Trichinae

Author
H. Ray Gamble, USDA, ARS, PBEL

Reviewer
Jimmy Keeton, Texas A&M University

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Introduction

Trichinella spiralis is a parasitic nematode (roundworm) which is found in many warm-blooded carnivores and omnivores, including pigs. *Trichinella* has a direct life cycle, which means it completes all stages of development in one host (Figure 1). Transmission from one host to another host can only occur by ingestion of muscle tissue which is infected with the encysted larval stage of the parasite. When ingested, muscle larvae excyst and enter tissues of the small intestine, where they undergo development to the adult stage. Male and female adult parasites mate and produce newborn larvae which leave the intestine and migrate, through the circulatory system, to striated muscle tissue. There, they penetrate a muscle cell, modify it to become a unique cyst, and mature to become infective for another host. The total time required for this development is from 17-21 days. Adult worms continue to produce larvae in pigs for several weeks before they are expelled. Once adult worms are expelled and larvae reach and encyst in musculature, no further contamination can occur. An animal that is infected with *Trichinella* is at least partially resistant to a subsequent infection due to a strong and persistent immunity.

Trichinella and pork

Trichinella spiralis has a long-standing association with pork products, not only in the US but also around the world. The concept, which many people have about the need to cook pork thoroughly, is based on the risk of becoming infected with this parasite. This concern is well founded in history. At the beginning of the 20th century conservative estimates showed a 2.5% infection rate in US pigs. Even more alarming were postmortem surveys, conducted in the 1930s. A National Institute of Health report published in 1943 found 16.2% of the US population to be infected (1 out of every 6 people). This type of information led to considerable publicity on the dangers of eating undercooked pork. The historical problem of *trichinae* infection in pigs is responsible for strict federal control of methods used to prepare ready-to-eat pork products in the US, and expensive carcass inspection requirements in Europe. These regulations are still in effect in the Code of Federal Regulations, for processed products, and in the Directives of the European Union.

Despite the historical problems of *trichinae* and its association with the pork industry, major changes have occurred in the last 50 years. Human cases of trichinellosis reported to the Centers for Disease Control declined from about 500/year in the 1940s to fewer than 50/year over the last decade. Further, many of these cases result from non-pork sources such as bear and other game meats. A major decline has also occurred in the prevalence of this parasite in pigs (see Table 1). While prevalence has declined considerably in US pigs, the lowest prevalence rates in domestic pigs are found in countries where meat inspection programs have been in place for many years (including countries of the European Union, notably Denmark and the Netherlands); these countries consider themselves essentially free of *trichinae*.

The dramatic declines in *trichinae* in pigs reflect changes in the industry. Historically, *trichinae* infection in pigs was associated with feeding of raw garbage. Major inroads were made into *trichinae* infection with the advent of garbage cooking laws passed for vesicular exanthema (1953-1954) and the hog cholera eradication program (1962). Of equal importance has been the movement to high levels of biosecurity and hygiene under which most pigs are now raised. Still, opportunities for exposure of pigs exist and some precautions should be implemented.

Year Positive	% Tested	Number	Comments
1898-1906	1.41	8 million	slaughter testing
1933-1937	0.95	13,000	grain/forage fed
	0.55	1,987	fed cooked garbage
	5.7	10,500	fed uncooked garbage
1948-1952	0.63	3,031	grain fed
	11.21	1,328	garbage fed
1961-1965	0.12	9,495	grain fed market hogs
	0.22	6,881	grain fed breeders
	2.6	5,041	fed cooked garbage
1966-1970	0.125	22,451	all hogs/national survey
	0.51	590	garbage fed hogs
1983-1984	0.73	5,315	New England slaughter samples
	0.58	33,482	mid-Atlantic slaughter samples
1990	0.16	3,048	APHIS National Swine survey
1994-1995	0.47	2,132	New England farm samples
	0.26	1,946	mid-Atlantic farm samples
1995	0.013	7,987	APHIS National Swine survey
1996	0	221,123	mid-Western market hogs

Table 1. Prevalence of *Trichinella spiralis* infection in pigs in the US.

Despite the fact that *trichinae* is rare in today's industry, pork still suffers from its legacy. Today, the *trichinae* issue is a question of perception versus reality. Dramatic declines in prevalence in pigs and the extremely low numbers of cases in humans are largely unrecognized by domestic consumers who still raise questions about "worms in pork". Further, lack of a *trichinae* control program creates problems for fresh pork in international markets despite the extremely low prevalence (essentially zero in intensive management systems).

