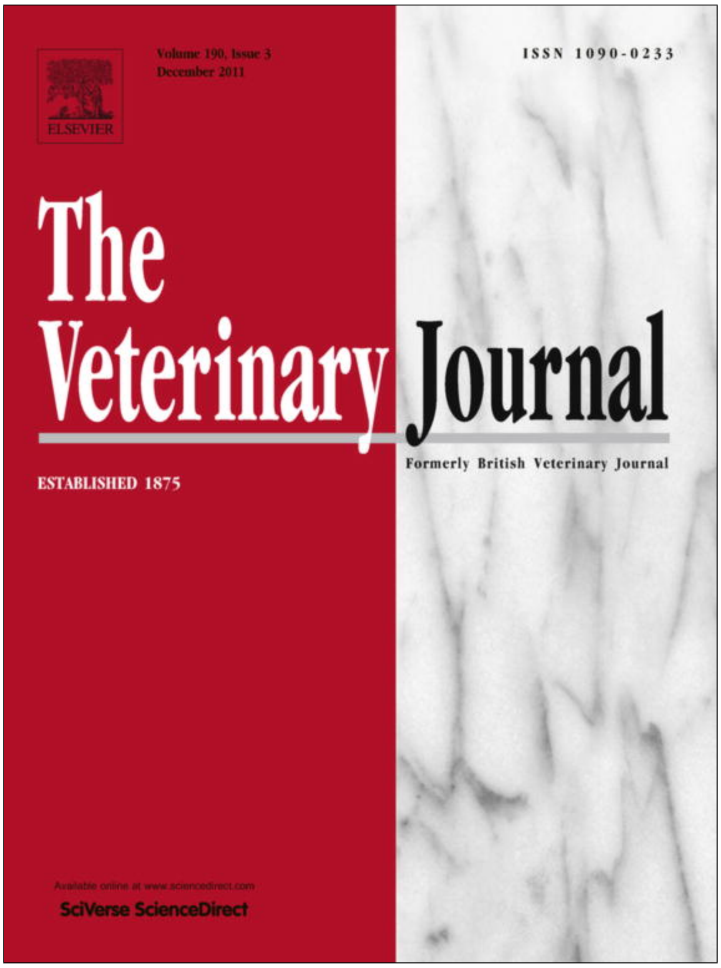
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Review

An epidemiological overview of swine trichinellosis in China

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ABSTRACT

Trichinellosis is a major food-borne zoonosis with health, social, and economic impacts. Epidemiological data on swine trichinellosis in China from 2005 to 2009 were obtained from seven Provinces/autonomous regions/Municipalities (P/A/M) and analyzed and sero-epidemiological data were acquired from five P/A. The seroprevalence ranged from 0.01% to 29.95% as determined by enzyme-linked immunosorbent assay or an immunochromatographic strip method. The prevalence of *Trichinella* infection in swine slaughtered at abattoirs varied from 0% to 5.75% in five P/A. Between 2005 and 2009, endemic areas of swine trichinellosis were located mainly in the Western (Guangxi and Qinghai), central (Henan and Hubei), and North-eastern parts (Heilongjiang) of China.

Swine trichinellosis in China is transmitted mostly through garbage. Pigs infected with *Trichinella* are predominately from small backyard farms where animals are raised under poor hygienic conditions, and from rural and mountainous areas where they range freely at pasture. The prevalence of *Trichinella* in pork sold at the market was reported in four P/A, and varied from 0.06% to 5.6% as determined by trichinoscopy or the digestion method. From 2005 to 2009, 15 outbreaks of human trichinellosis, with 1387 cases and 4 deaths, were recorded in three P/A of South-western China. Twelve (85.71%) of these 15 outbreaks were caused by the eating of raw or undercooked pork, which remains the predominant source of trichinellosis in humans. Pig-rearing practices must be improved, and mandatory inspection of pork further strengthened in rural and mountainous areas in Western China for the control of the disease.

Introduction

Trichinellosis is a serious food-borne parasitic zoonosis that is widely distributed. Of the world's 198 countries, infection with *Trichinella* spp. has been documented both in domestic animals (mainly pigs) and in wildlife in 43 (21.9%) and 66 (33.3%) countries, respectively. Human trichinellosis has been reported in 55 (27.8%) countries (Pozio, 2007) and usually follows the ingestion of raw or undercooked meat, especially pork and its products.

