DOI: 10.55415/deep-2023-0001.v1

A marked decline of *Taenia solium* taeniasis and cysticercosis infections in China: possible reasons from ecological determinant perspectives

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DOI: 10.55415/deep-2023-0001.v1

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DOI: 10.55415/deep-2023-0001.v1

Abstract

Taenia solium taeniasis/cysticercosis is an important global food-borne infectious diseases transmitted between humans and pigs. According to both national surveys and field prevalence investigations, the prevalence of the disease in China has decreased significantly in recent decades. The primary disease control measures are unquestionably health education and promotion, meat inspection, and chemotherapy. Some other factors that could also influence or have a fundamental impact on human and pig *T. solium* taeniasis/cysticercosis have been identified, such as pig farming patterns shift and the human toilet revolution, which led to *T. solium* transmission routes being cut off. Pig farming practices have shifted from backyard to large-scale intensive farming, making it harder for pigs to come into contact with or consume human excreta. The human toilet revolution, aiming at increasing the use of sanitary toilets, would ensure hygienic separation of human excreta from human contact, and prevent human excreta from polluting the environment, feeds, or water. The occurrence of the human *T. solium* infections has been drastically reduced as a result of the social process. This article with the objective of identifying ecological determinants, in addition to the previously noted factors, leading to the cysticercosis decline in China.

Key words: *Taenia solium*; epidemiology; pig farming patterns; toilet revolution; China

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INTRODUCTION

Taenia solium taeniasis/cysticercosis is an important food-borne infections that is transmitted between humans and pigs all over the world [1,2]. Taeniasis generally causes human intestinal diseases, whereas cysticercosis is a very serious disease that infect both humans and pigs [3]. Porcine cysticercosis primarily infects pig muscle and brain tissues, resulting in lower pork quality [4]. Human cysticercosis has been reported in a variety of forms, including neurocysticercosis (NCC), ocular cysticercosis (OCC), subcutaneous muscle cysticercosis, oral cavity cysticercosis, visceral cysticercosis, and others [5,6,7]. Human NCC is mainly responsible for seizures, high intracranial pressure, and psychiatric disorders, and it continues to be a major disease burden on people in many parts of the world [2,8,9,10].

T. solium taeniasis/cysticercosis is a severe cestode infection that is common in humans and domestic pigs (*Sus scrofa domestica*) or wild boar (*Sus scrofa*) co-existing in raised areas, particularly those with warm and mild climates in Latin America, Sub-Saharan Africa, Southeast Asia, the Indian subcontinent, and China [2,3,11]. In some *T. solium* endemic areas, cysticercosis is still a major cause of seizures and epilepsy in humans [12,13,14]. Travel and immigration make NCC is a health burden even in non-endemic regions such as the Americas and Europe [1,15]. *T. solium* cysticercosis causes NCC in approximately 50 million people worldwide, with more than 50,000 deaths per year [16], and studies show that the health burden of cysticercosis is larger than what public health systems have noted [17,18].

Humans and pigs both have an important role in the *T. solium* life cycle (Figure

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1). Humans become infected with tapeworms by consuming raw or undercooked pork that contains cysticerci [19]. The larval tapeworm matures into an adult worm in the human small intestine in about two months after being consumed [19]. Humans are the only natural definitive hosts for *T. solium* [3]. The worm's eggs or the most distal worm segments (proglottids) carrying mature eggs are periodically released/detached and subsequently discharged into the environment with human stool [3,20]. Via the fecal-oral route, these eggs can infect the same person (auto-infection) or other people through direct contact with tapeworm carriers or by the ingestion of contaminated food or water [19,21]. Pigs get infected when they consume infectious eggs (gravid proglottids) found in human excrement, food, water, and soil [3]. Humans and pigs could both act as intermediate hosts, and the embryo is released (oncosphere) after ingestion and migrates through the intestinal mucosa. Later, the larval stages (cysticercus) commonly infest host body organs such as the muscle, brain, eyes, subcutaneous tissues, and viscera via the blood circulatory system [3]. Following that, humans become infected by consuming raw or undercooked pork containing cysticerci, and the larval matures into adult worm in the small intestine in about two months [19].