Epidemiology

Several species of *Trichinella* are found in warm-blooded carnivores, omnivores and raptorial birds. In North America, there are five known species or types of *Trichinella*. These include *Trichinella spiralis, T. nativa, T. pseudospiralis, Trichinella* T-5, and T*richinella* T-6. *Trichinella spiralis* is most commonly associated with domestic pigs. The other species and types mentioned have low relative infectivity for pigs and are primarily of importance because they occur in game animals (T-5 in bears and other wildlife in the eastern US, T-6 in bears and other wildlife in the Northwestern US, and *T. nativa* in Alaska). Both *T. nativa* and *Trichinella* T-6 are resistant to freezing. *Trichinella pseudospiralis* has been reported infrequently from birds, but can infect pigs also.

Exposure of domestic pigs to *Trichinella* is limited to just a few risk factors which include: feeding of animal waste products contaminated with parasites; exposure to and consumption of muscle tissue from living or dead rodents or other wildlife infected with *trichinae*; or cannibalism among pigs within an infected herd. Other means of transmission such as tail biting or coprophagy are not important.

Generally, the way in which pigs become infected can be determined by a simple evaluation of farm management practices. Since it is illegal to feed raw garbage, this source of infection should never be an issue. However, feeding of any raw or undercooked meat scraps, including table waste could pose a risk. Of much greater significance is exposure of pigs to rodents and wildlife. Rodents, and rats in particular, serve as both a reservoir host and as a bystander host for *trichinae* infection. Rodents can pick up infection from landfills, carrion or even dead pigs. When rat populations are in close contact with pigs, it is possible that either live or dead rats will be caught and eaten. If the rat happens to be infected, then *trichinae* infection of the pig will occur. The same type of risk holds true for other small mammals. Pigs that have free range to browse outdoors occasionally encounter carcasses which they might chew on. Small mammals which have been shown to have high prevalence rates for trichinae include raccoons, skunks and opossums. By taking the following steps, risk of exposure of pigs to trichinae will be greatly reduced:

- Don't feed uncooked waste products, table scraps or animal carcasses to pigs. This is particularly important in the case of carcasses from hunted or trapped wildlife.
- Eliminate or minimize exposure of pigs to live wildlife. Create barriers which are effective in separating pigs from skunks, raccoons and other small mammals.
- Implement and maintain an effective rodent control program. Biosecurity, maintaining perimeters, baiting and trapping are all part of rodent control. For more information on rodent control, see the Pork Industry Handbook (Chapter PIH-04-04-04), published by Purdue University Cooperative Extension Service.
- Maintain good hygiene. Remove dead pigs as soon as they are found. Keep barns free from clutter and feed stored securely.

The use of good production/management practices for swine husbandry will preclude most risks for exposure to *trichinae* in the environment.

Control

There are a variety of ways in which *trichinae* control is approached. Many countries require slaughter testing of each carcass. In fact, for pork exported to the European Union, US packers test carcasses using the same methods employed by European meat inspectors. In the US, the traditional approach for *trichinae* control is strict control of processed products to inactivate *trichinae* and warnings to consumers of the need to cook fresh pork. This approach no longer seems appropriate since *trichinae* is almost non-existent in US pork. However, to overcome the stigma of *trichinae*, some organized approach to demonstrating product safety will be needed. The following summarizes the current methods used for *trichinae* control and a proposal for herd certification which could have a major positive impact on the image of US pork.

Slaughter testing - Despite the relatively low prevalence of *trichinae* in pigs in many developed countries, considerable energy goes into preventing human exposure. These efforts are largely a continuation of measures implemented when trichinae was a serious problem. In many countries, slaughter inspection programs are required, and these requirements are often imposed as trade barriers to countries that do not inspect for *trichinae*. As an example of the cost of this testing, the European Union spent $572 million in 1997 for *trichinae* inspection.

Approved inspection methods for *trichinae* in pigs include direct methods for visualization of parasites. Since it is not possible to see *trichinae* cysts within meat tissue by macroscopic examination, it is necessary to perform one of several laboratory tests. The oldest method, and one still frequently used, is called the compression method. Small pieces of pork collected from the pillars (crus muscle or hanging tenderloin) of the diaphragm are compressed between two thick glass slides (a compressorium) and examined microscopically for the presence of worms. A minimum of 1 gram is tested and the sensitivity of this test is approximately 3 larvae per gram of tissue. An improvement over the compression method, and a method which is now widely used in Europe, is the pooled sample digestion method. Samples of tissue collected from sites where parasites concentrate, such as the diaphragm, masseters or tongue, are subjected to digestion in acidified pepsin. Larvae, which are freed from their muscle cell capsules by this process, are recovered by a series of settling steps, then visualized and counted under a microscope. Requirements for performing the digestion test are found in the Directives of the European Economic Community, in the U.S. Code of Federal Regulations, and various other publications.

An alternative method of testing pigs for *trichinae* infection is an indirect method which looks for antibodies to the parasites in pig blood. This test, called the ELISA, has been used extensively for testing in both pre- and post-slaughter applications and is an extremely useful tool for determining or monitoring infection in herds.

