Porcine Cysticercosis

Disease Monograph Series – 06

Parasite | Taeniidae | *Taenium solium* | Pigs

IDRC | Bartay

This monograph forms part of a series of disease monographs commissioned by the International Development Research Centre over the period Nov 2015 to April 2016 to inform funding priorities for the Livestock Vaccine Innovation Fund (LVIF). The LVIF is a seven-and-a-half year, CA$57 million partnership between the Bill & Melinda Gates Foundation, Global Affairs Canada and Canada's International Development Research Centre. It focuses on those animal diseases posing the greatest risk to poor livestock keepers in Sub-Saharan Africa, South and Southeast Asia, targeting transboundary diseases to achieve lasting regional impact.

Table of Contents

Acronyms

Ab-ELISA	Antibody enzyme-linked immunosorbent assay
Ag-ELISA	Antigen enzyme-linked immunosorbent assay
CLTS	Community Led Total Sanitation
CWGESA	Cysticercosis Working Group in Eastern and Southern Africa
EITB	Enzyme-linked immunoelectrotransfer blot
ELISA	Enzyme-linked immunosorbent assay
FAO	Food and Agriculture Organization of the United Nations
IgG	Immunoglobulin G antibody
ITFDE	International Task Force for Disease Eradication
NCC	Neurocysticercosis
OIE	World Organization for Animal Health
OFZ	Oxfendazole
T. solium	*Taenia solium*
USA	United States of America
TSOL18	Vaccine made from recombinant protein of the *T. solium* homologue of 18-kDa
US CDC	U.S. Centers for Disease Control and Prevention
WAHID	Interface for the World Animal Health Information System
WAHIS	World Animal Health Information System

WHO	World Health Organization

Executive Summary

The OIE defines Cysticercosis as a

disease of farmed and wild animals which is caused by the larval stages (*metacestodes*) *of cestodes of the family* Taeniidae (*tapeworms*), *the adult stages of which occur in the intestine of humans, dogs or wild* Canidae*. Porcine cysticercosis [is a disease of pigs] that occurs primarily in muscle, the central nervous system and the liver caused by the metacestodes (cysticerci)* of *the human cestode T. solium. T. solium* is a digenetic parasite having a life cycle, which requires two hosts [1]. "Taeniasis" is the term used to describe the infection of humans with either adult pork tapeworms (*T. solium*) or beef tapeworms (*T. saginata*) [4].

Understanding of *T. solium* is derived mainly from experimental studies with small sample sizes within distinct national and regional contexts. Nevertheless, it is known that the diversity of genetic and immunological characteristics of *T. solium* is significant. Several peptide antigens are significant markers and some could be important to include as potential vaccine candidates. TSOL18 is an oncosphere antigen peptide of *T. solium* that is an ideal vaccine candidate [11].

Animals acquire infection from ingestion of food or water contaminated with sticky eggs, ingestion of segments or feces containing eggs and pigs also acquire *T. solium* by ingesting of the feces of pigs that have eaten segments of *Taenia*. Humans may be infected with *T. solium* by eggs present on vegetables, soil and in water that have been contaminated by feces, or through food contaminated by dirty hands, by fecal-oral transmission or through retroperistalsis [1]. The free-range pig husbandry system is identified as a leading risk factor in the digenetic host cycle through a complex web of epidemiological interactions at the human-pig-environmental interface [15]. Porcine cysticercosis ranks as the 7th most economically significant disease of pigs globally measured in livestock units lost globally, and additionally *T. solium* is a leading cause of epilepsy for humans in developing countries (global pooled prevalence estimate: 29%; 95% CI: 22.9%–35.5%) [3][4][23][25].