Domestication of wild boars began 9,000 years ago, and domestic pig rearing has been a common practice in Asian countries for more than 2,500 years [22]. Cysticercosis has long been a worldwide zoonosis transmitted between pigs and humans, and now it was as primarily imported cases in China [23]. *T. solium* taeniasis/cysticercosis prevalence in China has been significantly reduced in recent

DOI: 10.55415/deep-2023-0001.v1

decades as a result of ongoing health education and promotion, meat inspection, chemotherapy, and other measures [23,24,25]. Furthermore, there have been dramatic changes in pig farming patterns and human sanitary conditions in China's rural communities over the last few decades [26,27]. In this paper, we reviewed the epidemiology, traditional measures, and ecological determinants that contributed to the decline of *T. solium* taeniasis/cysticercosis in China.

We searched PubMed, Web of Science, MEDLINE, ScienceDirect, China National Knowledge Infrastructure (CNKI), and WANGFANG DATA for publications written both in English and Chinese about epidemiology records for humans and pigs using the search terms "*Taenia solium*" AND "China", OR "cysticercosis" AND "China" OR "taeniasis" AND "China" OR "Cysticercus cellulosae" AND "China". We restricted our search to updates published before April 31, 2021.The titles and abstracts of the literature were screened first, followed by the full articles, for inclusion in the epidemiology summary in this article. The literature from the recent reviews was also used to find the original records. Additional key references were retrieved from the published personal databases of all coauthors.

EPIDEMIOLOGICAL RECORDS

Three national surveys

China, until now, has undertaken three nationwide surveys on human intestinal parasitic diseases by morphological examination (the Kato Katz method was used) (Table 1). In the first national survey (1988-1992), a total of 1,477,742 individuals

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from 30 provinces (out of 31 provinces (autonomous regions and municipalities) in Chinese mainland) were investigated, and 2,449 individuals from 28 provinces had *Taenia* spp. infections [28]. Based on these findings, the overall number of *Taenia* spp. infections in this country was estimated to be around 1.3 million [29]. The second nationwide survey (2001-2004) was conducted in 31 provinces (out of 31 provinces (autonomous regions and municipalities) in Chinese mainland) with a total sample size of 356,629 people, with 983 people from 12 provinces (38.7%, 12/31) being determined to have *Taenia* spp. infection [30]. According to these findings, 0.55 million people were infected in total in estimation [30]. In the third nationwide survey (2014-2015), *Taenia* spp. was found in 1,752 people from 12 provinces (38.7%, 12/31) out of 617,441 people from 31 provinces (out of 31 provinces (autonomous regions and municipalities) in Chinese mainland) [31]. After accounting for demographic structure in the entire population, an average prevalence of 0.06% was calculated, implying that 0.37 million people were infected [31].

Three national human parasitic disease surveys in China revealed a significant decline in human *T. solium* taeniasis/cysticercosis. *T. solium* cysticercosis was historically prevalent in northeastern, southwestern, and central of China; and, three national surveys concluded that the occurrence of taeniasis has decreased considerably in most areas of China (Figure 2). Nevertheless, the infections have been slightly higher in areas of southwest China with poor socioeconomic conditions, particularly in Tibet, Sichuan, and Yunnan [23,32,33].

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Field prevalence of porcine cysticercosis

As human taeniasis/cysticercosis infections, there are some documents on the epidemiology of porcine cysticercosis, most of which were conducted during the slaughter quarantine, as reported in Chinese literature. When comparing the prevalence of pig cysticercosis in different years in the same area, it is found that the prevalence has significantly decreased (Figure 3). Since humans are the only natural definitive host of *T. solium*, pigs become infected by consuming human feces as well as contaminated food, water, and dirt, which is considered the most common transmission route [3,34].

Several field prevalence investigations of porcine cysticercosis revealed a significant decrease of the disease in pigs. During the pork meat inspection, macroscopic observation and microscopic examination based on parasite morphology were the primary detection methods for pig cysticercosis. Although, only a few fragments documented available, it could also reveal a significant decline with the few documents available for porcine cysticercosis infections (Figure 3).