Where fresh pork is not tested for *trichinae*, as is the case in the US, alternative methods are used to prevent exposure of humans to potentially contaminated product. These include processing methods such as cooking, freezing and curing along with recommendations to the consumer concerning requirements for thorough cooking.

Cooking - Commercial preparation of pork products by cooking requires that meat be heated to internal temperatures that have been shown to inactivate *trichinae*. For example, *Trichinella spiralis* is killed in 47 minutes at 52°C (125.6°F), in 6 minutes at 55°C (131°F), and in <1 minute at 60°C (140°F). It should be noted that these times and temperatures apply only when the product reaches and maintains temperatures evenly distributed throughout the meat. Alternative methods of heating, particularly the use of microwaves, have been shown to give different results, with parasites not completely inactivated when product was heated to reach a prescribed end-point temperature. The US Code of Federal Regulations for processed pork products reflects experimental data, and requires pork to be cooked for 2 hours at 52.2°C (126°F), for 15 minutes at 55.6°C (132°F), and for 1 minute at 60°C (140°F).

The US Department of Agriculture recommends that consumers of fresh pork cook the product to an internal temperature of 71°C or 160°F. The National Pork Producers Council recomments an internal cooking temperature of 68°C or 155°F for maximum juiciness and flavor. Although this is considerably higher than temperatures at which *trichinae* are killed (about 55°C or 131°F), it allows for different methods of cooking which do not always result in even distribution of temperature throughout the meat. It should be noted that heating to 77°C (171°F) or 82°C (180°F) was not completely effective when cooking was performed using microwaves.

Freezing - Experiments have been performed to determine the effect of cold temperatures on the survival of *T. spiralis* in pork. Predicted times required to kill *trichinae* were 8 minutes at -20°C (-4°F), 64 minutes at -15°C (5°F), and 4 days at -10°C (14°F). *Trichinae* were killed instantaneously at -23.3°C (-10°F). The US Department of Agriculture's Code of Federal Regulations, requires that pork intended for use in processed products be frozen at -17.8°C (0°F) for 106 hours, at -20.6°C (-5°F) for 82 hours, at -23.3°C (-10°F) for 63 hours, at -26.1°C (-15°F) for 48 hours, at -28.9°C (-20°F) for 35 hours, at -31.7°C (-25°F) for 22 hours, at -34.5°C (-30°F) for 8 hours, and at -37.2°C (-35°F) for 0.5 hours. These extended times take into account the amount of time required for temperature to equalize within the meat along with a margin of safety.

Curing - There are a great variety of processes used to prepare cured pork products (sausages, hams, pork shoulder, and other ready-to-eat products). Most processes currently used have been tested to determine their efficiency in killing *trichinae*. In the curing process, product is coated or injected with a salt mixture and allowed to equalize at refrigerated temperatures. Following equalization, product is dried or smoked and dried at various temperature/time combinations which have been shown to inactivate *trichinae*. The curing process involves the interaction of salt, temperature and drying times to reach a desired water activity, percent moisture, or brine concentration. Unfortunately, no single or even combination of parameters achieved by curing has been shown to correlate definitively with *trichinae* inactivation. All cured products should conform in process to one of many published regulations, such as the US Department of Agriculture's Code of Federal Regulations Title 9, Chapter III, §318.10.

Irradiation - Treatment of fresh pork with 30krad (0.3kGy) of cesium-137 has been proven to render *trichinae* completely non-infective. Irradiation with cobalt-60 or high energy x-rays at this same level should also be effective for inactivating trichinae.

Alternative methods for control

In lieu of carcass testing to show that pigs are not infected or treatment of pork products to inactivate *trichinae* presumed to be present, there are alternative methods to assure the safety of pork. These include herd testing to prove that trichinae infection is not present or raising pigs under conditions which prevent exposure. In the former case, considerable testing on a regular basis is required to document absence of infection. In the latter case, documentation of good management practices is required to show that pigs have not had an opportunity to become infected. Below is an example of the use of regular herd testing for *trichinae*. This example shows how this information has been used to declare an area "free" from *trichinae* infection. Then, an example of how a herd certification system for the US pork industry might be implemented will be discussed.

Certification by region - Canada has adopted the approach of regional freedom from *trichinae* in domestic pigs based on a history of testing and finding animals to be negative. This means that most of Canada is considered a "*trichinae*-free" zone; in one small focus of infection, which is not included in the *trichinae*-free zone, pigs are tracked and tested regularly. The basis for this regional approach is found in the OIE Code of Animal Health. OIE is an international organization devoted to animal and veterinary public health. The OIE Code states the following: A country, or part of the territory of a country may be considered free from *trichinae* in domestic swine when: 1) *trichinellosis* humans and animals is compulsorily notifiable in the country; 2) there is in force an effective disease reporting system shown to be capable of capturing the occurrence of cases; and 3) it has been found that *trichinae* infection does not exist in the domestic swine population as determined by regular testing of a statistically significant sample of the population; or 4) *trichinellosis* has not been reported in five years and a surveillance program shows that the disease is absent from wild animal populations.

