muscles is a third useful technique, especially in heavy infections. Adults are not commonly found in intestine because they usually are very small and live for less than 2 weeks. However, after recent ingestion of infected meat, adult worms can be found in the mucosa and epithelium of the small intestine with the aid of a dissecting microscope.

The diagnosis and identification of species and genotypes of *Trichinella* larvae have been dramatically improved through the development and application of biochemical techniques (LaRosa and others, 1992), molecular biology (Zarlenga and others, 1991), and PCR technology (Bandi and others, 1995; Zarlenga and others, 1999). Whereas these tests are valuable for identifying isolates of *Trichinella* and for surveys of animal populations, they are not recommended as a substitute for direct testing by trichinoscopy evaluation or digestion methods. Numerous **immunological** tests have been used to detect **antibodies** or circulating **antigens** (table 7) (Zarnke and others, 1997; Kociecka, 2000; Nockler and others, 2000). In humans, a history of eating infected meat, clinical symptoms, increased muscle enzyme levels, and the presence in blood of 5 to 80 percent or more eosinophils—a type of white blood cell—are also helpful in the diagnosis of infection (Capó and Despommier, 1996; Kociecka, 2000).

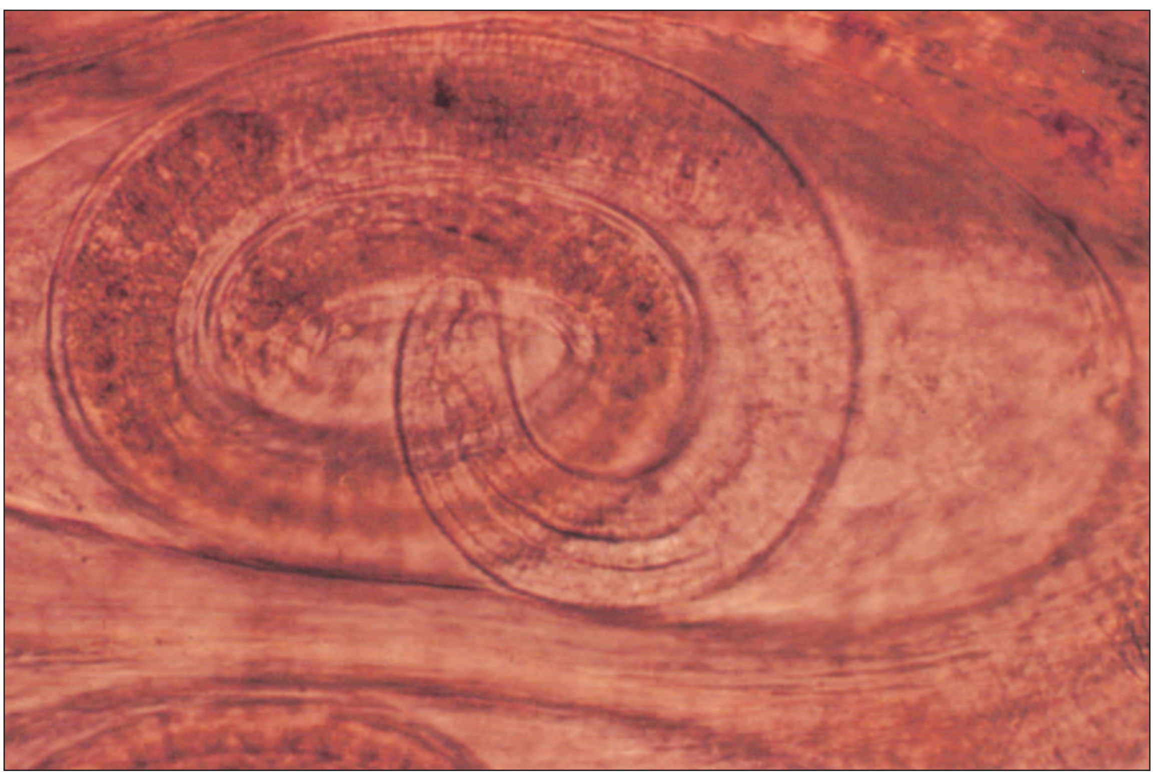


Photo courtesy of William Foreyt

Figure 6. Coiled larva in compressed muscle.

Disease Ecology

The usual source of trichinosis in humans is from eating pork products or meat from horses, dogs, or a variety of wildlife species, including wild pig, bear, walrus, and seal. *Trichinella* spp. are transmitted by two specific cycles, the domestic cycle and the sylvatic cycle (Campbell, 1983b; Dick and Pozio, 2001).

Domestic Cycle

The domestic cycle of transmission primarily involves *T. spiralis* in a cycle of pig-to-pig transmission, and humans enter the cycle through eating pork (fig. 7). The infection can be highly pathogenic in humans. **Synanthropic** rats, mice, cats, dogs, and horses, as well as many wildlife species, also contribute to the cycle in many areas. Pigs maintain the cycle by eating pieces of infected meat scraps, eating infected rats or mice, biting the tails of infected pigs, cannibalizing dead pigs, ingesting feces from pigs that have recently eaten infected meat, or eating other species of infected mammals (fig. 8). The domestic cycle is prevalent on small farms where disease control is not a primary objective in food production. Areas where infection is endemic are found throughout the world (fig. 9) (Dupouy-Camet, 2000; Ortega-Pierres and others, 2000; Dick and Pozio, 2001). In areas where pig trichinosis is enzootic, *T. spiralis* often is transmitted to wildlife and, occasionally, to horses (Kapel, 2000). Pigs, synanthropic mice and rats, and humans are the usual hosts for *T. spiralis*, but sylvatic species of *Trichinella* can also infect these hosts. Conversely, *T. spiralis* is also present in wildlife. In the United States, *T. spiralis* has been reported from black bear and gray fox in Pennsylvania; coyote in Indiana; raccoon, coyote, and red fox in Illinois; wild boar in New Hampshire; grizzly bear and bobcat in Montana; black bear in Arizona; and raccoon, opossum, and skunk in New Jersey (Dame and others, 1987; Murrell and others, 1987; Snyder and others,

Table 7. Common techniques for evaluating exposure to *Trichinella* spp. in humans and other animals.

Technique	Tissues evaluated	Comments
	Diagnosis of trichinosis	
Trichinoscopy	Diaphragm, tongue, masseter, intercostal muscles	Gold standard for diagnosis of *Trichinella* larvae in muscle tissue.
Digestion	Same	Another preferred assay for muscle tissue evaluations.
Histopathology	Muscles and intestine	Especially useful in heavy infections.
Polymerase chain reaction (PCR)	Muscles and blood	Not routinely used; expensive. May become more routinely used to detect circulating larvae or small numbers of larvae in muscle tissue.
	Surveys and isolate identification	
Enzyme-linked immunosorbent assay (**ELISA**)	Blood **serum**	Detect antibodies to *Trichinella* spp. exposure; used to determine prevalence of infections and early detection of infection.
Indirect immunoflourescence test **Competitive inhibition assay** **Immunoblotting** **Counterimmunoelectrophoresis** **Immunoradiometric assay**	Blood	Detection of antibodies or circulating antigens.
Polymerase chain reaction-restriction fragment length polymorphism (**PCR-RFLP**)	Larvae	Distinguish among species of *Trichinella* larvae. May be useful in identifying subspecies or geographical strains. Applicable to identifying sources of infection.

1987; Worley and others, 1994; Dick and Pozio, 2001; Pozio, Pence, and others, 2001). In Europe and Asia, *T. spiralis* and *T. britovi* have been found in wild boars, but in the frigid arctic and subarctic regions, *T. spiralis* is restricted to animals living in close proximity to human settlements (Pozio, 2000a). Based on all data, *T. spiralis* larvae in dead tissue are poorly adapted to environmental extremes, such as freezing, elevated temperatures, and degradation of host tissue. Thus, *T. spiralis* is found less frequently in wildlife when compared to the higher prevalence of the sylvatic species of *Trichinella*.

Sylvatic Cycle

The sylvatic cycle of transmission (fig. 10) predominantly involves predation, cannibalism, or scavenging behaviors of species of carnivorous wildlife. *Trichinella* spp. are transmitted when fresh, frozen, or decomposing carcasses or meat scraps are eaten. The parasite persists mostly through normal wildlife carnivorous and scavenging feeding habits, but humans can influence the prevalence and distribution of *Trichinella* in wildlife in several ways, such as by using infected carcasses or meat as bait for attracting animals to be harvested (Dick and others, 1986).

The species of *Trichinella* associated with the sylvatic cycle are *T. nativa*, *T. britovi*, *T. murrelli*, *T. nelsoni*, *T. pseudospiralis*, *T. papuae*, and *T. zimbabwensis*. *T. spiralis* can also affect wildlife in temperate and tropical regions, but it does not survive in arctic and subarctic regions because larvae do not survive in a frozen carcass. Many surveys of wildlife throughout the world have indicated various wildlife species are often infected with different species of *Trichinella* (Appendix 1). Sylvatic cycles maintain the parasite without pig or human interaction, but humans or pigs enter into the life cycle through the ingestion of infected meat. Some outbreaks of sylvatic trichinosis in humans have resulted from eating meat from bears in Greenland, Canada, the United States, Japan, Eastern Europe, and China; walrus in Canada

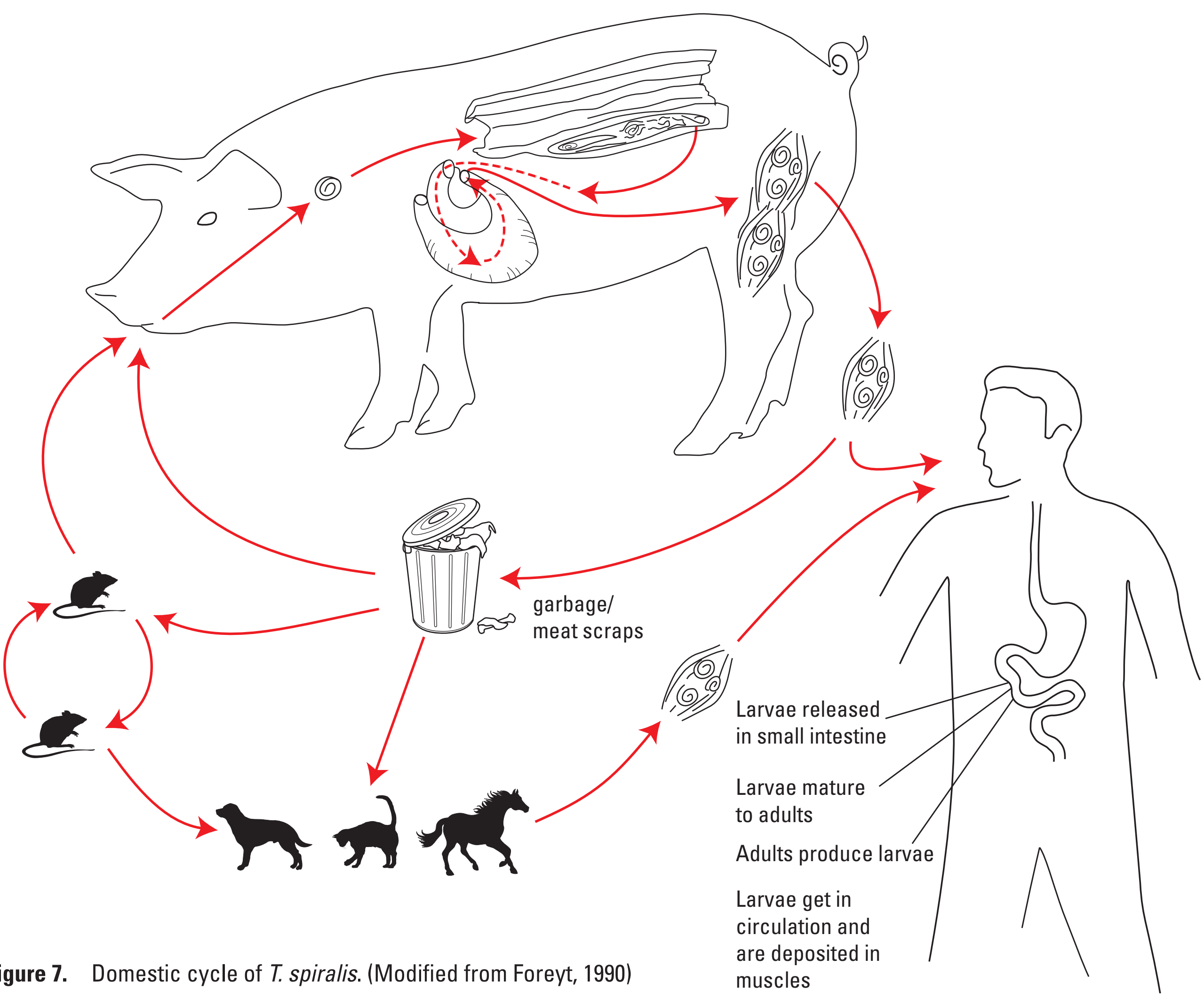


Figure 7. Domestic cycle of *T. spiralis*. (Modified from Foreyt, 1990)