From 1964 to 1999, 548 outbreaks of trichinellosis, with 23,004 cases and 236 deaths, occurred in 12/34 Provinces/autonomous regions/Municipalities (P/A/M) in China (Wang and Cui, 2001a). During 2000–2003, 17 outbreaks of human trichinellosis, with 828 cases and 11 deaths, were recorded in eight P/A with all mortalities in South-western China, where resident ethnic groups have the habit of eating raw meat (Wang, Z.Q., et al., 2006). Of 565 outbreaks between 1964 and 2003, 538 (95.22%) were caused by individuals eating raw or poorly cooked pork. If uncontrolled, this zoonotic disease could pose more serious problems because China is now the largest international producer of pork and in 2008 accounted for 46% of the total world output – a proportion that is predicted to increase (Best, 2010).

Between 1980 and 2004 swine trichinellosis was reported in 26 P/A/M, but the endemic foci were mainly located in seven P/A in the South-western (Guangxi, Sichuan, and Yunnan), central (Hubei and Henan) and North-eastern regions (Liaoning and Heilongjiang) (Wang and Cui, 2001b; Cui et al., 2006a).

This review summarises the current status of *Trichinella* infection in swine by analyzing Chinese publications reporting on the epidemiology of swine trichinellosis in China. All of the data were collected from either the Chinese Academic Literature database (2005–2009)[1] or the Chinese Scientific and Technological Journal database (2005–2009)[2] using the following query: (*Trichinella* or trichinellosis) and the name of the P/A/M.

Seroprevalence of swine trichinellosis

Surveys of the seroprevalence of swine trichinellosis were conducted in five P/A (Fig. 1). Serum anti-*Trichinella* antibodies (IgG) were determined by indirect enzyme-linked immunosorbent assay (ELISA) (Li et al., 1991) or an immunochromatographic strip

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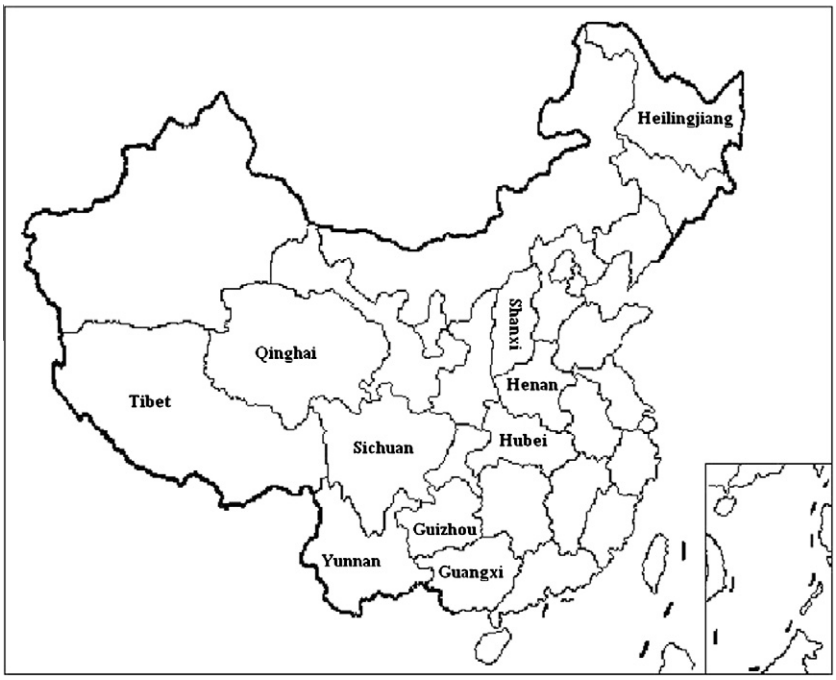

Fig. 1. Map of China indicating the Provinces or autonomous regions (P/A) where the surveys on swine trichinellosis were performed or outbreaks of human trichinellosis occurred during 2005–2009.

Table 1
Seroprevalence of swine trichinellosis in the Provinces/Municipalities (P/M) of China.