The majority of adult and larval tapeworm infections in humans and pigs respectively, cause little or no signs of overt disease. Exceptions are severe, potentially fatal human cases of NCC caused by *T. solium*, which may also cause muscle or ocular signs in humans. The OIE specifies that the *routine diagnosis of taeniosis continues to be mainly based on the morphology of the adult tapeworm and the presence of eggs or segments in the feces of infected definitive hosts* [1]. However this test lacks specificity as the eggs of *taenidii* cannot be distinguished morphologically [17]. Most of the serological techniques developed for the diagnosis of cysticercosis in humans have been adapted for analyzing pig sera [17]. Interpretation of serology in pigs remains difficult due to lack of sensitivity and specificity.

Of the 207 official reports of porcine cysticercosis submitted among the 20 selected countries under the LVIF, 47% were reported in Madagascar and 97% of all events were reported from African countries, while the remaining 3 % were reported in Myanmar. Country incidence reporting is very limited, especially in Asia and does not coincide with high prevalence statistics, particularly in Nepal, Indonesia and Viet Nam.

No registered vaccine for *T. solium* is currently available. However, a combination of vaccination with TSOL18 and OFZ treatment has been demonstrated to be highly effective in experimental control of natural transmission for pigs [1]. A holistic strategy for Porcine Cysticercosis vaccination includes the following considerations:

Short-term

- Support the transition from research projects to country programs including policy, advocacy and community needs assessments;
- License the current vaccine formulation and optimize the TSOL18 for a single dose regimen;
- Initiate the development of a rapid pen side tests: one for surveillance purposes to identify highly endemic areas and one for slaughter decision making and carcass disposition (whole versus partial carcass condemnation);
- Support field trials to validate and optimize field application of TSOL18 plus OFZ under a variety of epidemiological conditions;
- Integrate animal health, public health and private industry to advance advocacy and technology transfer, respectively.

Medium- to long-term

- Develop a one dose formulation for TSOL18 to deal with challenges in revaccinating free range pig rearing;
- Develop bivalent/multivalent TSOL18 formulation models in combination with classical swine fever (Asia) and African swine Fever (Africa) under a One Health approach to provide incentives for smallholder farmers and public health agencies;
- Support the development of comprehensive joint intersectoral, country-specific and culturally specific intervention models for cysticercus (source reduction) and taeniosis (human mitigation) at the human-animal-environmental interface. (Madagascar, Viet Nam, Burkina Faso, Nepal).

Gaps in knowledge or capacity impacting strategic planning and effective adoption and implementation of vaccination for Porcine Cysticercosis:

- Optimization of the field application of TSOL18 plus OFZ based on local risk, needs, cultural preferences under a comprehensive One Health approach;
- Need for a cheap, highly sensitive and highly specific pen side antigen detection test for *T. solium* for 1) routine surveillance and for 2) carcass disposition at slaughter plants;
- Shifting from academic approach to a government-led (user-driven) policy and programmatic framework. A program driven approach through policy development is currently being developed in Peru and Madagascar and soon in Viet Nam.

- Work on *T. solium* in pigs should be synergized with related needs for Schistosomiasis and prioritized pig diseases in order to identify high risk and high impact areas to promote complementary and synergistic interventions at the human-pig-environmental interface;
- Define the required market incentives needed to promote the vaccination and treatment of pigs for *T. solium.* The knowledge, attitudes and practices (KAP) of smallholders should be evaluated to define how to manage the disposition of slaughtered pigs which clear the infection as a result of vaccination;

New and alternative marketing options should be developed for acceptable products made from previously infected and healthy pigs including smoked processed meat products that can generate profits in niche markets.

Clinical disease overview

Etiology

The OIE defines Cysticercosis as:

"a disease of farmed and wild animals which is caused by the larval stages (*metacestodes*) *of cestodes of the family* Taeniidae (*tapeworms*), *the adult stages of which occur in the intestine of humans, dogs or wild* Canidae. *Porcine cysticercosis is a disease of pigs that occurs primarily in muscle, the central nervous system [CNS] and the liver caused by the metacestodes (cysticerci) of the human cestode T. solium. Cysticerci of T. solium also develop in the CNS and musculature of humans. Taenia asiatica is a less widespread cause of cysticercosis in pigs, with the cysts locating in the liver and viscera and the adult tapeworm occurring in humans* [1]*."*

T. solium signifies the genus and species respectively of the cestode (pork tapeworm) that is classified under the Phylum Platyhelminthes, Class Eucestoda and Order Taenioidea [2].