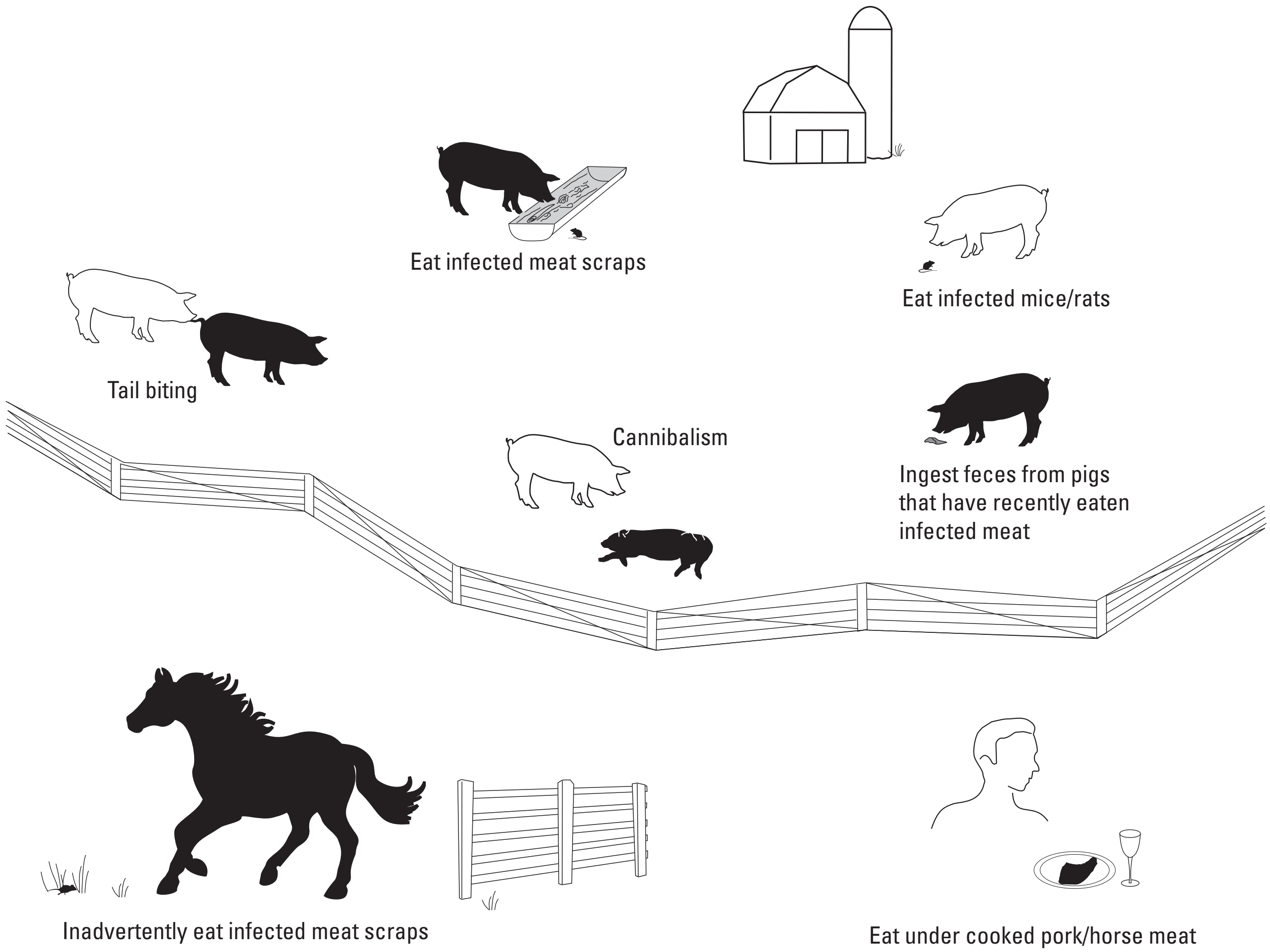


Figure 8. General domestic pathways for infection with *T. spiralis*.

and Alaska (Margolis and others 1979; Proulx and others, 2002); cougar in the United States (Dworkin and others, 1996); fox in Italy (Dupouy-Camet, 2000); sheep in China (Wang and others, 1998); warthog in Africa (Kefenie and Bero, 1992); and dog in China and Slovakia (Dubinsky and others, 1999). Most of these cases resulted from eating raw or improperly prepared meat or meat products, primarily sausage (Box 7). The severity of disease is usually directly related to the number of larvae eaten and the immune status of the host.

Although pigs are most often infected with *T. spiralis*, *T. britovi* has been diagnosed in pigs from some European countries, *T. nativa* from a pig in China, *T. pseudospiralis* from pigs in Russia, and *T. papuae* from pigs in southern New Guinea (Pozio and others, 1999; Dick and Pozio, 2001). Sylvatic species of *Trichinella* are of minor importance in pigs because they do not grow as well in pigs as in wildlife, the survival time of larvae in pigs is less than in wildlife, and the survival time of larvae in pork that has been exposed to cold or heat is limited. Therefore, the occurrence of sylvatic species of *Trichinella* in pigs is of limited importance compared with infections of *T. spiralis*.

Transmission cycles often vary with the species or isolate of *Trichinella*. In the Arctic and Subarctic, polar bear, brown bear, grizzly bear, Arctic fox, wolf, raccoon dog, seals, walrus, and other carnivores are commonly infected with *T. nativa*. The parasite is maintained through predation, cannibalism, and scavenging (fig. 11).

Characteristics of *T. nativa* are (1) a high resistance to freezing in muscles (Worley and others, 1990), (2) larvae surrounded by a thick capsule, and (3) low infectivity for domes-

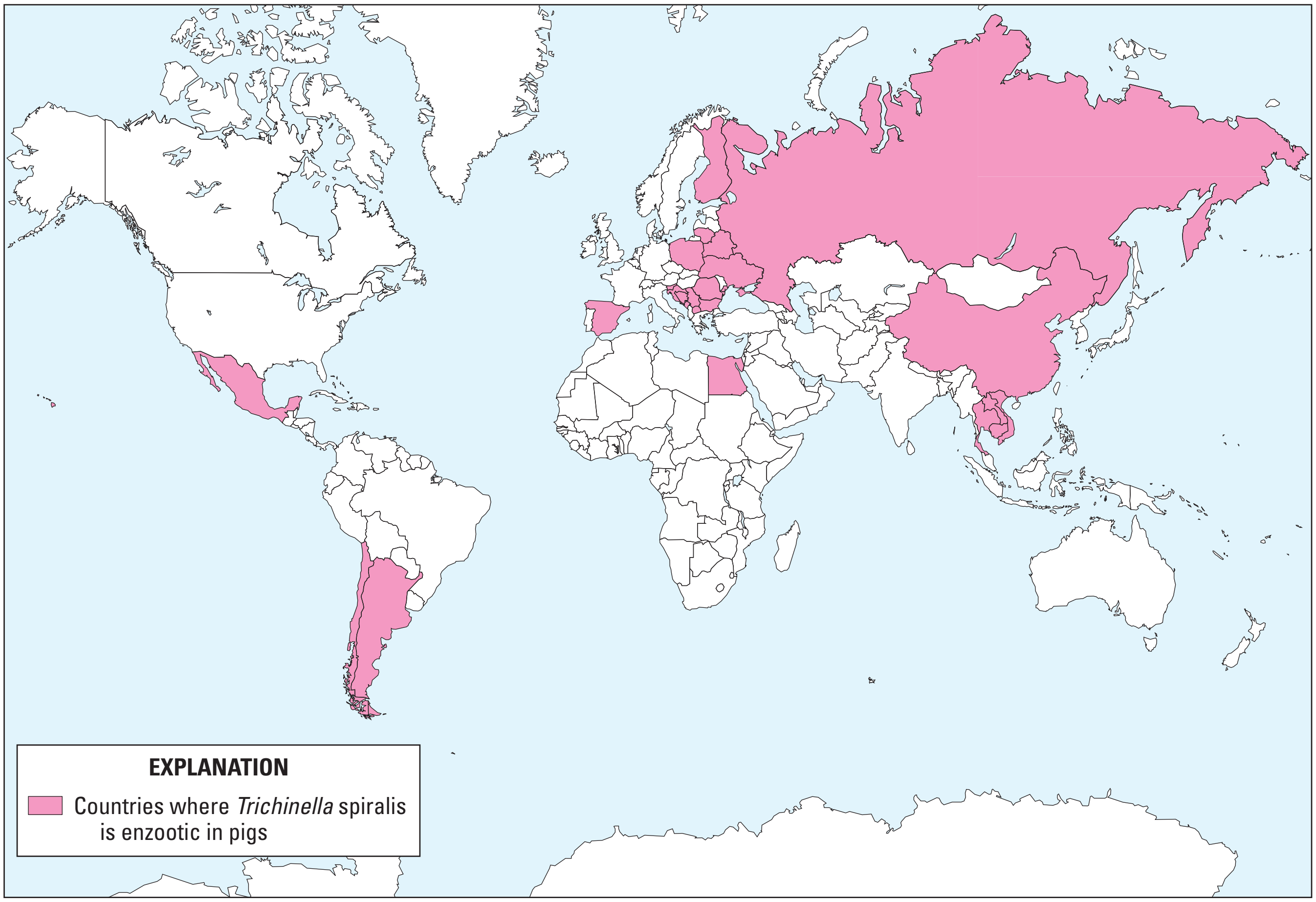


Figure 9. Countries where *T. spiralis* is enzootic in pigs. (Data from Dupouy-Camet, 2000; Ortega-Pierres and others, 2000; Dick and Pozio, 2001)

tic pigs and laboratory rats and mice. Larvae have survived in frozen meat for at least 3 years in naturally infected arctic wildlife (fig. 12) (Worley and others, 1986; Kapel and others, 1999; Dick and Pozio, 2001) and 5 years in experimentally infected raccoons (Dick and Pozio, 2001). In mice, pig, and wild boar, the freeze tolerance is not present. Survival rates for other species and genotypes in meat from laboratory animals and free-ranging wildlife have been published (Dick and Pozio, 2001).

Polar bears and Arctic foxes are the primary reservoirs for *T. nativa* in the Arctic. In polar bears, prevalence has been shown to increase with age (fig. 13) (Henriksen and others, 1994). The probable sources of infection in bears are ingestion of infected Arctic foxes and sled dogs. Prevalence of infection in Arctic foxes has been reported to range from 6 to 30 percent (table 6). Infected Arctic foxes in Greenland had an average of 38 larvae per gram of muscle (range 0.1 to 148) (Kapel and others, 1999). In Finland, European lynx are important hosts (table 6); the prevalence was correlated with the density of raccoon dogs that lynx utilize as food (Oksanen and others, 1998).

Trichinella nativa is a rare species in domestic swine because the adverse weather conditions and unfavorable habitat in which the parasite is most often found preclude most pig exposure to the parasite. Furthermore, larvae of *T. nativa* apparently do not persist in pigs (Kapel and others, 1998). In the more temperate regions of the world, *T. nativa* is present primarily in wild canids, the usual reservoir and source of infection.

Box 7 Diet Matters

Although trichinosis is most often associated with consumption of pork products, the infection can potentially be transmitted by any of the more than 150 species of animals known to be susceptible to infection, if people choose to eat these animals without proper safeguards and methods of preparation. Consumers who process their own meat can avoid infection by having it tested for *Trichinella* larvae before they eat it.

Cougar

In Idaho, a hunter killed a cougar and processed the meat for consumption (Centers for Disease Control and Prevention, 1996; Dworkin and others, 1996). After freezing the meat for 3 weeks, he made jerky by soaking it in a brine solution of table salt and then smoking it. He failed to use a commercial brine known to kill *Trichinella* larvae, and the smoker did not get hot enough to inactivate larvae. Eleven of 15 people who consumed the jerky were infected with *Trichinella*, strain T6. Although freezing normally kills *T. spiralis* larvae, T6 larvae are freeze-resistant and, thus, freezing was ineffective.

Bear

The consumption of bear meat has caused numerous outbreaks of trichinosis. In Canada, seven Chippewayan Indians were infected after eating boiled black bear meat (Emson and others, 1972). Four hunters in Alaska became infected after eating fried black bear meat cooked on a camp stove that did not reach high enough temperatures to kill the larvae (Alaska Division of Health and Social Services, 2000). Twenty-six people were infected with *T. nativa* in Canada after eating undercooked black bear meat even though the meat had been previously frozen; *T. nativa* larvae are freeze-resistant (McIntyre and others, 2007). Twelve people in Russia became infected after eating improperly cooked meat from an illegally killed bear that was not submitted for veterinary inspection (Despommier and Chen, 2004). Another outbreak in Russia involved 71 people who consumed smoked bear meat (Despommier and Chen, 2004).

Wild Boar

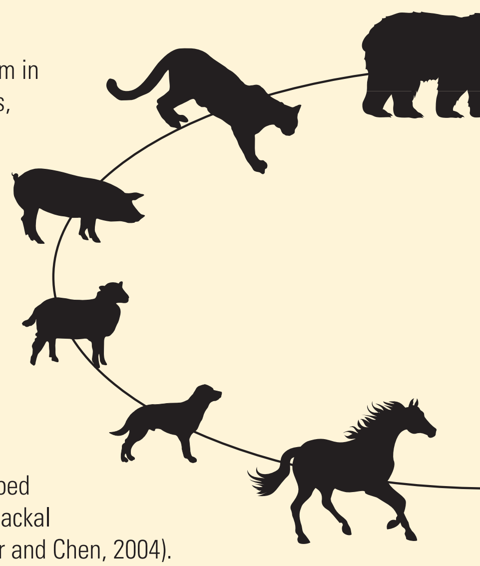
In Ethiopia, where there is a widespread tradition of eating raw meat, 20 soldiers who consumed uncooked wild boar meat became infected with *Trichinella* (Kefenie and Bero, 1992). In Europe, outbreaks of infection with *T. britovi* as a result of eating wild boar have occurred. Twenty-one people were infected in Spain after eating sausage made from wild boar killed on a private hunt, despite the boar's testing negative by trichinoscopy (Gallardo and others, 2007). Subsequent to the outbreak, the sausage tested positive by the artificial digestion method, which is more sensitive than trichinoscopy. In France, six people became infected after eating undercooked boar meat even though it had been previously frozen; *T. britovi* larvae are freeze-resistant (Gari-Toussaint and others, 2005). One person who ate the boar meat well-done did not become infected. *T. papuae* caused an outbreak of trichinosis in 28 people who ate raw wild boar meat in Thailand (Khumjui and others, 2008).

Warthog

Three French people developed trichinosis after eating warthog ham in Senegal (Dupouy-Camet and others, 2009). Three other people who also ate the ham were suspected of having trichinosis. The meat had been frozen before processing, suggesting infection by a freeze-resistant species, such as *T. britovi*.

Jackal

One person living in France developed trichinosis after eating barbecued jackal meat while in Algeria (Despommier and Chen, 2004).



Badger

In Russia, 25 people became infected with *Trichinella* after eating shish kebabs made from badger meat that was not thoroughly cooked (Despommier and Chen, 2004). Patients claimed badger meat to be tasty, exotic, and cheap.

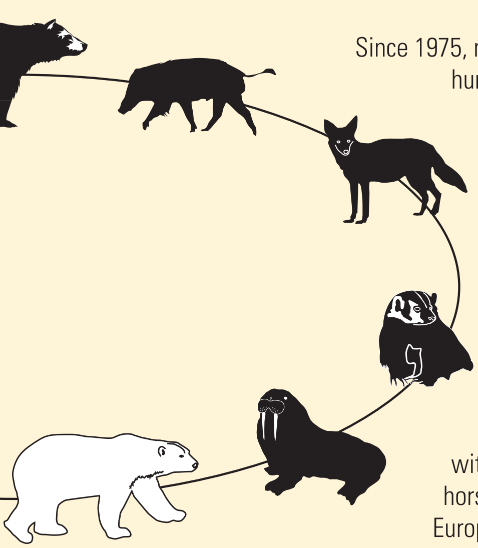
Walrus

Numerous cases of trichinosis have occurred in native Arctic peoples as a result of eating raw or undercooked walrus meat (*see* Box 6). Freezing of this meat is ineffective in killing the *T. nativa* larvae causing the infections.