In Canada, no cases of human *trichinellosis* caused by pork have been reported since 1980 and extensive surveillance has been in place since 1966. From 1980-1995, over 550,000 pigs were tested. This surveillance demonstrated that, except for one infected zone in the Province of Nova Scotia, Canada is free from *trichinae* in domestic pigs. Within the infected zone, movement of pigs is restricted. All pigs from the infected zone are tested at slaughter and depopulation of infected herds is required.

According to Canadian animal health personnel, maintaining freedom from trichinae infection throughout most of the country has been instrumental in the $1 billion annual export market ($410 million in fresh cuts) and the 28kg per capita annual consumption of pork.

Farm certification as a method of *trichinae* control - Like Canada and many other developed countries, the US has an extremely low incidence of *trichinae* infection in pigs. Although human *trichinellosis* is a reportable disease, the US has no history of regular testing to determine *trichinae* infection in pigs, nor do most states require reporting of *trichinae* infection in pigs if found. Considering the existing public perception of *trichinae* as a problem coupled with the reality of a very low level of occurrence, the US pork industry would likely benefit substantially from a program which assured the absence of *trichinae* from pigs. One way to accomplish this goal in a reasonable time frame is to certify herds free from *trichinae* based on the use of good production practices (GPPs). In this case, GPPs are defined as those production practices which reduce or prevent exposure of pigs to risks for *trichinae* infection.

Recent research efforts and pilot studies involving the National Pork Producers Council, the USDA's Animal and Plant Health Inspection Service, the Food Safety and Inspection Service, the Agricultural Research Service and private industry and packer groups have resulted in development of a model for herd certification. This model includes certification of production practices that eliminate or minimize risk factors for transmission of *trichinae* to pigs along with systematic monitoring of the product (*trichinae*-free pigs).

The model for a *trichinae*-free certification program incorporates many of the principles of HACCP. The hazard, of course, is the exposure of pigs to the parasite, *Trichinella spiralis.* Critical control points (CCPs) have been elucidated from a number of studies on the epidemiology of *trichinellosis* and its transmission to the domestic pig. These CCPs are limited to management practices which would allow pigs to ingest contaminated feed (uncooked waste products containing *trichinae*), rodents or animal carcasses, including other pigs that contain infective parasite stages.

In the certification model, documentation of GPPs for risk-reduced production practices is accomplished by completing a farm audit, administered by trained veterinarians. This audit, which would be conducted on a regular basis, takes into account all production practices that impact the *trichinae* status of market animals. Audits consider adherence to: 1) feed integrity, source and storage; 2) building construction and condition as it pertains to biosecurity; 3) integrity of rodent control programs; and 4) general management and hygiene issues as they pertain to rodent control, cannibalism and other issues. In addition, the producer assumes responsibility for maintaining the integrity of good production practices between trichinae-CCP audits. The process of raising pigs under GPPs to prevent *trichinae* infection requires both documentation (in the form of an audit as discussed above) and verification. Herds which meet GPPs, and thus receive certification, would still need to be monitored periodically (by testing pigs at slaughter) to verify the absence of infection. This monitoring could take of form of spot testing at the packer and testing would be based on a statistical sample of the "national certified herd". To summarize, the overall certification process includes the following elements:

- Accredited veterinary practitioners are trained in good production practices relative to *trichinae.* They work with producers to assure that risks are minimized in production systems. The farm audit is used on a regular basis to document absence of risk.
- Periodically, some pigs are tested to verify the absence of infection. Since the system is based on a pre-harvest HACCP approach, only a sample of production needs to be tested.
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Efforts to certify pork free from trichinae should have an immediate impact on international markets by producing a product which is competitive with countries that currently inspect for *trichinae*. The US pork industry can't catch up with the rest of the world on *trichinae* by starting now to test pigs at slaughter. We can however, initiate a better approach to food safety by implementing a system at the farm that is superior to individual animal testing. In addition, implementation of a *trichinae* certification system will provide an infrastructure for tackling more complex issues in on-farm certification.

In the domestic market, the issue of *trichinae* is primarily perception, since the infection is so rare in today's product. However, changing public perception requires education with respect to safety and educational efforts need to be supported by a process that validates the absence of the parasite from the pork supply. *Trichinae* has long been a stigma to the pork industry. Today, with a small effort on the part of producers, packers and government, it may be possible to put this issue to rest.

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