The key stages of the life history of *T. solium* is summarized in Table 1 and depicted graphically in Figure 2 [2][3].

Parasite biology

T. solium is a digenetic parasite having a life cycle, which requires two hosts. Man is the primary host and pigs are the secondary host for the tapeworm, *T. solium*. The body of the adult *T. solium* is elongated, dorso-ventrally flattened and ribbon-like body, which can be white, grey or cream in colour. The size of adult worm ranges from 3-5 meters but may grow up to 8 meters in length (Figure 1) [2].

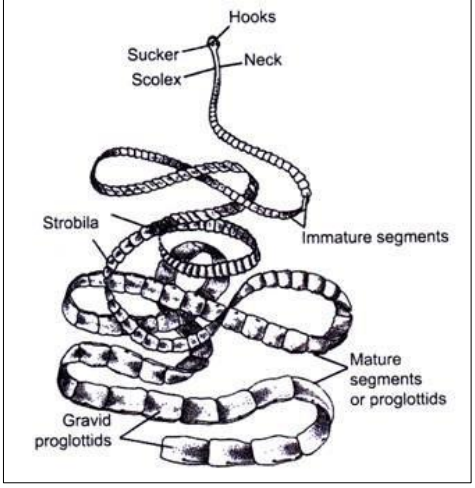


Figure 1: *T. solium* tapeworm (Source: Biology discussion. http://www.biologydiscussion.com/parasites/the-nstructure-and-life-cycle-of-taenia-with-diagram/2727 (Accessed 1/7/2016)

Table 1: Life cycle stages of *T. solium*.

Step	Host	Event
1	Humans Primary or definitive host for *T. solium*	Eggs or gravid proglottids are passed with feces and the eggs can survive for days to months in the environment
2	Pigs Secondary host of *T. solium*	Become infected by ingesting vegetation or feed contaminated with eggs or gravid proglottids; after pigs ingest the eggs, bile and enzymes trigger the disaggregation of the embryophoric blocks and digest the oncospheral membrane.
3	Pigs	In the animal's intestine, the oncospheres hatch, invade the intestinal wall, and migrate to the striated muscles, where they develop into cysticerci. A cysticercus can survive for several years in the animal.
4	Humans	Become infected by ingesting raw or undercooked infected meat; In the human intestine, the cysticercus develops over 2 months into an adult tapeworm, which can survive for years.
5	Humans	The adult tapeworms attach to the small intestine by their scolex
6	Humans	Adult tapeworms reside in the small intestine
7	Humans	The adults produce proglottids through self-fertilization which mature, become gravid, detach from the tapeworm, and migrate to the anus or are passed in the stool (approximately 6 per day); The eggs contained in the gravid proglottids are released after the proglottids are passed with the feces; *T. solium* may produce 50,000 eggs per proglottid.

"Taeniasis" is a term used to describe infection of humans with either adult pork tapeworms (*T. solium*) or beef tapeworms (*T. saginata*) [4]. It is critical to note that pigs or humans are infected by ingesting the embryonated eggs or gravid proglottids after ingesting food or water that is fecally contaminated. Significantly, autoinfection may occur in humans if proglottids pass from the intestine to the stomach via reverse peristalsis [5]. In this sense, humans can also act as an intermediate host, though it is unknown how often this happens [6].

The pig cysticerus larvae eaten by humans evaginate in the small intestine; the head (scolex) attaches to the mucosa and begins forming segments (proglottids). *T solium* has a scolex with four suckers and a double crown of hooks, a narrow neck, and a large strobila measuring 2–4 mm and consisting of several hundred proglottids. About 2 months after infection, gravid proglottids begin to detach from the distal end and are excreted in faeces; each segment contains 50–60 X 10^3 fertile eggs [6].