Polar Bear

Subsistence hunters consuming raw or undercooked polar bear meat may become infected with *T. nativa*. It has been suggested that three Swedish explorers searching for the North Pole by balloon in 1897 died as a result of trichinosis. After crashing onto the ice, the explorers were forced to hunt and eat polar bears, which they ate partially cooked or raw. Their remains and diaries detailing their ordeal were found 30 years later. A polar bear carcass with *Trichinella* larvae was also found in their camp. In 1987, three people in Alaska developed trichinosis after mistakenly eating dried polar bear meat intended for dogs (Alaska Division of Health and Social Services, 1987)

Horse



Since 1975, most cases of trichinosis in humans in western Europe have been caused by eating horsemeat. From 1975 to 1998, there have been more than 10 outbreaks infecting more than 2800 people in France and Italy, where horsemeat is traditionally eaten fresh and raw (Ancelle and others, 1998). In 1975, 89 people in Italy and 125 people in France were infected in unrelated outbreaks with *Trichinella* as a result of eating horsemeat imported from Eastern Europe. Horses imported from North America have also caused outbreaks of trichinosis in France. As a result of the large numbers of people who have been infected, more stringent inspection methods have been implemented to protect consumers and the horsemeat industry in Europe.

Dog

Dog meat, infected with *T. britovi* and used in making smoked sausages, was associated with an outbreak among villagers at a folk festival in the Slovak Republic (Dubinsky and others, 1999). Five people in Russia developed trichinosis after eating dog meat (Despommier and Chen, 2004).

Sheep

In China in 1994, 10 people became infected after eating scalded mutton (Mao and others, 1995). The meat had not been inspected prior to consumption.

Pig

Consumption of pork products that are produced from home-slaughtered pigs not subject to veterinary inspection or from areas with high levels of infection put people at increased risk of becoming infected with *Trichinella.* Outbreaks in China have resulted from the consumption of uninspected meat in poorly cooked dumplings and scalded pork dishes (Wang and others, 1998). In Serbia, salami made from pork led to the infection of 40–80 people (Bannister and others, 2000). Some of this salami was brought back to London as gifts where it infected 8 more people.

Similar outbreaks have occurred as a result of people bringing infective pork products from countries with high rates of *Trichinella* infection in pigs into other countries (Pozio and Marucci, 2003). Three people from Germany visited Romania, where they consumed mince meat, sausage, and bacon made from home-slaughtered pigs; the source of trichinosis was confirmed in these people by testing the pork products brought back with them from Romania (Nöckler and others, 2007). Four people in Italy were infected with *Trichinella* after consuming ham from an uninspected pig from Romania (Angheben and others, 2008). Physicians treating patients in countries with low prevalence of swine trichinosis may be unfamiliar with diagnosing the infection in people; a history of consumption of imported pork products is an important clue in making the correct diagnosis of trichinosis.

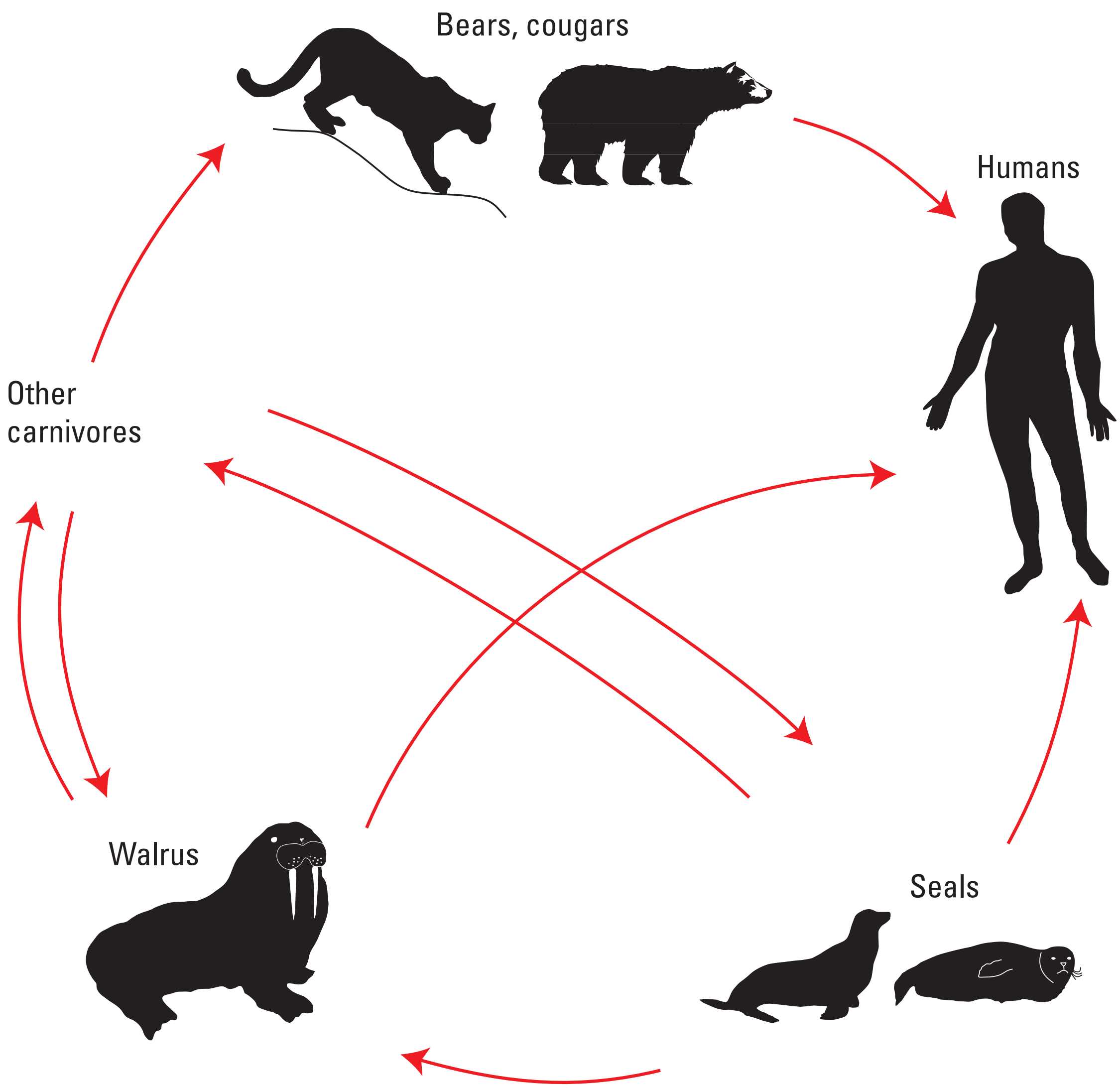


Figure 10. Sylvatic cycle of *Trichinella* spp.

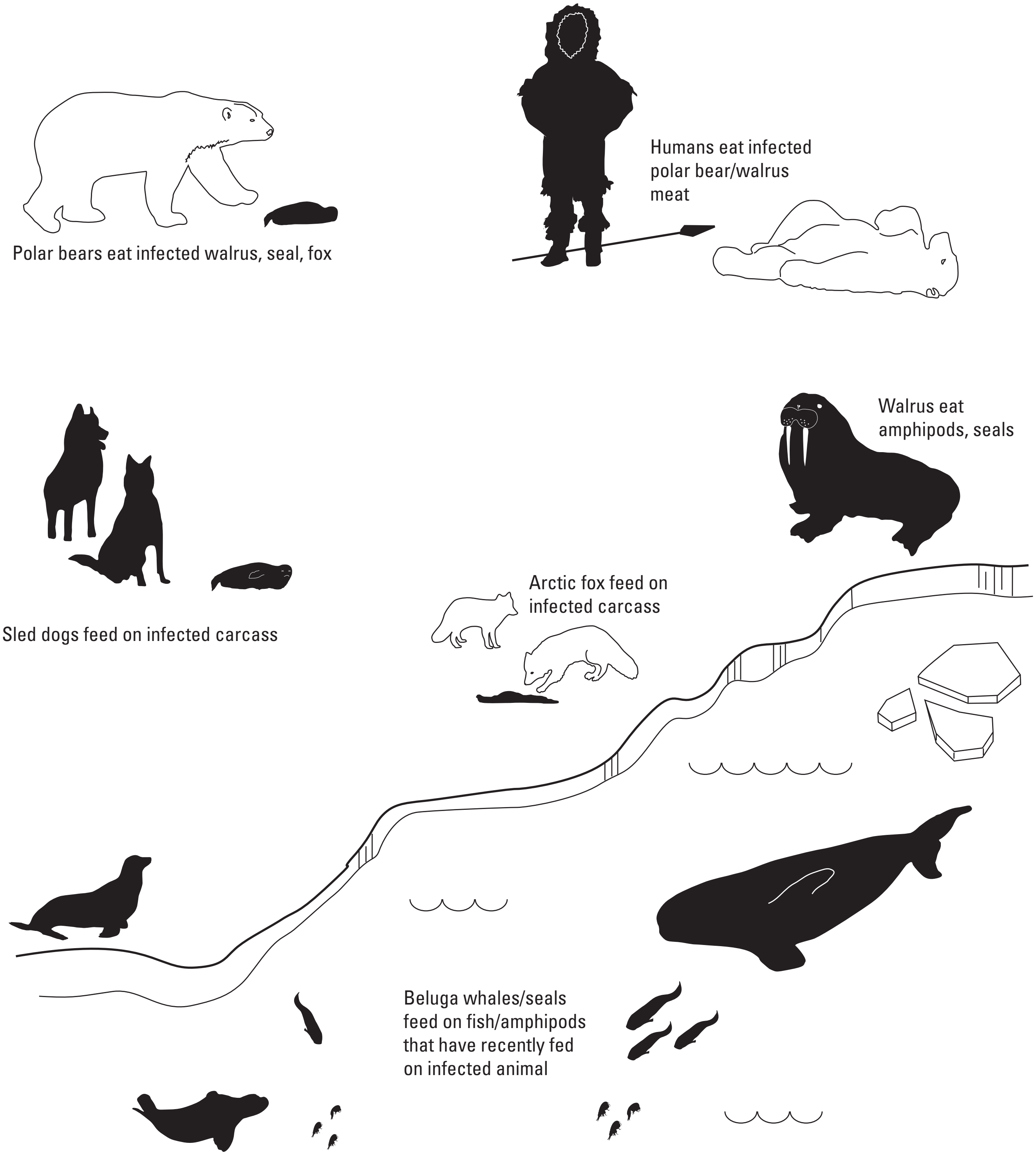


Figure 11. General pathways for infection of the arctic and subarctic cycles of *T. nativa*.

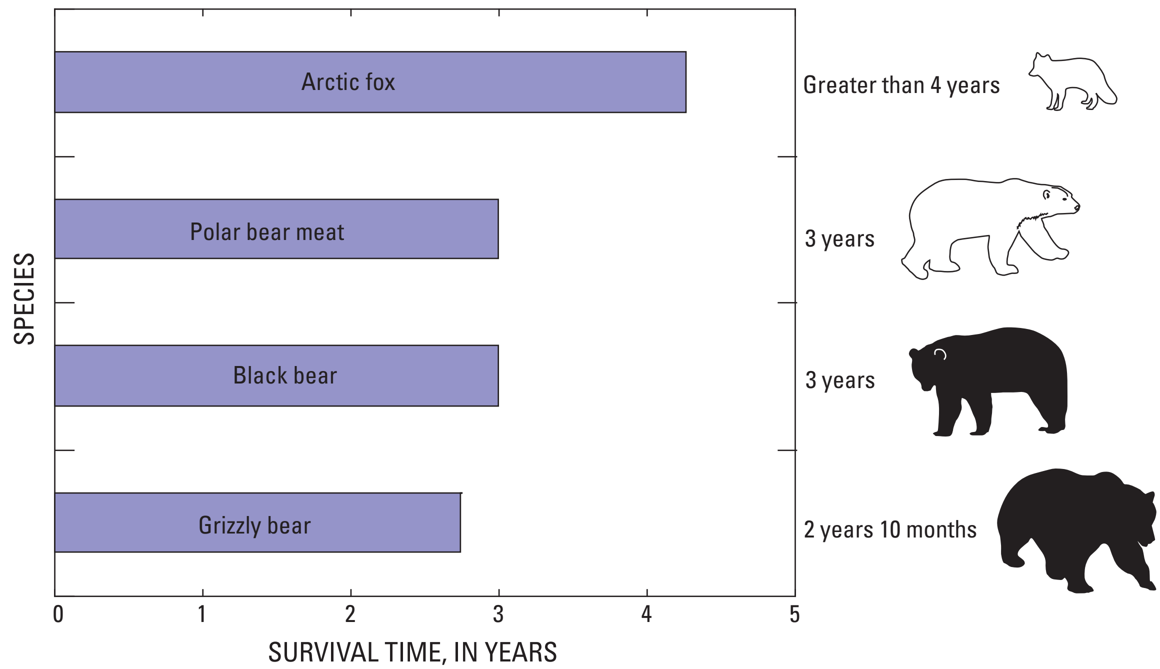


Figure 12. Examples of *T. nativa* larvae survival times in frozen tissue. (Data from Worley and others, 1986; Kapel and others, 1999; Dick and Pozio, 2001)

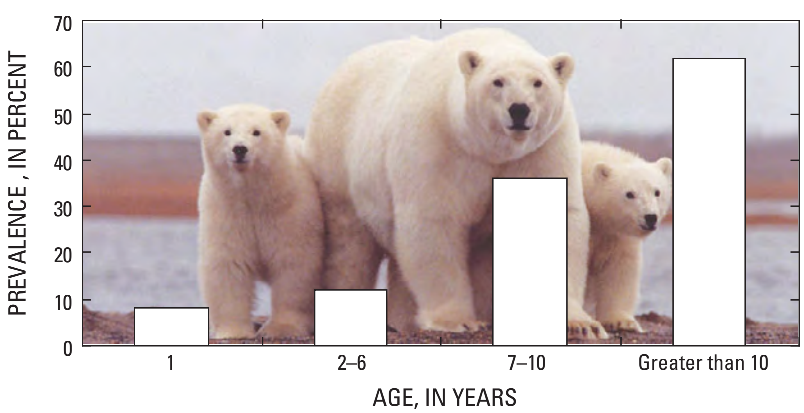


Figure 13. Increasing prevalence of *Trichinella* infection with age in polar bears. (Data from Henriksen and others, 1994)

Points to Ponder

Trichinosis is a food-borne zoonotic disease that is easily preventable in humans. Cooking all meat to an internal temperature of 71°C (160°F) will kill all larvae and prevent transmission. Freezing meat in areas where freeze-resistant *Trichinella* species are not present will also prevent transmission. International travelers who eat improperly cooked meat (McAuley and others, 1991) and people who have dietary preferences for raw or lightly cooked meats significantly increase their risk for infection. Improperly cooked wild game will continue to be a source of infection for hunters and others who eat wildlife, but with adequate cooking, human infection can be prevented.