P/M	Location	Number examined	Number positive	% Positive	Method	References
Guangxi	Chongzuo	8201	2128	25.95	ELISA	Wei and Huang (2008)
	Pubei	2714	541	19.93	ELISA	Chen et al. (2005)
	Lingshan	1645	293	17.81	ELISA	Teng et al. (2007)
	Qingzhou	4821	858	17.80	ELISA	Wen et al. (2006)
	Hechi	9003	1350	15.00	ELISA	Liu (2005)
		1790	194	10.83	ELISA	Wei and Chen (2008)
	Liuzhou	10,038	93	0.93	ELISA	Li (2007)
Guizhou		610	97	15.90	ELISA	Wei and Chen (2008)
Henan	Pingdingshan	1566	26	1.66	ELISA	Deng et al. (2006)
	Luoyang	33,848	3	0.01	Strip	Wang, M.W., et al. (2006)
	Nanyang	3887	104	2.93	Strip	Wang and Xiao (2007)
Hubei	Shiyan	1270	9	0.71	ELISA	Fang et al. (2005)
Qinghai	Luodu	558	133	23.84	ELISA	Ma et al. (2008)

method using the excretory–secretory (ES) antigen of *Trichinella spiralis* larvae (Zhang et al., 2006). For the ELISA optical density (OD) values <2.1 were regarded as negative and those ⩾2.1 as positive. The specificity and sensitivity of ELISA with ES antigens for pig serology are approximately 98%; the specificity and sensitivity of the immunochromatographic strip is similar (Deng et al., 2006; Zhang et al., 2006). Over the five P/A, seroprevalence ranged from 0.01% to 25.95% (Table 1). Higher seroprevalences were primarily found in Western China; up to 25.95% in some regions of Guangxi probably because this region has more backyard or outdoors pigs than other areas of the country.

Different feeding practices were closely associated with seroprevalence. A survey in Qinghai Province found an overall seroprevalence of 23.8% (133/558), but prevalence varied from 6.9% (9/130) in swine from indoor farms to 28.9% (124/428) in pigs raised outdoors (Ma et al., 2008). The seroprevalence in outdoor-raised pigs in Hechi city of Guangxi Province in 2003 was 35% (21/60), higher than 13.9% (15/108) in indoor-raised pigs (χ^2 = 10.210, P < 0.01) (Liu, 2005). In 2006, a survey of pigs slaughtered in abattoirs in Hechi found that the mean seroprevalence of *Trichinella* infection was 12.13% (291/2400), with the seroprevalence in swine kept at pasture being 11.26% (178/1581) compared to that of indoor-raised pigs of 7.66% (16/209), and outdoor-raised pigs from the mountainous regions of Guizhou Province of 15.9% (97/610) (Wei and Chen, 2008). In contrast, in 2006, the seroprevalence in industrialized pig farms in Luoyang city of Henan Province was only 0.01% (3/33,848) (Wang, M.W., et al., 2006).

Prevalence of swine trichinellosis

Abattoir surveys of swine trichinellosis were performed by direct microscopic examination or the artificial digestion method in slaughterhouses from five P/A during 2005–2009 (Fig. 1); the results are shown in Table 2. Higher prevalences were located mainly in the Western (Guangxi and Qinghai), central (Henan and Hubei), and North-eastern parts (Heilongjiang).

The prevalence of *Trichinella* infection in outdoor-raised pigs in rural areas was higher than that in animals raised on pig farms. For example, at slaughter, the prevalence of swine trichinellosis in

Table 2
Prevalence of trichinellosis in pigs slaughtered in abattoirs determined by trichinoscopy or artificial digestion method in the Provinces/Municipalities (P/M) of China.

P/M	Location	Number examined	Number infected	% Infected	Method	References
Guangxi	Pubei	2714	0	0	Trichinoscopy	Chen (2005)
	Luizhou	10,038	0	0	Digestion	Li (2007)
	Hechi	9196	13	0.1414	Digestion	Liu (2005)
		74,174	1	0.0013	Trichinoscopy	Wei and Chen (2008)
Henan	Luoyang	33,848	3	0.0089	Trichinoscopy	Wang, W.M., et al. (2006)
	Nanyang	304,621	754	0.2475	Trichinoscopy	Chen et al. (2005)
		3887	78	2.0067	Trichinoscopy	Wang and Xiao (2007)
	Pingdingshan	1566	19	1.2211	Trichinoscopy	Deng et al. (2006)
		1566	25	1.6067	Digestion	Deng et al. (2006)
Hubei	Shiyan	1270	9	0.7087	Trichinoscopy	Fang et al. (2005)
	Heilongjiang Harbin	18,360	44	0.2937	Trichinoscopy	Li (2008)
Qinghai	Delingha	400	23	5.7500	Trichinoscopy	Mao (2008)

Table 3
Prevalence of *Trichinella* infection in rats in China.