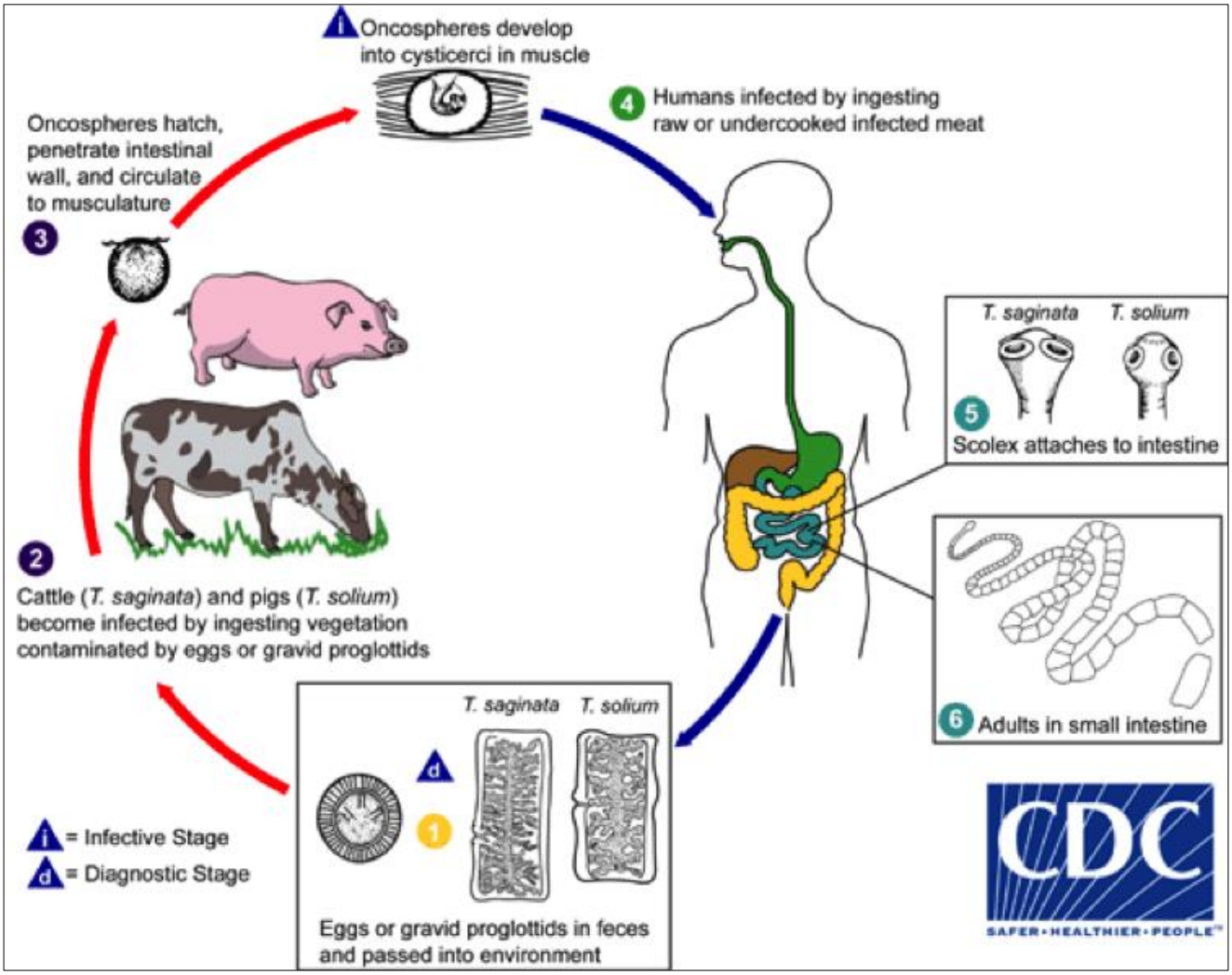
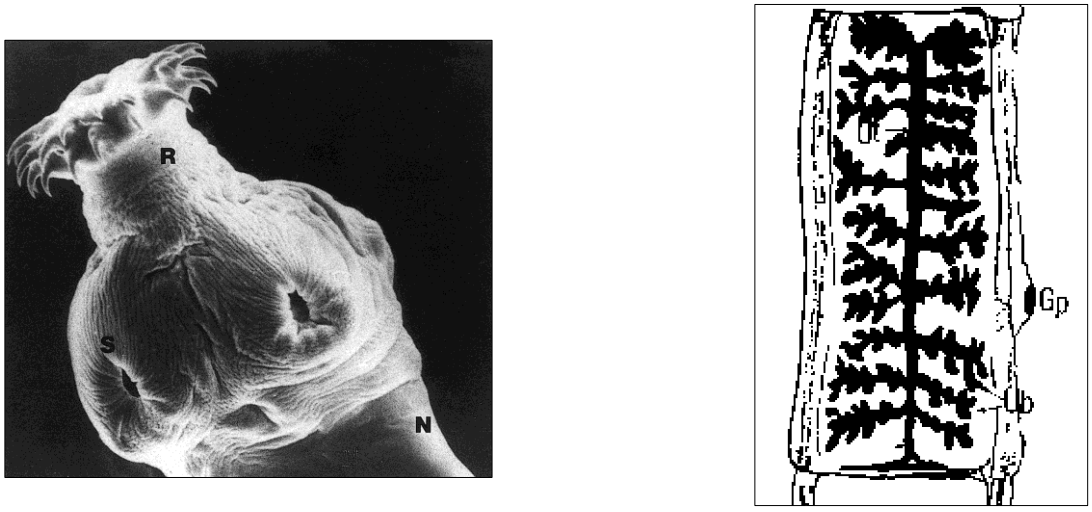