However, the epidemiology of the disease has changed significantly during the last 10 years, and trichinosis is now an emerging disease in many countries, especially in Eastern Europe. As world tourism increases and food transport services are improved, the probability of contact between humans and infected meat increases dramatically. In countries where veterinary inspection, responsible farm management, and adequate quality-controlled diagnostic methods are practiced, *Trichinella* has almost been eliminated from pigs. In many less-developed countries, the prevalence of *Trichinella* infections has increased because of an increase in the number of small farms. In several countries, the increase in the number of small farms with limited numbers of animals has resulted in increased farm animal contact with rodents and other reservoir hosts of *Trichinella*, increased feeding of food scraps to farm animals, and lack of post-mortem inspection of meat.

Wildlife management is also becoming more important in the maintenance and transmission of *Trichinella* spp. When land use and management favor an increase in wild pig and wild carnivore populations, an increase in infection rate in those animals is likely to result. Although this would have no overt effect on population dynamics or the health of infected wildlife, the potential for disease transmission to humans is likely to increase accordingly. The use of wildlife carcasses by hunters and trappers as bait for harvesting other animals has also been shown to be important in transmission among wildlife species (Dick and others, 1986). For example, *T. spiralis* recently found in a black bear from Arizona, in the United States, likely resulted from hunters who attracted the bear with raw meat trimmings from supermarkets and restaurants (Pozio, Pence, and others, 2001).

Disease Prevention and Control

Prevention and control of trichinosis is a matter of education and hygiene in the environment and in the home. The transmission of trichinosis to garbage-fed pigs can be prevented by cooking the garbage to an internal temperature of 71°C (160°F) for 1 minute, thus inactivating *Trichinella* larvae and eliminating the possibility of transmission (Pozio, 2001). Cooking all meat to 71°C (160°F) (Gadjahar and Gamble, 2000) will kill larvae and prevent human infection; however it is more effective for producers, meat suppliers, and health agencies to ensure that infected meat does not reach the consumer. Good management practices to prevent or minimize infection in pigs include biosecurity, rodent control, and avoidance of feeding waste (van Knapen, 2000). A complete set of recommendations on methods for the control of *Trichinella* in domestic and wild animals intended for human use has been published as the official position of the International Commission on Trichinellosis (Gamble and others, 2000). The recommendations include:

- Slaughter testing methods to prevent clinical infection in humans. For detection of larvae in pigs, pepsin-hydrochloric acid digestion of at least 1 gram of muscle, or microscopic evaluation of at least 0.5 grams of muscle, is a minimum requirement for each carcass. For detection of larvae in horses and wildlife, a greater mass from preferred muscles is recommended by the International Commission on Trichinellosis for testing.

- Cooking the meat. If the meat has not been evaluated for larvae, then cooking to a proper temperature for a specific time will kill larvae. The time of cooking is dependent on the internal temperature of the meat (Gamble and others, 2000), but a standard recommendation is to cook to a minimum internal temperature of 71°C (160°F). Lower temperatures over time are generally also acceptable (table 8). A change in the

Table 8. Minimum internal cold temperatures and times necessary to kill *T. spiralis* larvae in pork.

[From Gamble and others, 2000. °F, degrees Fahrenheit; °C, degrees Celsius]

Minimum internal temperature		Minimum time
°F	°C	
0	-17.8	106 hours
-5	-20.6	82 hours
-10	-23.3	63 hours
-15	-26.1	48 hours
-20	-28.9	35 hours
-25	-31.7	22 hours
-30	-34.5	8 hours
-35	-37.2	30 minutes

color of the meat from pink to grey throughout and a change in texture such that the muscle fibers are easily separated from each other are indicators that the meat is safe to eat. Microwave cooking is not recommended by the International Commission on Trichinellosis because of uneven heating.

- Freezing the meat. For pork and horse meat with *T. spiralis* larvae, freezing at -15°C (5°F) or lower for a minimum of 4 weeks is recommended by the International Commission on Trichinellosis for consumer safety (Gamble and others, 2000). For wildlife meat, freezing is not recommended because wildlife often contains freeze-resistant *Trichinella* species, which survive freezing for long periods. Therefore, proper cooking of wildlife meat is recommended.

- **Irradiation**. At levels that have been shown to inactivate larvae (0.3 kilogray), irradiation is an acceptable method for rendering meat safe for human consumption for sealed packaged food in countries were irradiation methodology is allowed.

- Curing, drying, and smoking. Curing, drying, and smoking processes are not recommended by the International Commission on Trichinellosis for control of *Trichinella* in meat because of the variability in the salt concentrations, temperatures used, and drying times. Only meat that has been found to be free of larvae should be used for curing, drying, and smoking.

Theoretically, the disease in humans can be prevented through education, by cooking or freezing all pork, by cooking all other meats, and by effective veterinary surveillance programs. With modern farm management practices and veterinary surveillance, the disease could be eliminated from domestic pigs.

Treatment

Most infections in animals and humans are undetected because of limited signs and symptoms, and mild infections are often misdiagnosed as influenza or other medical conditions. In humans, clinical trichinosis is often treated on a symptomatic basis with **corticosteroids**. Resolution of symptoms is generally the result of corticosteroid treatment rather than **anthelminthic** treatment, suggesting that the symptoms associated with trichinosis are primarily **inflammatory** and **allergic reactions** to the larvae. However, corticosteroid treatment may also increase the intensity of muscle invasion and may lead to an increased number of larvae in muscles.

Anthelmintic drugs that have been used to treat infected humans are generally benzimidazole derivatives, such as albendazole, fenbendazole, flubendazole, and mebendazole (Kociecka, 2000). Pyrantel has also been used to treat infected humans. These drugs are often effective against adult worms and early migrating larval stages, but they are generally ineffective against larvae once they are encapsulated in muscle nurse cells. Therefore, the goal is to treat within the first 3 days after infection to kill the adult worms and prevent subsequent muscular invasion of larvae and development of clinical disease. Encapsulated larvae will live several years in muscles until the nurse cell induces the progressive **calcification** of the larvae. In severe human infections, complications of the **respiratory**, **cardiovascular**, and **neurological systems** can occur between 3 and 8 weeks after infection. Severe infections in humans can be life threatening, and intensive supportive therapy, including hospitalization and administration of fluids to compensate for water and **electrolyte** deficits, is mandated.

References Cited

Alaska Division of Health and Social Services, 1987, Trichinosis from dried polar bear meat: State of Alaska Epidemiology Bulletin, v. 17, accessed July 16, 2008, at *http://www.epi.hss.state.ak.us/bulletins/docs/b1987_17.htm*.

Alaska Division of Health and Social Services, 2000, Five cases of trichinosis—Why bear meat must be thoroughly cooked: State of Alaska Epidemiology Bulletin, v. 18, accessed July 16, 2008, at *http://www.epi.hss.state.ak.us/bulletins/docs/b2000_18.htm*

American Public Works Association and U.S. Public Health Service Joint Committee, 1953, Refuse collection and disposal for the small community: Washington, D.C., U.S. Public Health Service, 39 p.

Ancelle, T., 1998, History of trichinellosis outbreaks linked to horse meat consumption 1975–1998: Eurosurveillance, v. 3, no. 8, accessed July 14, 2008, *http://www.eurosurveillance.org/ViewArticle.aspx?ArticleId=120.*

Ancelle, T., De Bruyne, A.E., Poisson, D., and Dupouy-Camet, J., 2005, Outbreak of trichinellosis due to consumption of bear meat from Canada, France, September 2005: Eurosurveillance, v. 10, accessed July 14, 2008, *http://www.eurosurveillance.org/ViewArticle.aspx?ArticleId=2809*.

Anderson, R.C., 1992, Nematode parasites of vertebrates: Their development and transmission: Wallingford, United Kingdom, CAB International, p. 552–554.

Angheben, A., Mascarello, M., Zavarise, G., Gobbi, F., Monteiro, G., Marocco, S., Anselmi, M., Azzini, A., Concia, E., Rossanese, A., and Bisoffi, Z., 2008, Outbreak of imported trichinellosis in Verona, Italy, January 2008: Eurosurveillance, v. 13, no. 22, accessed July 18, 2008, at *http://www.eurosurveillance.org/ViewArticle.aspx?ArticleId=18891.*

Appleyard, G., and Gajadhar, A., 2000, A review of trichinellosis in people and wildlife in Canada: Canadian Journal of Public Health, v. 91, p. 293–297.

Bandi, C., La Rosa, G., Bardin, M.G., Damiani, G., Comincini, S., Tasciotti, L., and Pozio, E., 1995, Random amplified polymorphic DNA fingerprints of the eight taxa of *Trichinella* and their comparison with allozyme analysis: Parasitology, v. 110, p. 401–407.

Bannister, B., Bhagani, S., Burn, M., Milne, L., 2000, Outbreak of trichinellosis in south east England: Eurosurveillance, v. 4, no. 2, accessed July 18, 2008, at *http://www.eurosurveillance.org/ViewArticle.aspx?ArticleId=1676.*

Boireau, P., Vallee, I., Roman, T., Perret, C., Mingyuan, L., Gamble, H.R., and Gajadhar, A., 2000, *Trichinella* in horses: A low frequency infection with high human risk: Veterinary Parasitology, v. 93, p. 309–320.

Bolpe, J., and Bofi, R., 2001, Causitry of human trichinellosis in Argentina registered from 1990–1999: Parasite, v. 8 (supp.), p. S78–S80.

Born, E.W., and Henriksen, S.A., 1990, Prevalence of *Trichinella* sp. in polar bears (*Ursus maritimus*) from northeastern Greenland: Polar Research, v. 8, p. 313–316.

Brandly, P.J., and Rausch, R., 1950, A preliminary note on trichinosis investigations in Alaska: Arctic, v. 3, p. 105–107.

Butler, C.E., and Khan, R.A., 1992, Prevalence of *Trichinella spiralis* in black bears (*Ursus americanus*) from Newfoundland and Labrador, Canada: Journal of Wildlife Diseases, v. 28, p. 474–475.

Campbell, W.C., 1983a, Historical introduction, *in* Campbell, W.C., ed., *Trichinella* and trichinosis: New York, Plenum Press, p. 1–30.

Campbell, W.C., 1983b, Epidemiology I: Modes of transmission, *in* Campbell, W.C., ed., *Trichinella* and trichinosis: New York, Plenum Press, p. 425–444.

Capó, V., and Despommier, D.D., 1996, Clinical aspects of infection with *Trichinella* spp.: Clinical Microbiology Reviews, v. 9, p. 47–54.

Centers for Disease Control and Prevention, 1994, Summary of notifiable diseases, United States, 1994: Morbidity and Mortality Weekly Report, v. 42, p. 1–73.

Centers for Disease Control and Prevention, 1996, Outbreak of trichinellosis associated with eating cougar jerky—Idaho, 1995: Morbidity and Mortality Weekly Report, v. 45, p. 205–206.

Centers for Disease Control and Prevention, 2004, Trichinellosis associated with bear meat—New York and Tennessee, 2003: Morbidity and Mortality Weekly Report, v. 53, p. 606–610.

Centers for Disease Control and Prevention, 2007, Summary of notifiable diseases, United States, 2007: Morbidity and Mortality Weekly Report, v. 56, p. 1-94.

Centers for Disease Control and Prevention, 2009, Trichinellosis surveillance, United States, 2002–2007: Morbidity and Mortality Weekly Report, v. 58, p. 1–9.

Cui, J., and Wang, Z.Q., 2001, Outbreaks of human trichinellosis caused by consumption of dog meat in China: Parasite, v. 8 (supp. S), p. S74–S77.

Cuperlovic, K., Djordjevic, M., Pavlovic, S., and Sofronic-Milosavljevic, L., 2001, Present status of trichinellosis in Yugoslavia-Serbia: Parasite, v. 8, p. S95–S97.

Dame, J.B., Murrell, K.D., Worley, D.E., and Schad, G.A., 1987, *Trichinella spiralis*: Genetic evidence for synanthropic subspecies in sylvatic hosts: Experimental Parasitology, v. 64, p. 195–203.

Davies, L.E.C., and Cameron, T.W.N., 1961, Trichinosis in the Northwest territories: Medical Services Journal of Canada, v. 17, p. 99–104.

Despommier, D.D., 1990, *Trichinella spiralis*: The worm that would be virus: Parasitology Today, v. 6, p. 193–196.

Despommier, D., and Chen, S.X., 2004, The *trichinella* page: New York, Columbia University, Malman School of Public Health, accessed June 10, 2008, at *http://www.trichinella.org.*

Dick, T.A., Kingscote, B., Strickland, M.A., and Douglas, C.E., 1986, Sylvatic trichinosis in Ontario, Canada: Journal of Wildlife Diseases, v. 22, p. 42–47.

Dick, T.A., and Pozio, E., 2001, *Trichinella* spp. and trichinellosis, *in* Samuel, W.M., Pybus, M.J., and Kocan, A.A., eds., Parasitic diseases of wild mammals: Ames, Iowa State University Press, p. 380–396.

Dubinsky, P., Kinecekova, J., Tomasovicova, O., Reiterova, K., Ondriska, F., and Budajova, D., 1999, *Trichinella britovi*: Outbreak in the Slovak Republic: Helminthologia, v. 36, p. 45.

Dupouy-Camet, J., 2000, Trichinellosis: A worldwide zoonosis: Veterinary Parasitology, v. 93, p. 191–200.

Dupouy-Camet, J., Lecam, S., Talabani, H., and Ancelle, T., 2009, Trichinellosis acquired in Senegal from warthog ham, March 2009: Eurosurveillance, v. 14, no. 21, accessed March 23, 2010, at *http://www.eurosurveillance.org/ViewArticle.aspx?ArticleId=19220.*

Dworkin, M.S., Gamble, H.R., Zarlenga, D.S., and Tennican, P.O., 1996, Outbreak of trichinellosis associated with eating cougar jerky: The Journal of Infectious Diseases, v. 174, p. 663–666.