TRADITIONAL CONTROL MEASURES

Health education and promotion

Health education and promotion have been shown to be highly beneficial in controlling *T. solium* taeniasis/cysticercosis in rural communities worldwide, not just in China [24,25,35,36]. It refers to a comprehensive social and political process including not only improving knowledge and developing life skills for individual but

DOI: 10.55415/deep-2023-0001.v1

also changing the societal, environmental, and economic conditions to reduce the unhealthy impact on individual and community [24,37]. In order to effectively control *T. solium* taeniasis/cysticercosis in China, health promotion and education are primarily directed at the susceptible population and infected individuals [24,25,35].

Meat inspection

Pork contaminated with cysticercus is an important source of *T. solium* taeniasis and cysticercosis in humans [38]. Meat inspection of pigs at slaughter is an important public health measure to prevent *T. solium* transmission to humans [39,40]. Meat inspection during pig slaughter has also been implemented in China as a crucial public health precaution [19].

Chemotherapy

In most cases, antiparasitic drugs such as praziquantel, niclosamide, albendazole, and others are used to destroy live or degenerating cysticerci [13]. Recently, a combination of pumpkin seeds and areca nut has been explored against taeniasis, while praziquantel and albendazole are administrated simultaneously against cysticercosis, with promising efficacy and low side effects [23]. Surgery is also required in severe cysticercosis cases, such as to reduce intracranial pressure and resolve hydrocephalus in NCC, OCC, and other cases [41,42,43].

ECOLOGICAL DETERMINANTS

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Pig farming patterns shifting from backyard to large-scale intensive

In general, there are three types of pig farming patterns in China: backyard farms (raising fewer than five pigs per year), specialized household farms (annual pig production of 5 to 500 heads, with 50 to 200 heads being the most common), and large-scale intensive pig farms (raising ranges from 500 to 50,000 pigs per year, or above) [26]. Smallholders (backyard farms) produced most of China's pork for the past thousands of years. Prior to 1978, no less than 95% of the national pork was produced on these "backyard farms", which farmed fewer than five pigs per year, raising along with crops and other domestic animals [44]. In backyard farms, pigs' feeding troughs, the human toilet, and the pigsty are always next to each other, and pigs easily consume human stool or contaminated food and water [44].

Following China's Reform and Opening (which began in 1978), the structure of pig farming in China began to change, starting off a trend towards large-scale intensive commercial pig husbandry that is still going strong today [24]. Production scales on these farms vary from 500 to 50,000 pigs in a year, and they are quickly increasing each year. A single farm may produce 100,000 pigs in a single year, which is not uncommon [26]. These farms were responsible for only 2.5% of the overall pork yield in 1985, but by 2007, their share had increased to 21.8%, and it reached 43.3% in 2015 [45]. In this situation, the human toilets and the pigsties are completely separated, and the pigs are not allowed to consume human waste or contaminated feeds and water (Figure 1).

At the same time, the specialized household farms fall somewhere between the

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backyard farm and the large-scale intensive pig farm. The proportion is significantly different in some areas, such as in Sichuan Province, where specialized households account for 25% of the total, while large-scale intensive pig farms account for only 5% [26]. Backyard farms produced around 27% of all pork produced in China in 2007, while the share of smallholders (backyard farms) is significantly higher in some areas, demonstrating the unbalanced development of pig farming across geographical regions. For example, during the same time period (2007), backyard farmers produced 70% of the pigs in Sichuan Province, China, which is the historical and current national leader in pork production, compared to roughly only 20% in Guangdong Province, China [26].

Overall, pig farming is irreversibly progressing from backyard to large-scale intensive as time passes in China [26]. As pig farming practices have changed, it has become increasingly difficult for pigs to come into contact with or consume human excreta or contaminated feeds and water. Thus, the transmission of *T. solium* between humans and pigs has largely been cut off in some large-scale intensive pig farming areas. As a result, shifting pig farming patterns create unfavorable conditions for intermediate host pigs to become infected with cysticercus, disrupting the *T. solium* transmission pathway and ultimately halting disease spread [24].

Human toilet revolution aimed at improving sanitary conditions

Poor sanitation and lack of sanitary toilets have been identified as the main risk factors for the presence of *T. solium* circulating infections in epidemic areas [46].

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Human cysticercosis was once more common in China's vast rural areas, where there was poor sanitation and a lack of sanitary toilets [47,48].