Figure 2: Life cycle of pig tapeworm (*T. solium*) and beef tapeworm (*T. saginata*)

The structure of the adult *T. solium* tapeworm head is presented in Figure 3a. The following features are noteworthy: rostellum (R); sucker (S); and neck (N). Suckers and rostellum are responsible for attaching to the intestinal wall. Gravid proglottids measure 12 × 6 mm and possess a genital pore (Gp) uterus with seven to ten lateral branches (Ub) containing both testes and ovary (Figure 3b) [7].



a) b)

Figure 3: a) Electron micrograph of an adult tapeworm head; b) Gravid proglottid

Epidemiology

Early Hebrew and Muslim cultures knew about the disease in ancient times. In 1855, Kuchenmaister conducted a study by feeding condemned prisoners with cysticercosis-infected pork and recovered young tapeworms at autopsy [6]. The infection occurs today in many countries in Europe and sporadically in the United States of America (USA), Canada, Australia and New Zealand primarily through infected immigrants. *T. solium* of humans is associated with both porcine cysticercosis and human NCC. It is found principally in Mexico, Central and South America, sub-Saharan Africa, non-Islamic countries of Asia, including India and China in regions with poor sanitation and free-ranging, scavenging pigs. Cysticercosis remains highly endemic in humans and is linked to poverty, lack of awareness, lack of suitable diagnostic, sanitation and management capacity and the appropriate prevention and control strategies [1][7].

The genetic analysis of a wide variety of tapeworm species reveals that those taenids that infect humans are most closely related genetically to those that infect modern lions and hyenas (Figure 4). This evidence contradicts the view that humans originally acquired tapeworms from domesticated livestock, cattle and swine, following the agricultural revolution around 10,000 years ago [8][9]. The epidemiological relationships among primary and secondary hosts have changed over time.