Emson, H., Baltzan, M., and Wiens, H., 1972, Trichinosis in Saskatchewan: An outbreak due to infected bear meat: Canadian Medical Association Journal, v. 106, p. 897–898.

Fay, F.H., 1960, Carnivorous walrus and some arctic zoonoses: Arctic, v. 13, p. 111–122.

Feldmeier, H., Biensle, U., Jansen-Rosseck, R., Kremsner, P.G., Wieland, H., Dobos, G., Schroeder, S., Fengler-Dopp, D., and Peter, H.H., 1991, Sequelae after infection with *Trichinella spiralis*: A prospective cohort study: *Wiener Klinische Wochenschrift*, v. 103, p. 111–116.

Forbes, L.B., 2000, The occurrence and ecology of *Trichinella* in marine mammals: Veterinary Parasitology, v. 93, p. 321–334.

Foreyt, W.J., 1990, Veterinary parasitology reference manual: Pullman, Washington State University Press, p. 136.

Foreyt, W.J., High, W.A., and Green, R.L., 1999, Search for *Prouterina wescotti* in black bears in Oregon: Journal of Wildlife Diseases, v. 35, p. 622–623.

Foster, W. D., 1965, A history of parasitology: Edinburgh, United Kingdom, Livingstone, p.68–79.

Gajadhar, A.A., and Gamble, H.R., 2000, Historical perspectives and current global challenges of *Trichinella* and trichinellosis: Veterinary Parasitology, v. 93, p. 183–189.

Gallardo, M.T., Mateos, L., Artieda, J., Wesslen, L., Ruiz, C., Garcia, M.A., Galmés-Truyois, A., Martin, A., Hernández Pezzi, G., Andersson, Y., Gárate, T., and Christensson, D., 2007, Outbreak of trichinellosis in Spain and Sweden due to consumption of wild boar meat contaminated with *Trichinella britovi*: Eurosurveillance, v. 12, no. 11, accessed July 16, 2008, at *http://www.eurosurveillance.org/ViewArticle.aspx?ArticleId=3154.*

Gamble, H.R, Bessonov, A.S., Cuperlovic, K., Gajadhar, A.A., van Knapen, F., Noeckler, K., Schenone, H., and Zhu, X., 2000, International commission on trichinellosis: Recommendations on methods for the control of *Trichinella* in domestic and wild animals intended for human consumption: Veterinary Parasitology, v. 93, p. 393–408.

Gamble, H.R., and Bush, E., Seroprevalence of *Trichinella* infection in domestic swine based on the National Animal Health Monitoring System's 1990 and 1995 swine surveys: Veterinary Parasitology, v. 80, p. 303–310.

Gari-Toussaint, M., Tieulié, N., Baldin, J.L., Dupouy-Camet, J., Delaunay, P., Fuzibet, J.G., Le Fichoux, Y., Pozio, E., Marty, P., 2005, Human trichinellosis due to *Trichinella britovi* in southern France after consumption of frozen wild boar meat: Eurosurveillance, v. 10, no. 6, accessed July 16, 2008, at *http://www.eurosurveillance.org/ViewArticle.aspx?ArticleId=550.*

Gottstein, B., Pozio, E., and Nöckler, K., 2009, Epidemiology, diagnosis, treatment, and control of trichinellosis: Clinical Microbiology Reviews, v. 22, p. 127–145.

Gould, S.E., 1970, History, *in* Gould S.E., ed., Trichinosis in man and animals: Springfield, Ill., Charles C. Thomas, p. 3–46.

Gould, S.E., 1983, Symptomatology, *in* Campbell, W.C., ed., *Trichinella* and trichinosis: New York, Plenum Press, p. 269–306.

Harms, G., Binz, P., Feldmeier, H., Zwingenberger, K., Scheehauf, D., Dewes, W., Kress-Hermesdorf, I., Klindworth, C., and Bienzle, U., 1993, Trichinosis: A prospective controlled study of patients 10 years after acute infection: Clinical Infectious Diseases, v. 17, p. 637–643.

Henriksen, S.A., Born, E.W., and Eiersted, L., 1994, Infections with *Trichinella* in polar bears (*Ursus maritimus*) in Greenland: Prevalence according to age and sex, *in* Campbell, W.C., Pozio, E., and Bruschi, F., eds., Trichinellosis—Proceedings of the 8th International Conference on Trichinellosis: Rome, Innstito Superiore di Sanita Press, p. 565–568.

International Trichinella Reference Center, *Trichinella* systematics and distribution, accessed February 12, 2010, at *http://www.iss.it/site/trichinella/scripts/sydi.asp?lang=2*.

Jongwutiwes, S., Chantachum, N., Kraivichian, P., Siriyasatien, P., Putaporntip, C., Tamburrini, A., La Rosa, G., Sreesunpasirikul, C., Yingyourd, P., and Pozio, E., 1998, First outbreak of human trichinellosis caused by *Trichinella pseudospiralis*: Clinical Infectious Diseases, v. 26, p. 111–115.

Kapel, C.M.O., 2000, Host diversity and biological characteristics of the *Trichinella* genotypes and their effect on transmission: Veterinary Parasitology, v. 93, p. 263–278.

Kapel, C.M.O., Henriksen, S.A., Berg, T.B., and Nansen, P., 1996, Epidemiologic and zoogeographic studies on *Trichinella nativa* in arctic fox, *Alopex lagopus*, in Greenland: Journal of the Helminthological Society of Washington, v. 63, p. 226–232.

Kapel, C.M.O., Pozio, E., Sacchi, L., and Prestrud, P., 1999, Freeze tolerance, morphology, +RAPD-PCR identification of *Trichinella nativa*-infected arctic foxes: The Journal of Parasitology, v. 85, p. 144–147.

Kapel, C.M.O., Webster, P., Lind, P., Pozio, E., Henriksen, S.A., Murrell, K.D., and Nansen, P., 1998, *Trichinella spiralis, Trichinella britovi,* and *Trichinella nativa*: Infectivity, muscle larvae distribution and antibody response after experimental infection of pigs: Parasitology Research, v. 84, p. 264–271.

Kefenie, H., and Bero, G., 1992, Trichinosis from wild boarmeat in Gojjam, Northwest Ethiopia: Tropical and Geographical Medicine, v. 44, p. 278–280.

Khumjui, C., Choomkasien, P., Dekumyoy, P., Kusolsuk, T., Kongkaew, W., Chalamaat, M., and Jones, J.L., 2008, Outbreak of trichinellosis caused by *Trichinella papuae*, Thailand, 2006: Emerging Infectious Diseases, v. 14, p. 1913–1915.

Kim, C.W., 1983, Geographic distribution and prevalence, *in* Campbell, W.C., ed., *Trichinella* and trichinosis: New York, Plenum Press, p. 445–500.

Kociecka, W., 2000, Trichinellosis: Human disease, diagnosis and treatment: Veterinary Parasitology, v. 93, p. 365–383.

La Rosa, G., Pozio, E., Rossi, P., and Murrell, K.D., 1992, Allozyme analysis of *Trichinella* isolates from various host species and geographic regions: The Journal of Parasitology, v. 78, p. 641–646.

Larsen, J.N., ed., 2004, Arctic Human Development Report, 2004: Akureyri, Iceland, Stefansson Arctic Institute, 242 p., accessed June 6, 2008, at *http://www.svs.is/AHDR/AHDR%20chapters/English%20version/Chapters%20PDF.htm*.

Larsen, T., and Kjos-Hanssen, B., 1983, *Trichinella* sp. in polar bears from Svalbard, in relation to hide length and age: Polar Research, v. 1, p. 89–96.

Ljungström, I., Murrell, D., Pozio, E., and Wakelin, D., 1998, Trichinellosis, *in* Palmer, S.R., Soulsby, L., and Simpson, D.I.H., eds., Zoonoses: Biology, clinical practice, and public health control: New York, Oxford University Press, p. 789–802.

Lo, Y.-C., Hung, C.-C., Lai, C.-S., Wu, Z., Nagano, I., Maeda, T., Takahashi,Y., Chiu, C.-H., and Jiang, D.D.-S., 2009, Human trichinosis after consumption of soft-shelled turtles, Taiwan: Emerging Infectious Diseases, v. 15, p. 2056–2058.

MacLean, J.D., Poirier, L., Gyorkos, T.W., Proulx, J.F., Bourgeault, J., Corriveau, A., Illisituk, S., and Staudt, M., 1992, Epidemiologic and serologic definition of primary and secondary trichinosis in the Arctic: The Journal of Infectious Diseases, v. 165, p. 908–912.

MacLean, J.D., Viallet, J., Law, C., and Staudt, M., 1989, Trichinosis in the Canadian Arctic: Report of five outbreaks and a new clinical syndrome: The Journal of Infectious Diseases, v. 160, p. 513–520.

Madsen, H., 1961, The distribution of *Trichinella spiralis* in sledge dogs and wild mammals in Greenland under a global aspect: Meddelelser on Grønland, v. 159, no. 7, p. 124.

Mao, F., Wang, Z., Cui, J., Wu, F., and Jin, X., 1995, Studies of an outbreak of trichinosis caused by the intake of scalded mutton: Journal of Henan Medical University, v. 30, p. 292–293.

Margolis, H.S., Middaugh, J.P., and Burgess, R.D., 1979, Arctic trichinellosis: Two Alaska outbreaks from walrus meat: Journal of Infectious Diseases, v. 139, p. 102–105.

McAuley, J.B., Michelson, M.K., and Schantz, P.M., 1991, *Trichinella* infection in travelers: Journal of Infectious Diseases, v. 164, p. 1013–1016.

McIntyre, L., Pollock, S., Fyfe, M., Gajadhar, A., Isaac-Renton, J., Fung, J., Morshed, M., 2007, Trichinellosis from consumption of wild game meat: Canadian Medical Association Journal, v. 176, p. 449–451.

Mitreva, M., and Jasmer, D.P., 2006, Biology and genome of *Trichinella spiralis*: WormBook, Nov. 23, 2006, p. 1–21, accessed July 21, 2008, at *http://www.wormbook.org/chapters/www_genomesTrichinella/genomesTrichinella.html.*

Moorhead, A., Grunenwald, P.E., Dietz, V.J., Schantz, P.M., 1999, Trichinellosis in the United States, 1991–1996: Declining but not gone: American Journal of Tropical Medicine and Hygiene, v. 60, p. 66–69.

Moretti, A., Piergili Fioretti, D., Pasquali, P., Mechelli, L., Rossidivita, M.E., and Polidoro, G.A., 1997, Experimental infection of fish with *Trichinella britovi*: Biological evaluations, *in* Ortega Pierres, G., Gamble, R., van Knapen, R., and Wakelin, D., eds., Trichinellosis: Mexico, Centro de Investigacion y Estudios Avanzados del Instituto Politecinco Nacional, p. 135–142.

Mukaratirwa, S., and Foggin, C.M., 1999, Infectivity of *Trichinella* sp. isolated from *Crocodylus niloticus* to the indigenous Zimbabwean pig: International Journal for Parasitology, v. 29, p. 1129–1131.

Murrell, K.D., 1994, Beef as a source of trichinellosis: Parasitology Today, v. 10, p. 434.

Murrell, K.D., 2000, Trichinellosis: Now and forevermore: Parasite, v. 8, p. S11–S13.

Murrell, K.D., Djordjevic, M., Cuperlovic, K., Sofronic, Lj., Savic, M., Djordjevic, M., and Damjanovic, S., 2004, Epidemiology of *Trichinella* infection in the horse: The risk from animal product feeding practices: Veterinary Parasitology, v. 123, p. 223–233.

Murrell, K.D., Lichtenfels, R.J., Zarlenga, D.S., and Pozio, E., 2000, The systematics of the genus *Trichinella* with a key to species: Veterinary Parasitology, v. 93, p. 293–307.

Murrell, K.D., and Pozio, E., 2000, Trichinellosis: The zoonosis that won't go quietly: International Journal for Parasitology, v. 30, p. 1339–1349.

Murrell, K.D., Stringfellow, F., Dame, J.B., Leiby, D.A., Duffy, C., and Schad, G.A., 1987, *Trichinella spiralis* in an agricultural ecosystem. II. Evidence for natural transmission of *Trichinella spiralis* from domestic swine to wildlife: The Journal of Parasitology, v. 73, p. 103–109.

Nöckler, K., Pozio, E., Voigt, W.P., and Heidrich, J., 2000, Detection of *Trichinella* infection in food animals: Veterinary Parasitology, v. 93, p. 335–350.

Nöckler, K., Wichmann-Schauer, H., Hiller, P., Müller, A., and Bogner, K., 2007, Trichinellosis outbreak in Bavaria caused by cured sausage from Romania, January 2007: Eurosurveillance, v. 12, no. 34, accessed July 16, 2008, at *http://www.eurosurveillance.org/ViewArticle.aspz?ArticleId=3254.*

Nutter, F.B., Levine, J.F., Stoskopf, M.K., Gamble, H.R., and Dubey, J.P., 1998, Seroprevalence of *Toxoplasma gondii* and *Trichinella spiralis* in North Carolina black bears (*Ursus americanus*): Journal of Parasitology, v. 84, p. 1048–1050.

Oksanen, A., Lindgren, E., and Tunkkari, P., 1998, Epidemiology of trichinellosis in lynx in Finland: Journal of Helminthology, v. 72, p. 47–53.

Olteanu, G.H., 1997, New studies on epidemiology and control of trichinellosis in Romania, *in* Ortega-Pierres, M.G., Gamble, H.R., Van Knapen, F., and Wakelin, D., eds., Trichinellosis: Mexico, Centro de Investigacion y Estudios Avanzados del Instituto Politecnico Nacional, p. 517–531.

Ortega-Pierres, M.G., Arriaga, C., and Yepez-Mulia, L., 2000, Epidemiology of trichinellosis in Mexico, Central and South America: Veterinary Parasitology, v. 93, p. 201–225.

Owen, R., 1835, Description of a microscopic entozoon infesting the muscles of the human body: Transactions of the Zoological Society of London, v. 1, p. 315–323.

Parkinson, A.J., 2008, The international polar year, 2007–2008, an opportunity to focus on infectious diseases in Arctic regions: Emerging Infectious Diseases, v. 14, p. 1–3.