The initial goal of the human toilet revolution was to promote the use of sanitary toilets in China's vast rural communities [49]. Nowadays, the concept of the toilet revolution is being expanded upon, covering the overall sanitary system, not just the toilet [50]. In rural China, the number of sanitary toilets has significantly increased over the last few decades, and the toilet revolution has made significant progress in improving sanitation infrastructure [51]. Thus, human sanitary toilet coverage has increased from 7.5% in 1993 to 81.7% in 2017 [49,52].

The toilet revolution sought to ensure the hygienic separation of human fecal materials from human touch as well as to prevent human feces from contaminating the environment [49,50]. In this situation, the volume of untreated excrement (which contains worm eggs or gravid proglottids) released into the environment was significantly reduced, while the possibility of pigs easily consuming human excreta was greatly reduced (Figure 1).

During the ongoing toilet retrofitting campaign in rural areas, China has made significant progress toward a new socialist countryside, with sanitary condition in rural communities significantly improving [52]. These environmental reconstructions disrupt the life cycle and transmission of *T. solium* between humans and pigs, halting disease spread.

COMBINATION OF COMPREHENSIVE DETERMINANTS

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T. solium is transmitted by the fecal-oral route between humans and pigs. The spread of human taeniasis/cysticercosis is leading by inadequate sanitation, poor hygiene, the use of human excrement (untreated or partially treated) in agriculture, inappropriate food preparation, insufficient knowledge about the risk of infection while visiting endemic locations, and the ingestion of raw or undercooked pork, especially in areas where pigs are reared in deplorable conditions [53,54,55,56]. In the prevention and control of *Taenia* spp. infections and cysticercosis, sanitary cleanliness and health education should be included, as should treatments consisting of human chemotherapy with better diagnostic techniques for taeniasis, as well as porcine chemotherapy, or even vaccination [57].

In the past few decades, significant efforts have been made and are still being made to eliminate human cysticercosis. Among these efforts are health promotion, meat inspection, chemotherapy, and combined comprehensive measures, which are without a doubt the primary control measures for the diseases [24]. However, some additional factors, such as changes in pig farming practices and the development of modern toilets, that could affect human and pig *T. solium* taeniasis/cysticercosis have also been identified. These changes could cut off the *T. solium* transmission route. Although, these two factors were often mentioned in the previous articles [2,58,59], the fundamental significance for reducing human cysticercosis by stopping disease transmission was not adequately covered in those earlier articles.

The spread of *T. solium* taeniasis and cysticercosis is being gradually and noticeably stopped along with the shift in pig farming practices from small-scale to

DOI: 10.55415/deep-2023-0001.v1

large-scale intensive, as well as the revolution in the use of sanitary toilets by humans. However, *T. solium* taeniasis and cysticercosis are still prevalent in some low-socioeconomic areas of China, particularly in rural communities in Sichuan, Yunnan, and Guangxi, where pigs are reared in substandard management conditions, and the consumption of raw or undercooked pork is a traditional living habit [32,44,53,54,55]. Therefore, before completely eliminating cysticercosis, health education and promotion, meat inspection, and chemotherapy are necessary.

LIMITATIONS

Although the marked decline of taeniasis and cysticercosis infections in China has been widely accepted, it suffers from some limitations concerning the epidemiological records both for humans and pigs. The relatively low-sensitive detection technique such as Kato Katz method was used during all three nationwide surveys for *Taenia* eggs. With regard to pig cysticercosis, only a few documents were available at the same place in China. Likewise, both the control measures and ecological determinants have been considered as combined comprehensive social processes leading to the gradual decline of taeniasis and cysticercosis in China. However, it was very difficult to provide further information regarding the nexus between the exact factors and disease decline one by one.

CONCLUSIONS

T. solium taeniasis/cysticercosis is an important food-borne zoonotic parasitic disease.

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A number of factors have contributed to the decrease in taeniasis/cysticercosis in humans and pigs. Besides health education and promotion, meat inspection at slaughterhouses, and chemotherapy contributed to China's marked decrease in *T. solium* taeniasis/cysticercosis. Furthermore, the structural shift in pig farming from backyard to large-scale intensive pig farming, as well as the toilet revolution intended to improve sanitary conditions, both of which created unfavorable conditions for the intermediate hosts, pigs acquired cysticercosis. They are the two crucial factors that should be taken into consideration for decline or restrict the spread of *T. solium* between humans and pigs.