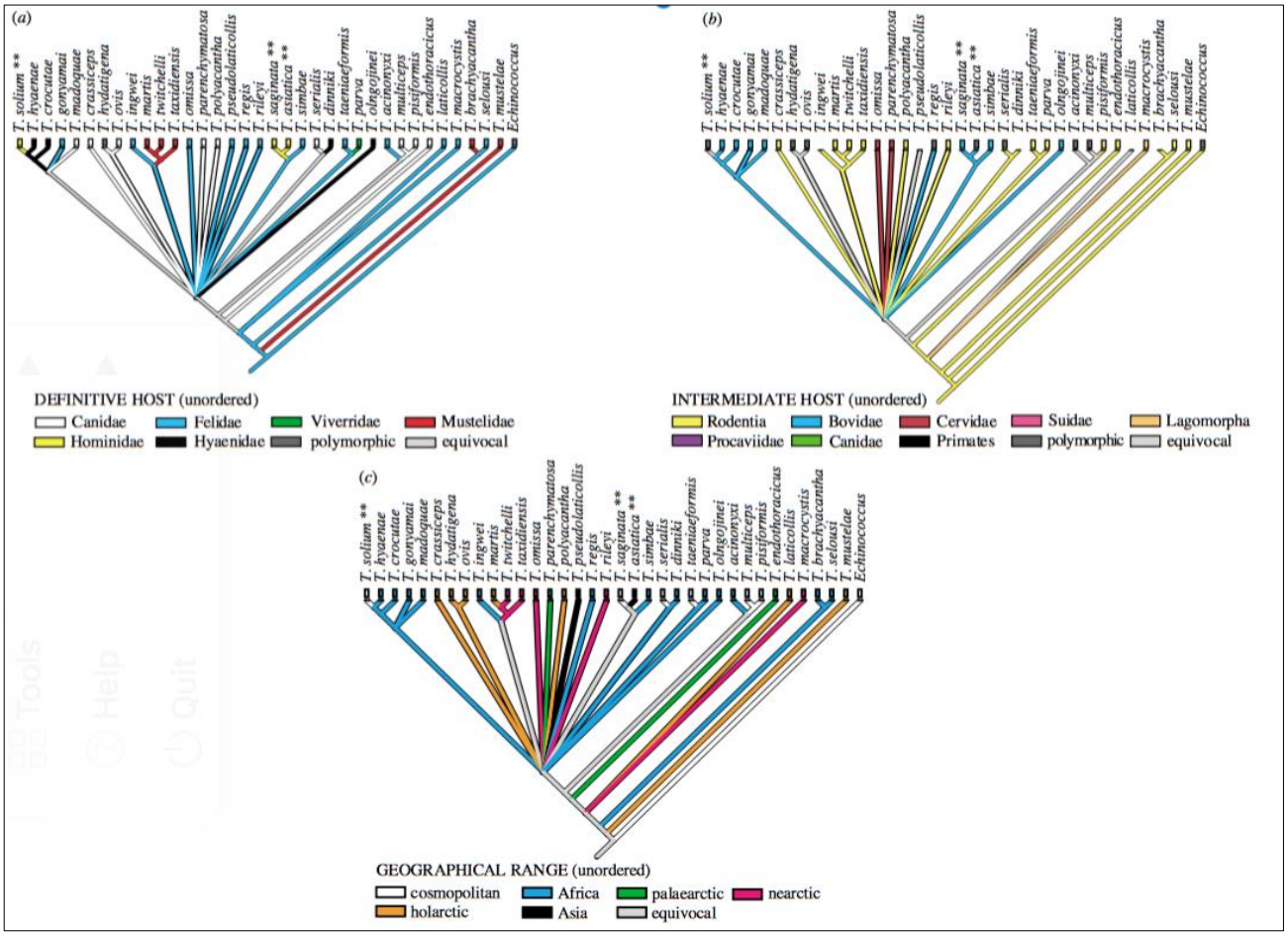


Figure 4: Geographic, genetic and host relationships of *T. solium* and other Taenia species

Agent Factors

The antigenic diversity of *T. solium* is of great practical significance and remains challenging to interpret. To date, knowledge of *T. solium* is derived mainly from experimental studies with small sample sizes within specific regional contexts. What is known is that the diversity of genetic and immunological characteristics of *T. solium* is significant. In one of the few formal immunotaxonomic studies conducted, it was found that among 15 different collections of cysticerci, they shared only 30% of their antigens as assessed by immunoelectrophoresis indicating a wide diversity of antigens [10].