Pawlowski, Z.S., 1983, Clinical aspects in man, *in* Campbell, W.C., ed., *Trichinella* and trichinosis, New York, Plenum Press, p. 367–402.

Polley, L., Gaschler, C., and Gajadhar, A., 2000, National occurrence reporting of *Trichinella* and trichinellosis using a computerized database: Veterinary Parasitology, v. 93, p. 351–363.

Pozio, E., 2000a, Factors affecting the flow among domestic synanthropic and sylvatic cycles of *Trichinella*: Veterinary Parasitology, v. 93, p. 241–262.

Pozio, E., 2000b, Is horsemeat trichinellosis an emerging disease in the EU?: Parasitology Today, v. 16, p. 266.

Pozio, E., 2001, New patterns of *Trichinella* infection: Veterninary Parasitology, v. 98, p. 133–148.

Pozio, E., 2005, The broad spectrum of *Trichinella* hosts: From cold- to warm blooded animals: Veterinary Parasitology, v. 132, p. 3–11.

Pozio, E., Foggin, C.M., Marucci, G., La Rosa, G., Sacchi, L., Corona, S., Rossi, P., and Mukaratirwa, S., 2002, *Trichinella zimbabwensis* n.sp. (Nematoda), a new non-encapsulated species from crocodiles (*Crocodylus niloticus*) in Zimbabwe also infecting mammals: International Journal for Parasitology, v. 32, p. 1787–1799.

Pozio, E., and La Rosa, G., 2000, *Trichinella murrelli* n. sp.: Etiological agent of sylvatic trichinellosis in temperate areas of North America: The Journal of Parasitology, v. 86, p. 134–139.

Pozio, E., La Rosa, G., Rossi, P., and Murrell, D., 1992, Biological characterization of *Trichinella* isolates from various host species and geographical regions: The Journal of Parasitology, v. 78, p. 647–653.

Pozio, E., and Marucci, G., 2003, *Trichinella*-infected pork products: A dangerous gift: Trends in Parasitology, v. 19, p. 338.

Pozio, E., Owen, I.L., La Rosa, G., Sacchi, L., Rossi, P., and Corona, S., 1999, *Trichinella papuae* n.sp. (Nematoda), a new nonencapsulated species from domestic and sylvatic swine of Papua New Guinea: International Journal for Parasitology, v. 29, p. 1825–1839.

Pozio, E., Owen, I.L., Marucci, G., and La Rosa, G., 2004, *Trichinella papuae* in saltwater crocodiles (*Crocodylus porosus*) of Papua New Guinea: Emerging Infectious Diseases, v. 10, p. 1507–1509.

Pozio, E., Pence, D.B., La Rosa, G., Casulli, A., and Henke, S.E., 2001, *Trichinella* infection in wildlife of the southwestern United States: The Journal of Parasitology, v. 87, p. 1208–1210.

Pozio, E., and Zarlanga, D.S., 2005, Recent advances on the taxonomy, systematics and epidemiology of *Trichinella*: International Journal for Parasitology, v. 35, p. 1191–1204.

Pozio, E., Zarlenga, D.S., and La Rosa, G., 2001, The detection of encapsulated and non-encapsulated species of *Trichinella* suggests the existence of two evolutive lines in the genus: Parasite, v. 8, p. 27–29.

Proulx, J.-F., MacLean, J.D., Gyorkos, T.W., Leclair, D., Richter, A.-K., Serhir, B., Forbes, L., and Gajadhar, A., 2002, Novel prevention program for trichinellosis in Inuit communities: Clinical Infectious Diseases, v. 34, p. 1508–1514.

Ransom, B.H., 1915, Trichinosis: Report on US Livestock Sanitary Association, Chicago, 16–18 February 1915, p. 147–165.

Rockiene, A., and Rocka, V.S., 1997, Seroprevalence studies on human trichinellosis in Lithuania, *in* Ortega Pierres, M.G., Gamble, H.R., Van Knapen, F., and Wakelin, D., eds., Trichinellosis: Mexico, Centro de Investigacion y Estudios Avanzados del Instituto Politecnico Nacional, p. 503–506.

Saunders, D., 2008, Romanians in a showdown with bears: The Globe and Mail, accessed July 14, 2008, at *http://www.theglobeandmail.com/servlet/story/RTGAM.20080312.wbears12/BNStory/International*.

Schad, G.A., Leiby, D.A., Duffy, C.H., Murrell, K.D., Alt, G.L., 1986, *Trichinella spiralis* in the black bear (*Ursus americanus*) of Pennsylvania: Distribution, prevalence, and intensity of infection: Journal of Wildlife Diseases, v. 22, p. 36–41.

Serhir, B., MacLean, J.D., Healey, S., Segal, B., and Forbes, L., 2001, Outbreak of Trichinellosis associated with arctic walruses in northern Canada, 1999: Canada Communicable Diseases Report, v. 26–04, accessed July 16, 2008, at *http://www.phac-aspc.gc.ca/publicat/ccdr-rmtc/01vol27/dr270S4eb.html*.

Snyder, D.E., 1987, Prevalence and intensity of *Trichinella spiralis* infection in Illinois wildlife: The Journal of Parasitology, v. 73, p. 874–875.

Soule, C., Dupouy-Camet, J., Georges, P., Ancelle, T., Gillet, J.P., Vassaire, J., Delvigne, A., and Plateau, E., 1989, Experimental trichinellosis in horses; biological and parasitological evaluation: Veterinary Parasitology, v. 32, p. 19–36.

Stoll, N.R., 1947, This wormy world: The Journal of Parasitology, v. 33, p. 1–18.

Stromberg, B.E., and Prouty, S.M., 1987, Prevalence of trichinellosis in the north-central United States: Proceedings of the Helminthological Society of Washington, v. 54, p. 231–232.

Takahashi, Y., Mingyuan L., and Waikagul J., 2000, Epidemiology of trichinellosis in Asia and the Pacific Rim: Veterinary Parasitology, v. 93, p. 227–239.

Theodoropoulos, G., Kapel, C.M.O., Webster, P., Saravanos, L., Zaki, J., and Koutsotolis, K., 2000, Infectivity, predilection sites, and freeze tolerance of *Trichinella* spp. in experimentally infected sheep: Parasitology Research, v. 86, p. 401–405.

Thorshaug, K.N., and Rosted A.F., 1956, Researches into the prevalence of trichinosis in animals in arctic and Antarctic waters: Nordisk Veterinaermedicin, v. 8, p. 115–129.

van Knapen, F., 2000, Control of trichinellosis by inspection and farm management practices: Veterinary Parasitology, v. 93, p. 385–392.

Viallet, J., MacLean, J.D., Goresky, C.A., Staudt, M., Routhier, G., Law, C., 1986, Arctic trichinosis presenting as prolonged diarrhea: Gastroenterology, v. 91, p. 938–946.

Villella, J.B., 1970, Life cycle and morphology, *in* Gould, S.E., ed., Trichinosis in man and animals, Springfield, Ill., Charles C. Thomas, p. 19–60.

Wang, Z., Li, H., Wu, L., and Mao, F., 1998, Some observations on trichinellosis in China: Helminthologia, v. 35, p. 27–29.

Wang, Z.Q., Cui, J., and Xu, B.L., 2006, The epidemiology of human trichinellosis in China during 2000–2003: Acta Tropica, v. 97, p. 247–251.

Weyermann, D., Worley, D.E., and Seesee, F.M., 1993, Survey of *Trichinella* nativa in Alaskan polar bears, *Ursus maritimus*: Helminthologia (Bratislava), v. 30, p. 143–145.

Wheeldon, E.B., Dick, T.A., and Schulz, T.A., 1983, First report of *Trichinella spiralis* var. *pseudospiralis* in North America: The Journal of Parasitology, v. 69, p. 781–782.

Worley, D.E., Seesee, F.M., Espinosa, R.H. and Sterner, M.C., 1986, Survival of sylvatic *Trichinella spiralis* isolates in frozen tissue and processed meats: Journal of the American Veterinary Medical Association, v. 189, p. 1047–1049.

Worley, D.E., Zarlenga, D.S., and Seesee, F.M., 1990, Freezing resistance of a *Trichinella spiralis nativa* isolate from a gray wolf, *Canis lupus*, in Montana (USA) with observations on genetic and biological characteristics of the biotype: Journal of the Helminthological Society of Washington, v. 57, p. 57–60.

Worley, D.E., Seesee, F.M., Zarlenga, D., and Murrell, K.D., 1994, Attempts to eradicate trichinellosis from a wild boar population in a private game park (USA), *in* Campbell, W.C., Pozio, E., and Bruschi, F., eds., Trichinellosis: Rome, Instituto Superiore di Sanita Press, p. 611–616.

Zarlenga, D.S., Al-Yaman, F., Minchella, D.J., and La Rosa, G., 1991, A repetitive DNA probe specific for a North American sylvatic genotype of *Trichinella*: Molecular and Biochemical Parasitology, v. 48, p. 131–138.

Zarlenga, D.S., Chute, M.B., Martin, A., and Kapel, M.O., 1999, A single multiplex PCR for unequivocal differentation of sex distinct geographical genotypes of *Trichinella pseudospiralis*: International Journal for Parasitology, v. 29, p. 215–221.

Zarnke, R.L., Gamble, R., Heckert, R.A., and Verhoef, J., 1997, Serologic survey for *Trichinella* spp. in grizzly bears (*Ursus arctos*) from Alaska, 1973 to 1987: Journal of Wildlife Diseases, v. 33, p. 474–479.

Zimmermann, W.J., 1977, Trichinosis in bears of western and north central United States: American Journal of Epidemiology, v. 106, p. 167–171.

Glossary

A

acute Sharp or severe, such as an illness with a sudden onset and a relatively short course.

allergic reaction Development of a hypersensitivity reaction by the host in response to foreign substances in the body, primarily antigens and other proteins.

amphipod A small, shrimp-like crustacean living mainly in aquatic habitats.

anorexia Lack of appetite.

anthelmintic A chemical substance used to treat infestations of parasitic worms.

antibody A protein formed in the body of a vertebrate that is used by the immune system to identify and neutralize the effects of foreign invading proteins, called antigens, such as bacteria and viruses.

antigen Any foreign substance (generally proteins) to which the body reacts by producing antibodies. Antigens may be soluble substances such as toxins, particulate matter such as pollen, or microorganisms such as bacteria or viruses.

arctic Referring to regions near the North Pole or describing very cold or frigid conditions.

arthropod A member of the phylum Arthropoda, invertebrate animals that have exoskeletons, segmented bodies, and jointed legs, including insects, crabs, spiders, etc.

autopsy Examination of a dead human body to determine the cause of death.

B

biopsy A test involving the removal of cells or tissues from a living subject for examination, usually by microscope, to determine the presence or extent of a disease.

birds Warm-blooded vertebrates, belonging to the Class Aves, with wings and feathers (although the wings are poorly developed for some flightless species like ostriches). (*See* warm-blooded.)

bronchitis Inflammation of the bronchi, the airways connecting the nose and the lungs, characterized by coughing and difficulty breathing.

C

cadaver A dead body, most often a human body, preserved for anatomical study.

calcification The hardening of a tissue by deposition of calcium salts.

canid Mammal within the Family Canidae,for example, wolves, coyotes, jackals, foxes, and other dog-like animals.

cannibalism The act of eating the flesh of one's own species.

cardiovascular system The system that circulates blood throughout the body, consisting of the heart and blood vessels.

carnivore Mammals with teeth and other body adaptations for feeding on flesh; primarily species belonging to the Order Carnivora (for example, wolves, bears, raccoons, weasels, civets, hyenas, and tigers).

carnivorous Eating flesh.

carrion Dead and decaying animal flesh.

central nervous system (CNS) The brain and spinal cord.

chronic Persisting for a relatively long time.

circumpolar Surrounding or near the North or South pole.

clinical signs Readily observable indications of a disease or injury. (*See also* symptoms.)

cloacal opening The opening of the common passage for the fecal, urinary, and reproductive discharges of most lower vertebrates (birds, reptiles, and amphibians).

cluster outbreak The occurrence of a higher-than-expected level of disease among individuals in proximity to each other and within a particular time period.

cold-blooded Species such as fishes and reptiles, which have blood that varies in temperature to approximately that of the surrounding environment.

collagen The protein component of connective tissue found in skin, tendon, bone, and cartilage.

competitive inhibition assay A laboratory test used to measure the concentration of antigen in a sample by simultaneously adding sample and labeled-antigen to antibody bound to a surface; the result is a color change that is inversely proportional to the concentration of unlabeled antigen in the sample.

compound microscope An instrument used to magnify small objects and structures not distinguishable by the naked eye, using two lens systems to increase the power of magnification.

conjunctivitis Inflammation of the mucous membrane that lines the inner surface of the eyelid and the exposed surface of the eyeball.

convalescence Gradual healing after sickness or injury.

convulsion A seizure or violent involuntary contraction or series of contractions of the voluntary muscles.

coprophagic Ingesting dung or feces.

corticosteroid Class of steroid hormones that are produced in the adrenal cortex or synthetically and are used as anti-inflammatory agents and to suppress the immune response.

cosmopolitan Having a worldwide distribution wherever the habitat is suitable.

counterimmunoelectrophoresis A laboratory technique used to evaluate the binding of an antibody to its antigen in which an electrical field is applied across a substance, such as a polyacrylamide gel, to induce migration of antibodies and antigen toward one another until they bind forming a line of precipitation.

cyst A stage in the life cycle of certain parasites, during which they are enclosed within a protective wall.

D

dedifferentiation A loss of differentiation of cells and of their orientation to one another.

digastricus The muscle that acts to lower the jaw.

dissecting microscope A type of microscope using separate optical paths to provide slightly different viewing angles for each eye to create a three-dimensional visualization of the sample.

DNA (deoxyribonucleic acid) The carrier of genetic information for all organisms except the RNA viruses and found in all living cells.

domestic Pertaining to an environment managed by humans.

domestication The adaptation of an animal or population of animals to life under human management through captive breeding for the purposes of human benefit; examples are dogs for companionship and service, livestock for food and labor.

E

edema The accumulation of excessive fluid in the intercellular tissue spaces of the body; may be peripheral (in the limbs) or within organs.

electrolyte A charged molecule, such as sodium, potassium, calcium, and chloride, needed by cells to control the flow of water molecules through cell walls.