Location	Number examined	Number infected	% Infected	Method	Reference
Guangxi	3254	49	1.51	Trichinoscopy	Yang et al. (2007)
Henan	68	4	5.88	Trichinoscopy	Wang et al. (2007)
Hubei	2667	279	10.46	Trichinoscopy	Chen (2006)
Yunnan	956	12	1.26	Trichinoscopy	Wang et al. (2007)

Nanyang in Henan was 2.01% (78/3887); however, in these 3887 pigs, the prevalence in those raised outdoors was 2.54% (59/2321), higher than the 1.21% (19/1,566) in swine from indoor farms ($\chi^2 = 8.395$, $P < 0.01$) (Wang and Xiao, 2007). Additionally, the prevalence of trichinellosis in Delingha city in Qinghai Province was 5.75% (23/400) (Mao, 2008). In this region, all pigs were reared in the open, fed raw waste materials, had access to rodents, and could scavenge wild and domestic animal carcasses.

Prevalence of *Trichinella* infection in rats

A survey of rat trichinellosis was carried out by trichinoscopy in four P/A (Table 3). In Guangxi, the overall prevalence of *Trichinella* infection in rats was 1.5%; however, the prevalence was higher in areas where swine trichinellosis and poor hygienic conditions were common. For example, the prevalence of murine *T. spiralis* infection was 4.46% (46/1031) in Debao County (Yang et al., 2007).

Prevalence of *Trichinella* infection in pork sold at the market

The policy that pigs must be collectively slaughtered and inspected for *Trichinella* larvae in appointed public abattoirs began in 1996. However, the prevalence of *Trichinella* infection in pork sold at markets in remote rural areas has tended to be higher, probably because of clandestine slaughter without veterinary inspection. From 2005 to 2009, the prevalence of *Trichinella* infection in pork sold at the market was investigated in four P/A by direct microscopic examination or the artificial digestion method. The prevalence of *Trichinella* varied from 0.06% in Guangxi to 5.60% in Hubei (Table 4).

Table 4
Prevalence of *Trichinella* infection in pork sold at market in the Provinces/Municipalities (P/M) of China.

P/M	Number examined	Number infected	% Infected	Method	References
Guangxi	3584	2	0.06	Trichinoscopy	Yang et al. (2007)
Hubei	12,373	693	5.60	Trichinoscopy	Chen (2006)
Qinghai	144	5	3.47	Trichinoscopy	Wang and Han (2006)
	96	3	3.13	Trichinoscopy	Ruo et al. (2006)
	97	3	3.09	Trichinoscopy	Wan (2006)
	393	18	4.58	Trichinoscopy	Cao and Tang (2008)
	135	6	4.44	Trichinoscopy	Liu and Zhang (2009)
Shanxi	684	4	0.78	Digestion	Wang (2008)

Outbreaks of human trichinellosis after consumption of pork

From 2005 to 2009, 15 outbreaks of human trichinellosis, with 1387 cases and four deaths, were recorded in three P/M (Ke et al., 2007; Gong et al., 2008; Ma, 2008; Zheng et al., 2008; Ci et al., 2009; Feng and Wang, 2009; Wang et al., 2009). All of the epidemic foci of these outbreaks were located in South-western China (nine in Yunnan, two in Sichuan, and four in Tibet), where ethnic groups have the habit of eating raw meat. All four deaths occurred in the South-western region (one in Yunnan, one in Sichuan, and two in Tibet). Although swine *Trichinella* infections were also found in central (Henan and Hubei) and North-eastern regions (Heilongjiang), no outbreaks of human trichinellosis were reported in these areas, probably because the inhabitants of these areas do not eat raw meat.

Pork is still the predominant source of human trichinellosis in China. Of 15 outbreaks, 12 were caused by the eating raw or undercooked pork and two resulted from consumption of raw wild boar (Zheng et al., 2008; Wang et al., 2009). The remaining outbreak of trichinellosis, which involved 49 cases in Yunnan during December 2006, was the first recorded outbreak of imported trichinellosis in China from Laos (Yao, 2008). The affected people had the signs and symptoms of acute trichinellosis 15–20 days after returning to Yunnan from Laos, where they had eaten raw and poorly cooked meat; however, the source of infection (e.g. the kind of meat involved) could not be identified.