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CONFLICTS OF INTEREST

The authors declare no competing interests.

AUTHOR CONTRIBUTION

LZ and JL conceived the idea for this review, JL and LZ wrote the first draft for this manuscript. JL, FX, YC, KZ and YW, did the literature search, analyzed the data, made the figures, and also assisted in writing. MRK, XL, PD, and RW explored the data, smoothed the language and assisted in overall improvement of the manuscript. All authors have read and approved the final version of the review.

ACKNOWLEDGMENTS

This work was partially supported by the National Natural Science Foundation of China (32102689), the Outstanding Talents of Henan Agricultural University (30501055), and the Leading Talents of the Thousand Talents Program of Central China (19CZ0122).

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DOI: 10.55415/deep-2023-0001.v1

FIGURE CAPTIONS:

FIGURE 1: The life cycle and mode of transmission of *Taenia solium* in humans and pigs.

The blue cycle indicates the traditional life cycle of *Taenia solium*. Humans become infected and the tapeworms colonize in the gut after consuming raw or undercooked pork containing cysticerci. The larval tapeworm matures into an adult worm in the human small intestine in about two months. The worm's eggs or the most distal worm segments (proglottids) carrying mature eggs are periodically released/detached and subsequently discharged into the environment with human stool. Pigs get infected when they consume infectious eggs (gravid proglottids) in human excrement, food, water, and soil. Humans and pigs could both serve as intermediate hosts, and the embryo is released (oncosphere) after ingestion and migrates through the intestinal mucosa. Later, the larval stages (cysticercus) commonly infest host body organs such as the brain, eyes, subcutaneous tissues, and viscera via the blood circulatory system. Following that, humans become infected by consuming raw or undercooked pork containing cysticerci, and the larval stage matures into an adult worm in the small intestine in about two months. **The gray dashed cycle represents the rebuilding *T. solium* life cycle.** As a result of a structural shift in pig farming from backyard to large-scale intensive pig farming, as well as a toilet revolution aimed at improving sanitary conditions, the transmission of *T. solium* between humans and pigs has been significantly interrupted, and the disease's spread is being gradually stopped.

FIGURE 2: Three national surveys on human taeniasis/cysticercosis in China

DOI: 10.55415/deep-2023-0001.v1

(adapted from Qian et al., 2020).

Different colors represent different prevalence of taeniasis during three national surveys. The darker color (red) indicates the higher prevalence rate, and the lighter color (green) indicates the lower prevalence rate. *T. solium* cysticercosis was historically prevalent in northeastern, southwestern, and central China, and three national surveys claimed that the frequency of taeniasis has decreased considerably in most areas of China. However, infections have been high in areas of southwest China with poor socioeconomic conditions, particularly in Chinese Tibet, Sichuan, and Yunnan.

FIGURE 3: Investigations of porcine cysticercosis by regional distributions, and the degree of intensive pig farming and sanitary toiler coverage over the last few decades.

The prevalence of porcine cysticercosis has been noticeably declining, according to a comparison of the documented cases during the slaughter quarantine for various years in the same region. Furthermore, the degree of intensive pig farming (from 2.5% in 1985 up to 43.3% in 2015) and sanitary toilet coverage (from 7.5% in 1993 up to 81.7% in 2017) in Chinese rural areas increased year by year during these periods.

DOI: 10.55415/deep-2023-0001.v1

TABLE 1 National surveys on human taeniasis/cysticercosis in China

Surveys	Sampling periods	Number of provinces surveyed/ total number of participants	Positive provinces/participants	Estimated prevalence in whole nation	Estimated infection cases in whole nation
First	1988-1992	30/1,477,742	28/2,449	0.17%	1.3 million
Second	2001-2004	31/356,629	12/983	0.28%	0.55 million
Third	2014-2015	31/617,441	12/1,752	0.06%[a]	0.37 million

[a] It was a weighted prevalence, and it was estimated after adjustment by the population structure in total population