ELISA (enzyme-linked immunosorbent assay) A molecular-based test used to detect the presence of either antigen or antibody in a sample.

emerging Referring to infectious diseases that have newly appeared and/or increased in frequency of occurrence within the past three decades, or threaten to increase in the near future relative to populations affected, geographic distribution, or magnitude of effects.

encapsulated Enclosed within a protective cover.

encystment The process of becoming enclosed by a protective covering. (*See* cyst.)

endemic A disease that is commonly present within a human population or a geographical area or having the quality of being constantly present in a human population in a specific location.

enteral Within or via the small intestine.

enzootic An animal disease that is commonly present within a population or geographical area or having the quality of being constantly present in a specific location within an animal population.

enzyme A substance, usually a protein, produced by the body to facilitate a chemical reaction.

eosinophils The white blood cells involved in combating parasitic infections and controlling allergic reactions.

epidemic An outbreak of disease affecting a disproportionately large number of humans within a population, community, or region during a period of time.

epidemiological Pertaining to epidemiology. (*See* epidemiology.)

epidemiology The study of the causes, occurrence, and control of disease in populations.

epithelial Pertaining to the cells that cover the external and internal surfaces of the body.

epithelium The cellular covering of the internal and external surfaces of the body and organs.

eradicate To completely eliminate.

F

fecal-oral route/transmission Passing a disease from one individual to another via direct or indirect ingestion of feces containing pathogens.

felids Mammals within the Family Felidae (for example, domestic cats, lion, tiger, leopard, lynx, cheetah, and many other wild cats).

fish Refers to finfish (for example, cold-blooded strictly aquatic vertebrates with a well differentiated skull and a bony skeleton), in contrast to shellfish (invertebrates) and jawless fishes.

G

gastrointestinal tract The tubular organs that form a digestive pathway from the mouth to the anus, including the esophagus, stomach, and intestines.

genotype The genetic makeup of a cell, an organism, or an individual usually with reference to a specific character under consideration.

H

helminthological Pertaining to the scientific study of parasitic worms.

herbivores Mammals that feed almost exclusively on plants (for example, cattle, sheep, manatee).

histopathologic Pertaining to histopathology. (*See* histopathology.)

histopathology The study of the microscopic changes in tissues caused by disease.

host An organism that harbors or nourishes microbes, viruses, and parasites.

I

immune status Refers to the host's ability to fight infections.

immunoblotting A laboratory test in which proteins are separated by their lengths using gel electrophoresis. The proteins are then transferred to cellulose sheets and identified by staining with specific antibodies. The test can also be used to identify the presence of antibodies to specific antigens in serum samples. Also known as Western blotting.

immunocompromised Incapable of developing a normal immune response, usually as a result of disease, malnutrition, or immunosuppressive therapy. (*See* immunosuppressive agents.)

immunological Relating to immunology, the study of the structure and function of the immune system.

immunoradiometric assay A laboratory test using radiolabeled antibodies to measure specific proteins in the blood.

immunosuppressive agents Drugs that are used to inhibit or prevent activity of the immune system in patients undergoing organ transplantation and treatment of autoimmune diseases.

incidence The probability of a new case of a specific disease developing in a population at risk during a specified time period.

indigenous Native to a particular place or country.

infective Capable of producing infection.

inflammatory Pertaining to or characterized by inflammation, the reaction of tissue to injury or infection that is characterized by redness, pain, swelling, and heat.

intercostals The muscles between adjacent ribs.

intracellular Within a cell or cells.

intramulticellular Within more than one cell.

Inuit A member of a group of native people of northern North America, inhabiting areas from Greenland and eastern Canada to Alaska.

invertebrates Animals lacking a spinal column (for example, insects, crustaceans).

irradiation The use of gamma rays, X-rays, or electron beams to sterilize food.

isolate A bacterial or fungal strain that has been separated as a pure strain from a mixed bacterial or fungal culture.

J

K

L

larva/larval The immature, early form of an organism that at birth or hatching is not like its parent and has to undergo a series of form and size changes before assuming adult features.

larynx Part of the respiratory tract between the pharynx and trachea that contains the vocal cords. Also known as the "voice box."

lymph nodes Rounded, encapsulated aggregations of lymphoid tissue distributed throughout the body along the lymphatic system. These nodes filter the flow of lymph circulating within the body.

lymphatics The lymphatic system, a vast network of tubes transporting lymph, a clear, watery, sometimes faintly yellowish fluid derived from body tissues that contains white blood cells and acts to remove bacteria and certain proteins from the tissues, transport fat from the small intestine, and supply mature lymphocytes to the blood. (*See* lymphocyte.)

lymphocyte A type of white blood cell important for producing antibodies (B-lymph-cytes) and cellular immunity (T-lymphocytes).

M

maintenance The act of continuing or keeping in existence, for example, a maintenance host is an organism that keeps a disease agent in existence in nature and is a source of infection for susceptible hosts.

malaise A vague feeling of bodily discomfort, as at the beginning of an illness.

mammal Warm-blooded vertebrate animal that possesses hair during some part of its life and suckles its young. (*See* warm-blooded.)

marsupials Mammalian species having an external abdominal pouch (marsupium) enclosing the mammary glands for carrying their young until their development is complete; young of these species are born in a very underdeveloped state and must be carried and nourished for a prolonged period of time (for example, opossums, kangaroos, koala, and wombats).

masseter The muscle used to close the jaw during chewing.

molt The normal shedding of hair, horns, feathers, and external skin before replacement by new growth, usually on an annual basis.

morphology The study of the form and structure of an organism or its parts.

mucosa The thin layer of tissue that lines body cavities and passages; mucous membrane.

mucosal Pertaining to the mucosa. (*See* mucosa).

muscular insertion The point of attachment of a skeletal muscle to the bone that it moves.

mustelid Mammal within the Family Mustelidae, for example, weasels, otters, mink, ferrets, and badgers.

myocarditis Inflammation of the heart muscle.

N

nearctic The biogeography subregion that includes Greenland, arctic America, and the parts of North America north of tropical Mexico.

nematode Unsegmented, cylindrical parasitic worm of the class Nematoda; roundworm.

neuritis Inflammation of a nerve or group of nerves that is characterized by pain, loss of reflexes, and atrophy of the affected muscles.

neurological system The group of structures (brain, spinal cord, nerves) that regulate the body's reactions to external and internal stimuli. Also known as the nervous system.

nodule A small solid lump.

nurse cell A skeletal muscle cell infected by the trichinosis parasite that stimulates blood vessel development so the cell can provide nutrients to the parasite.

O

ocular Pertaining to the eye.

omnivore An animal with a diet of both plants and animals.

outbreak The occurrence of a specific disease within a small, localized group of people or organisms.

P

palearctic The biogeographic subregion that includes Europe, Asia north of the Himalayas, Arabia, and Africa north of the Sahara.

papillae Plural of papilla, a small nipple-shaped projection.

paralysis The loss of muscle function resulting in the inability to move affected body parts.

parasite An organism that lives in or on another organism of a different species from which it derives nutrients and shelter.

parasitic Pertaining to parasites. (*See* parasite).

parenteral Located outside the digestive tract.

pathogen Typically, microorganisms capable of inducing disease, but broadly includes all disease-inducing agents.

pathogenic Able to produce disease.

pathogenicity The ability of an agent to produce disease in another organism.

pathological Pertaining to pathology. (*See* pathology).

pathologist A person who studies pathology (*See* pathology.)

pathology The study of the structural and functional effects of disease.

PCR (polymerase chain reaction) A laboratory technique used to amplify exponentially a single or few copies of a selected sequence of DNA using enzymatic replication of the DNA in order to generate millions or more copies of a particular DNA sequence. (*See* DNA.)

PCR-RFLP (polymerase chain reaction-restriction fragment length polymorphism) A laboratory technique in which a DNA sample is amplified by PCR and then fragmented by restriction enzymes. The DNA fragments are separated by length using gel electrophoresis. The differences in lengths of similar DNA molecules are analyzed to identify specific genotypes. (*See* DNA, PCR.)

pectoral Pertaining to the thorax or chest.

periorbital Located around the eye socket.

peripheral circulation The system of blood vessels outside of the heart, the central circulation.

pneumonitis Inflammation of the lung.

predation The characteristic of preying on other animals as a source of food.

prevalence The total number of cases of a disease divided by the number of hosts examined in a population at a given time.

prevalent Widely or commonly occurring.

public health The science and practice of protecting and improving the health of a community, through disease prevention, education, control, surveillance, and sanitation.

putrefied Decayed or rotten with a foul odor.

Q

R

reptile Vertebrates of the Class Reptilia that breathe by means of lungs and have external coverings of scales or bony plates; includes snakes, lizards, crocodiles, turtles, and dinosaurs.

reservoir The host population that maintains the disease agent in nature and provides a source of infection to susceptible hosts.

resistance The ability of an organism to remain either uninfected or disease-free despite becoming infected by a disease-causing organism; the ability of an organism, a tissue, or a cell to tolerate the effects of a harmful physical or environmental condition.

respiratory system The group of structures (airways, lungs, and muscles) that act to bring air into the body to supply oxygen to the blood and to expel carbon dioxide and other gaseous wastes.

retina The thin layer of neural cells lining the back of the eye.

rodent Member of the Order Rodentia, a diverse group of mammals characterized by incisor teeth that grow throughout life and must be worn away by cutting and gnawing hard materials; includes squirrels, mice, rats, voles, chipmunks, gophers, lemmings, beaver, porcupines, and many others.

roundworm *See* nematode.

ruminant Even-toed, hoofed mammals that have complex four-chambered stomachs and chew the cud; includes cattle, sheep, goats, and deer.

S

sarcoplasm The cytoplasm of a striated muscle fiber.

scavenging Feeding on dead or decaying matter.

schizophrenia A psychiatric disorder marked by severely impaired thinking, emotions, and behavior.

sera/serum The pale fluid that remains after blood has clotted.

spicules Parts of the male genital apparatus in nematodes that are used to engage the female genital orifice during copulation.

splinter hemorrhage Linear bleeding under a toenail or fingernail that resembles a splinter.

strain A genetically or biochemically distinguishable subtype of a microorganism.

striated muscle A muscle with fibers arranged in parallel bands, for example, skeletal muscle.

subarctic Pertaining to the area immediately south of the Arctic Circle covering much of Canada and Siberia where temperatures range from below -30°C (-22°F) in the winter to 30°C (86°F) in the summer.

subclinical Pertaining to an inapparent, asymptomatic infection.

subsistence hunting The practice of pursuing and killing wild animals for food and other essentials necessary for living, as opposed to recreational purposes.

surveillance The systematic collection, analysis, and interpretation of data pertaining to the occurrence of specific diseases for the purpose of monitoring trends in disease and death.

susceptibility/susceptible Pertaining to the ability of an animal to become infected by a disease-causing organism or to develop disease after becoming infected.

swine Pigs, hogs, and boars.

sylvatic Existing normally in the wild, not in the human environment.

symptoms A subjective indication of a disorder or disease perceived by the patient, such as pain, nausea, fatigue, or weakness.

synanthropic Living in or around human dwellings.

syndrome A group of signs and symptoms characterizing a specific disease or condition.

T

taxonomic Pertaining to taxonomy. (*See* taxonomy.)

taxonomy The systematic principles and procedures of grouping and arranging organisms into a hierarchical order.

temperate Marked by moderate temperatures, weather, or climate.

thoracic duct The largest lymph vessel in the body, that collects lymph from the portions of the body posterior to the diaphragm and from the left side of the body anterior to the diaphragm.

tinnitus A ringing, buzzing, or whistling sound in one or both ears, not caused by any external stimulus.

trichinoscopy A method for identifying *Trichinella spiralis* larvae in muscles by compressing small pieces of striated muscle between two plates of glass until they become translucent and then viewing the pieces of muscle under a dissecting or compound microscope to look for coiled larvae.

Trichuris A genus of parasitic roundworms that infect the intestines of mammals; also called whipworms.

U

V

venous circulation The network of blood vessels, i.e., veins, used to transport deoxygenated blood from the capillaries to the heart and lungs.

vertigo Dizziness characterized by a feeling of movement of oneself or one's surroundings.

vesicular exanthema A highly infectious viral disease of pigs with vesicles on the snout, feet, and inside the mouth.

villi Tiny, finger-like projections on the mucous membrane of the small intestine that increase the surface area to enable rapid absorption of nutrients from food.

viscera The internal organs, particularly of the thoracic and abdominal cavities, such as heart, lungs, liver, kidneys, and intestines.

viviparous Bearing living offspring rather than laying eggs.

W

warm-blooded Species, such as birds and mammals, that have a constant body temperature, independent of the surrounding environment.

X

Y

Z

zoologist A person who studies animals.

zoonosis Infectious disease transmissible between animals and humans, and vice versa.

zoonotic Transmissible between animals and humans, and vice versa.