Control of swine trichinellosis

To interrupt the transmission of trichinellosis, control measures, including improvement of pig feeding (boiling all swill for 30 min before giving it to pigs and raising pigs in a piggery) and eradication of rats, were applied in Liuzhou city of Guangxi during 2001–2004. The seroprevalence of swine trichinellosis decreased from 2.29% (305/10,191) before the interventions started to 0.93% (93/10,038) at the end of 2004 ($\chi^2 = 111.049$, $P < 0.01$) (Li, 2007).

The development of industrialized pig farms and improvement in pig production practices are clearly associated with a decreased prevalence of trichinellosis. After the establishment of industrialized pig farms in Luoyang city of Henan Province, the prevalence decreased from 1.26% (7451/491,401) in 2002 to 0.0089%

(3/33,848) in 2006 (χ^2 = 512.342, $P < 0.01$) (Wang and Wang, 2002; Wang, M.W., et al., 2006). All 17,210 pigs raised under good hygienic and sanitary conditions from industrialized pig farms were negative for *Trichinella* infection by both artificial digestion and strip procedures (Wang, M.W., et al., 2006).

Wildlife reservoirs

In China, *Trichinella* infection is transmitted mainly by garbage (i.e., feeding pigs with swill containing raw pork scraps). Pigs raised on small farms in city suburbs are often fed garbage or swill from restaurants or hotels. In some rural and mountainous areas of central and South-western China, pigs are raised in backyards under poor hygienic conditions or in open areas where they feed on raw waste products or animal carcasses and are exposed to rodents and wildlife (Chen et al., 2005).

Recently, commercial pig farms where pigs are fed outdoors and kept at pasture have been established in some mountainous areas. However, pastured pigs are vulnerable to *Trichinella* infection through exposure to wild reservoir hosts, which may increase the risk of transmission of *Trichinella* from wildlife to domestic swine (Murrell and Pozio, 2000; Burke et al., 2008). Only limited data are available on the prevalence of trichinellosis in wildlife in China.

In the 1960s, it was reported that 47.1% (49/104) of wild foxes in Gansu Province and 7.7% (1/13) of wild bears in Heilongjiang Province were infected with *T. spiralis* (Liu and Yu, 1960; Cui, 1962). The prevalence of *Trichinella* infection in wild boar was 0.07% in Heilongjiang in the 1990s. *Trichinella* infection has also been recorded in polecats (*Mustela eversmannii* and *Vormela peregusna*) in Inner Mongolia, raccoon dogs in Heilongjiang, and wild boar and bamboo rats in Yunnan Province (Wang et al., 2007).

The wildlife population has increased in recent years because of legal protection and the prohibition of hunting. The role played by wildlife or environmental reservoirs in the transmission of trichinellosis to pigs needs further investigation, and the molecular identification of *Trichinella* isolates from reservoirs may be useful in assessing the risk attribution and identifying reservoirs of infection (Pozio and Murrell, 2006).

In Nandan County in the North-western part of Guangxi, where 23 ethnic groups live and eat raw meat, pigs are raised outdoors. An outbreak of human trichinellosis occurred in this County in 2000, with 36 cases caused by eating acidic fermented, raw pork (Yang et al., 2007). In the village where the outbreak occurred, the seroprevalence in outdoor-raised pigs was 35% (21/60) compared with 13.9% (15/108) in farm-raised pigs (χ^2 = 10.210, $P < 0.01$) (Liu, 2005). The results are similar to epidemiological surveys of swine trichinellosis in Argentina, where pigs raised outdoors were more likely to be infected than pigs raised on pig farms, and those fed waste products containing meat were 12.5 times more likely to be infected than pigs not fed waste containing meat (Ribicich et al., 2009).

Wang et al. (2008) found that villagers in some mountainous and rural areas often buried carcasses of swine that died of other infectious diseases or discarded the carcasses into the fields. However, *T. spiralis* larvae in carcasses can survived and remain infectious at depths of 30, 50, and 100 cm for 90 days (Jovic et al., 2001), as the anaerobic metabolism of *T. spiralis* larvae in nurse cells allows their survival in extremely decayed meat for 2–3 months (Pozio, 2000). Other animals (e.g. rats, foxes, pigs) may dig in the ground, scavenge on the buried carcasses, and acquire the *Trichinella* infection. Thus, the domestic or sylvatic cycle of *T. spiralis* is common in mountainous and rural areas.