Appendix 1. Locations and Hosts of the Different Species of *Trichinella*, and Common and Scientific Names of Hosts

North America (Nearctic)

T. spiralis

Black bear, *Ursus americanus*

Bobcat, *Lynx rufus*

Brown bear, *Ursus arctos*

Brown rat, *Rattus norvegicus*

Coyote, *Canis latrans*

Domestic cat, *Felis catus*

Domestic pig, *Sus scrofa*

Horse, *Equus caballus*

Humans, *Homo sapiens*

Pig, *Sus scrofa*

Red fox, *Vulpes vulpes*

T. nativa

Blue fox, *Alopex lagopus*

Domestic dog, *Canis lupus familiaris*

Marten, *Martes americana*

Polar bear, *Ursus maritimus*

Red fox, *Vulpes vulpes*

Wolf, *Canis lupus*

T. pseudospiralis

Black vulture, *Coragypus atratus*

Trichinella spp. (T5, T6, T8, or uncertain)

Badger, *Taxidea taxus*

Bearded seal, *Erignathus barbatus*

Beaver, *Castor canadensis*

Black bear, *Ursus americanus*

Bobcat, *Lynx rufus*

Brown lemming, *Lemmus sibiricus*

Common shrew, *Sorex minutus*

Coopers hawk, *Accipiter cooperi*

Cougar, *Felis concolor*

Coyote, *Canis latrans*

Ermine, *Mustela erminia*

Fisher, *Martes pennanti*

Fox squirrel, *Sciurus niger*

Gray fox, *Urocyon cinereoargenteus*

Gray wolf, *Canis lupus*

Great horned owl, *Bubo virginianus*

Grizzly bear, *Ursus arctos*

Ground squirrel, *Citellus undulatus*

Lesser shrew, *Sorex minutus*

Marten, *Martes americana*

Mink, *Mustela vison*

Mountain lion, *Felis concolor*

Muskrat, *Ondatra zibethicus*

Opossum, *Didelphis marsupialis*

Pomarine jaeger, *Stercorarius pomarinus*

Raccoon, *Procyon lotor*

Red-backed vole, *Clethrionomys rutilus*

Red fox, *Vulpes vulpes*

Red squirrel, *Tamiasciurus hudsonicus*

Ringed seal, *Phoca hispida*

Spotted skunk, *Spilogale interrupta*

Striped skunk, *Mephitis mephitis*

Varying hare, *Lepus americanus*

Vole, *Microtus gregalis*

Walrus, *Odobenus rosmarus*

Weasel, *Mustela frenata*

Weasel, *Mustela nivalis*

Weasel, *Mustela rixosa*

White-footed deer mouse, *Peromyscus maniculatus*

White-footed mouse, *Peromyscus leucopus*

North America (Nearctic)—Continued

Trichinella spp. (T5, T6, T8, or uncertain)—Continued

- White whales, *Dilphinapterus leucas*
- Wolverine, *Gulo gulo*

South America (Neotropical)

T. spiralis

- Cougar, *Felis concolor*
- Pig, *Sus scrofa*

Eurasia (Palearctic, Mediterranean, Oriental)

T. spiralis

- Blue fox, *Alopex lagopus*
- Brown rat, *Rattus norvegicus*
- Domestic cat, *Felis catus*
- Domestic dog, *Canis lupus familiaris*
- Pig, *Sus scrofa*
- Red fox, *Vulpes vulpes*
- Wildcat, *Felis silvestris*
- Wolf, *Canis lupus*

T. nativa

- Blue fox, *Alopex lagopus*
- Brown bear, *Ursus arctos*
- Brown rat, *Rattus norvegicus*
- Corsac fox, *Vulpes corsax*
- Domestic cat, *Felis catus*
- Domestic dog, *Canis lupus familiaris*
- Far eastern forest cat, *Felis euptilura*
- Jackal, *Canis aureus*
- Lynx, *Lynx lynx*
- Polar bear, *Ursus maritimus*
- Raccoon dog, *Nyctereutes procyonoides*
- Red fox, *Vulpes vulpes*
- Tiger, *Panthera tigris*
- Wild boar, *Sus scrofa*
- Wolf, *Canis lupus*

T. britovi

- Badger, *Meles meles*
- Beech marten, *Martes foina*
- Black bear, *Ursus americanus*
- Black rat, *Rattus rattus*
- Brown bear, *Ursus arctos*
- Brown rat, *Rattus norvegicus*
- Domestic cat, *Felis catus*
- Domestic dog, *Canis lupus familiaris*
- Horse, *Equus caballus*
- Human, *Homo sapiens*
- Jackal, *Canis aureus*
- Lynx, *Lynx lynx*
- Raccoon dog, *Nyctereutes procyonoides*
- Red fox, *Vulpes vulpes*
- Wildcat, *Felis silvestris*
- Wolf, *Canis lupus*

T. pseudospiralis

- Eagle, *Aquila rapax*
- Human, *Homo sapiens*
- Little owl, *Athene aoctua*
- Pig, *Sus scrofa*
- Raccoon dog, *Nyctereutes procyonoides*
- Tawny owl, *Strix aluco*

Trichinella spp. (T5, T6, T8, or uncertain)

- Afghan hedgehog, *Hemiechinus megalotis*
- Black bear, *Ursus americanus*
- Buzzard, *Buteo buteo*
- Common mole, *Talpa europea*
- Common shrew, *Sorex araneus*
- Corsac fox, *Vulpes corsac*
- Domestic pig, *Sus scrofa*
- Fared seal, *Eumetopias jubatus*
- Greenland seal, *Phoca groenlandica*
- Harvest mouse, *Micromys minutus*
- Hedgehog, *Erinaceus europeus*
- Human, *Homo sapiens*
- Indian mole rat, *Bandicota bengalensis*
- Jackal, *Canis aureus*
- Laxmann's shrew, *Sorex caecutiens*

Eurasia (Palearctic, Mediterranean, Oriental)—Continued

Trichinella spp. (T5, T6, T8, or uncertain)—Continued

- Lesser shrew, *Sorex minutus*
- Marten, *Martes martes*
- Muskrat, *Ondatra zibethicus*
- Polecat, *Mustela putorius*
- Reindeer, *Rangifer tarandus*
- Rook, *Corvus frigileus*
- Sable, *Martes zibellina*
- Siberian ferret, *Mustela sibiricus*
- Squirrel, *Sciurus vulgaris*
- Striped field mouse, *Apodemus agrarius*
- Water shrew, *Neomys fodiens*
- Wildcat, *Felis silvestris*
- Yellow-necked mouse, *Apodemus flavicollis*

Africa (Ethiopian)

T. spiralis

- Black-backed jackal, *Canis mesomelas*
- Bush pig, *Potamochoerus porcus*
- Domestic cat, *Felis catus*
- Domestic dog, *Canis lupus familiaris*
- Human, *Homo sapiens*
- Pig, *Sus scrofa*
- Serval, *Felis serval*
- Soft-furred rat, *Praomys natalensis*
- Striped jackal, *Canis adustus*
- Wildcat, *Felis silvestris*
- Wild dog, *Lycaon pictus*

T. nelsoni

- Bat-eared fox, *Otocyon megalotis*
- Cheetah, *Acinonyx jubatus*
- Leopard, *Panthera pardus*
- Lion, *Panthera leo*
- Spotted hyena, *Crocuta crocuta*
- Striped hyena, *Hyaena hyaena*
- Wart hog, *Phacochoerus aethiopicus*

T. zimbabwensis

- Crocodile, *Crocodylus niloticus*
- Monitor lizard, *Varanus exanthematicus*

Trichinella spp. (T5, T6, T8, or uncertain)

- Bat-eared fox, *Otocyon megalotis*
- Cheetah, *Acinonyx jubatus*
- Lion, *Panthera leo*
- Striped hyena, *Hyaena hyaena*
- Spotted hyena, *Crocuta crocuta*

Australia, New Zealand, New Guinea, Tasmania, Hawaii (Oceanic)

T. spiralis

- Brown rat, *Rattus norvegicus*

T. papuae

- Pig, *Sus scrofa*
- Saltwater crocodile, *Crocodylus porosus*

T. pseudospiralis

- Spotted-tailed quolls, *Dasyurus maculatus*
- Wild boar, *Sus scrofa*

Trichinella spp. (T5, T6, T8, or uncertain)

- Black rat, *Rattus rattus*
- Little rat, *Rattus exulans*
- Mongoose, *Herpestes javanicus*
- Wild hog (scientific name unknown)

Appendix 2. Common and Scientific Names for Species Cited

Common name	Scientific name
Mammals	
Arctic fox	*Vulpes lagopus*
Arctic hare	*Lepus arcticus*
Badger (European)	*Meles meles*
Bandicoot (Eastern barred)	*Perameles gunnii*
Bear	*Ursus* spp.
Bearded seal	*Erignathus barbatus*
Beluga whale	*Delphinapterus leucas*
Bennett's wallaby (red-necked wallaby)	*Macropus rufogriseus*
Bison	*Bison bison*
Black bear	*Ursus americanus*
Black-faced kangaroo (western grey)	*Macropus fuliginosus*
Black-flanked rock wallaby	*Petrogale lateralis*
Bobcat	*Lynx rufus*
Bottlenose dolphin	*Tursiops truncatus*
Brown bear	*Ursus arctos arctos*
Brown hare	*Lepus europaeus*
California sea lion	*Zalophus californianus*
Camel	*Camelus* spp.
Canadian cougar (North American)	*Puma concolor cougar*
Caribou	*Rangifer tarandus*
Cat (domestic)	*Felis catus*
Cattle (domestic)	*Bos taurus*
Cheetah	*Acinonyx jubatus*
Chicken	*Gallus gallus*
Chinchilla	*Chinchilla* spp.
Common dolphin	*Delphinus delphis*
Cougar	*Puma concolor*
Coyote	*Canis latrans*
Cuvier's gazelle	*Gazella cuvieri*
Dama gazelle	*Gazella dama*

Common name	Scientific name
Mammals—Continued	
Dasyurid (kowari and mulgara)	*Dasyuroides byrnei* and *Dasycercus cristicauda*
Dik-dik	*Madoqua guentheri*
Dog (domestic)	*Canis lupus familiaris*
Duck (mallard)	*Anas platyrhynchos*
Eastern barred bandicoot	*Perameles gunnii*
European lynx (Eurasian lynx)	*Lynx lynx*
Ferret (European polecat)	*Mustela putorius furo*
Fox	*Vulpes* spp.
Gerenuk	*Litocranius walleri*
Goat (domestic)	*Capra hircus*
Gray fox	*Urocyon cinereoargenteus*
Greenland seal (harp seal)	*Pagophilus groenlandicus*
Gray seal	*Halichoerus grypus*
Grizzly bear	*Ursus arctos horribilis*
Gundi	*Ctenodactylus gundi*
Harbor seal	*Phoca vitulina*
Harp seal	*Pagophilus groenlandicus*
Hawaiian monk seal	*Monachus schauinslandi*
Hooded seal	*Cystophora cristata*
Horse (domestic)	*Equus caballus*
Human	*Homo sapiens*
Indo-Pacific bottlenose dolphin	*Tursiops aduncus*
Iriomote cat	*Prionailurus iriomotensis*
Jackal (golden)	*Canis aureus*
Jaguar	*Panthera onca*
Koala	*Phascolarctos cinereus*
Lion	*Panthera leo*
Lynx (Canadian)	*Lynx canadensis*
Mink (American)	*Neovison vison*
Moose	*Alces alces*
Mountain gazelle	*Gazella gazella*
Mule deer	*Odocoileus hemionus*
Narwhal	*Monodon monoceros*
Northern fur seal	*Callorhinus ursinus*
Ocelot	*Felis pardalis*

Common name	Scientific name
Mammals—Continued	
Opossum (Virginia)	*Didelphis virginiana*
Pacific walrus	*Odobenus rosamarus*
Pallas cat	*Felis manul*
Pig (domestic)	*Sus scrofa*
Polar bear	*Ursus maritimus*
Pronghorn	*Antilocapra americana*
Rabbit	family Leporidae
Raccoon dog	*Nyctereutes procyonoides*
Raccoon	*Procyon lotor*
Rat	*Rattus* spp.
Red deer (elk, wapiti)	*Cervus elaphus*
Red fox	*Vulpes vulpes*
Red kangaroo	*Macropus rufus*
Reindeer	*Rangifer tarandus*
Rhim gazelle	*Gazella leptoceros*
Ribbon seal	*Histriophoca fasciata*
Ringed seal	*Pusa hispida*
Risso's dolphin	*Grampus griseus*
Roe deer (western)	*Capreolus capreolus*
Saiga antelope	*Saiga tatarica*
Sand cat	*Felis margarita*
Sea lion (California)	*Zalophus californianus*
Sheep (domestic)	*Ovis aries*
Skunk	*Spilogale putorius, Mephitis mephitis*
Southern sea otter	*Enhydra lutris nereis*
Spinner dolphin	*Stenella longirostris*
Spotted seal	*Phoca largha*
Squirrel	*Sciurus carolensis, Sciurus griseus, Spermophilus tridecemlineatus, Tamiasciurus hudsonicus*
Striped dolphin	*Stenella coeruleoalba*
Tammar wallaby	*Macropus eugenii*
Tasmanian pademelon	*Thylogale billardierii*
Turkey	*Meleagris* spp.

Common name	Scientific name
Mammals—Continued	
Walrus	*Odobenus rosmarus*
Wapiti (elk)	*Cervus elaphus*
Warthog	*Phacochoerus aethiopicus, Phacochoerus africanus*
Water buffalo	*Bubalus bubalis*
White-tailed deer	*Odocoileus virginianus*
Wild boar	*Sus scrofa*
Wolf	*Canis lupus*
Wombat (common)	*Vombatus ursinus*
Yellow-footed rock wallaby	*Petrogale xanthopus*
Birds	
American coot	*Fulica americana*
American crow	*Corvus brachyrhynchos*
Blue-gray tanager	*Thraupis episcopus*
Brewer's blackbird	*Euphagus cyanocephalus*
Canary	*Serinus canaria*
Cattle egret	*Bubulcus ibis*
Clay-colored robin	*Turdus grayi*
Common barn owl	*Tyto alba*
Common grackle	*Quiscalus quiscula*
Crimson-backed tanager	*Ramphocelus dimidiatus*
Finch	Carduelis spp.
Great-tailed grackle	*Quiscalus mexicanus*
Hawaiian crow	*Corvus hawaiiensis*
House sparrow	*Passer domesticus*
Laughing gull	*Larus atricilla*
Little penguin (fairy penguin)	*Eudyptula minor*
Mockingbird (northern)	*Mimus polyglottos*
Ostrich	*Struthio camelus*
Palm tanager	*Thraupis palmarum*
Plain wren	*Thryothorus modestus*
Red-winged blackbird	*Agelaius phoeniceus*
Ring-billed gull	*Larus delawarensis*
Robin (American)	*Turdus migratorius*

Common name	Scientific name
Bird—Continued	
Rock dove	*Columba livia*
Ruddy ground dove	*Columbina talpacoti*
Spotted dove	*Streptopelia chinensis*
Starling (common)	*Sturnus vulgaris*
Tree sparrow (Eurasian)	*Passer montanus*
Turkey vulture	*Cathartes aura*
Turkey (wild)	*Meleagris gallopavo*
Vulture (white-backed)	*Gyps africanus*
Wood duck	*Aix sponsa*
Cold-blooded animals	
Carp (common)	*Cyprinus carpio*
Crocodile (Nile)	*Crocodylus niloticus*
Horned toad (horned lizard)	*Phrynosoma* spp.
Monitor lizard	*Varanus exanthematicus*
Northern anchovy	*Engraulis mordax*
Saltwater crocodile	*Crocodylus porosus*

Publishing support was provided by the USGS Columbus Publishing Service Center.
Layout by Elizabeth Ciganovich.
Illustrations by Rosemary Stenback.

For more information concerning this report, contact:

Director
U.S. Geological Survey
National Wildlife Health Center
6006 Schroeder Road
Madison, WI 53711-6223
jsleeman@usgs.gov

or visit our Web site at:
http://www.nwhc.usgs.gov/

Foreyt—**Trichinosis**—Circular 1388

ISBN 978-1-4113-3638-4

ISSN 1067–084X (print)
ISSN 2330–5703 (online)
http://dx.doi.org/10.3133/cir1388