The prevalence of murine *T. spiralis* infection was 4.46% (46/1031) in Debao County of Guangxi in which the endemic areas of swine trichinellosis had poor hygienic conditions (Yang et al., 2007). Similarly, in Croatia, *Trichinella*-infected rats were detected only on farms with *T. spiralis*-positive pigs and low, or formerly low, sanitation; no infected rats were detected on farms with *T. spiralis*-negative pigs (Stojcevic et al., 2004). Although the role played by rats in the transmission of trichinellosis to pigs has been debated for >100 years and definitive conclusions have yet to be reached, transmission in a swine herd can be stopped if a microbiological barrier is introduced against rodents and other synanthropic animals in pig sties and in the food silos together with other control measures (Pozio, 2000; Ribicich et al., 2009).

Evidence shows that *Trichinella* infection is emerging in Western China (e.g., Qinghai Province), where several minority ethnic groups (Tibetan, Muslim, Mongolian) reside (Cui et al., 2006b). Beef and mutton are the main meats consumed because pork consumption is limited by religious customs. Routine surveillance confirmed the absence of domestic trichinellosis in Qinghai before 1989, with trichinoscopy of >35,000 pigs killed in Xining (the Provincial capital city) revealing no infections (Dong et al., 1995). However, the Western Region Development strategy of the 1990s elicited migration and settlement of large numbers of people from central to Western China, resulting in increased importation of pork products, either commercially or privately.

In 1990, the incidence of infected pork samples from markets in Xining city was only about 0.12% (Dong et al., 1995), but the abattoir surveys in the Province found a rise to 15.9% in Xining city in 1997 and to 5.75% in Delingha city in 2008, in which all infected pigs sent to abattoirs were raised in backyards or open areas (Zhai et al., 1999; Mao, 2008). From 2005 to 2009, sampling from pork markets in Qinghai Province showed a rising prevalence to 4.05%, with most of the infected pork from pigs slaughtered at private premises without inspection (Wang and Han, 2006; Cao and Tang, 2008). These data show Qinghai Province clearly represents an area of growing risk although no cases of human trichinellosis have yet been reported.

Because trichinellosis in pigs or humans is not a nationally reportable disease, reports of the disease have been provided on a voluntary basis and rely on veterinarians or parasitologists who are studying the parasite. Data obtained from published papers could merely be the tip of a huge iceberg. Hence, a national trichinellosis surveillance system should be established in China as soon as possible. In addition, the prevalence of swine *Trichinella* infection reported in this paper may be potentially biased because of different methods of sample collection (size and site of samples) and inspection (trichinoscopy or artificial digestion).

Good farming hygiene and good feeding practices are the most important measures for controlling *Trichinella* infection in pigs. Improved rearing methods of rearing pigs with all pigs raised in piggery facilities, and all swill boiled for 30 min before being fed would greatly reduce the zoonotic risk (Gamble et al., 2000). To prevent *Trichinella* infections in humans, mandatory inspection of pork should be further strengthened particularly in rural and mountainous areas. In the minority communities whose habit of eating raw or undercooked meat cannot realistically be changed, such food (e.g. raw skins, chop raw, cross bridge rice line, acidic meat) must be prepared only when the meat has been inspected. Additionally, new methods, which can inactivate the *Trichinella* larvae in meat and will still allow the minority communities to maintain their cultural preferences, should further be studied for ensuring ethnic food safety.

Conclusions

Trichinellosis is a serious food-borne parasitic zoonosis, which over the past 5 years has been located mainly in Western (Guangxi and Qinghai), central (Henan and Hubei), and North-eastern parts

(Heilongjiang) of China. Swine trichinellosis is transmitted mainly by garbage. Pigs infected with the parasite are predominately from small backyard farms where animals are raised under poor hygienic conditions, and from some rural and mountainous areas where pigs are pastured freely and feed on raw waste products or animal carcasses. *Trichinella*-positive pork sold at the markets originates mainly from remote rural and mountainous areas where some pigs have been clandestinely slaughtered at home without veterinary inspection. Pork is still the predominant source of outbreaks of human trichinellosis in China. Pig-rearing practices should be improved; all pigs should be raised in piggery facilities, more industrialized pig farms should be established, and mandatory inspection of pork should be further strengthened for control of trichinellosis.

Conflict of interest statement

None of the authors of this paper has a financial or personal relationship with other people or organizations that could inappropriately influence or bias the content of the paper.

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