Vega et al. considered the genetic diversity of *T. solium* cysticerci in humans using random amplified polymorphic DNA in individual cysticerci collected from pigs in Madagascar and two regions in Mexico [11]. Inclusion of Madagascar is epidemiologically significant since the inhabitants have cultural and trade links to East

African, South Asian and Southeast Asian countries. The findings of this study are summarized below in Figure 5 (genetic diversity) and Table 2 (important antigens) [11].

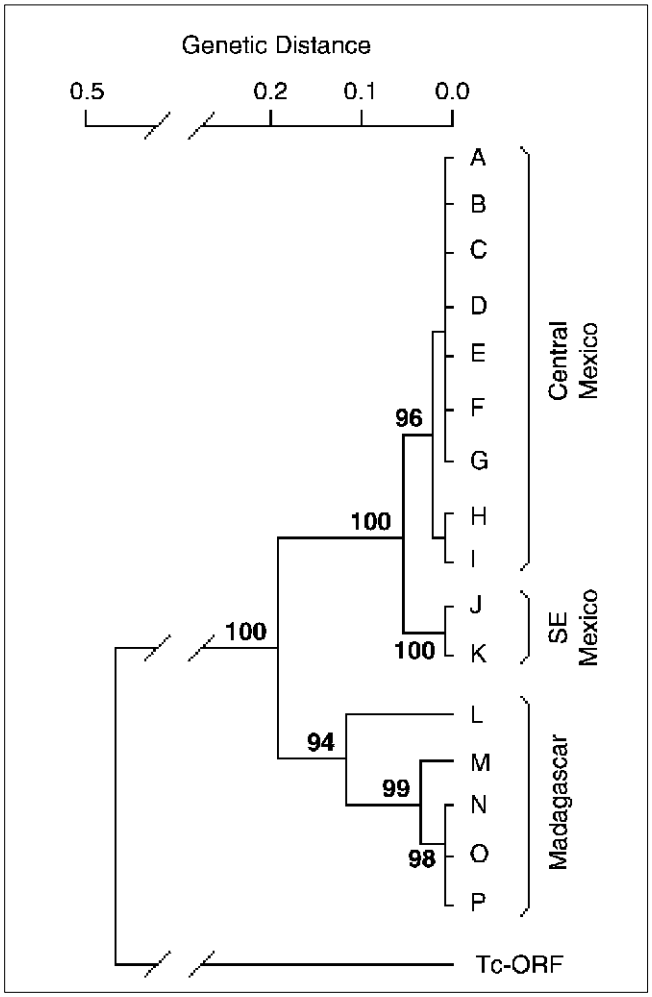


Figure 5: Genetic differences among 16 pig *T. solium* cysticerci (A-P) from Madagascar and two regions in Mexico

Figure 5 illustrates that each geographic region lies within a distinct though related (Mexican isolates) genetic cluster based on the origin. The Tc-ORF marker acts as a positive control to distinguish between species of Taenia using the random amplified polymorphic DNA analysis.

Table 2: *T. solium* antigens associated with NCC patients

		characterization		
	26 kDa 35 kDa 70 kDa		Antigenic differences between cysticerci from different continents	
Oncosphere	TSOL18 TSOL45 22, 22·5 kDa 31·3 kDa 64 kDa 70 kDa	Diagnostic	Almost complete protection in experimental porcine cysticercosis Antibody detection in serum from pigs with porcine cysticercosis Detection of teniosis	(55–58)
Scolex	13 kDa 17 kDa 26 kDa	Diagnostic	Antibody detection in serum of active NC patients Specific PBMC proliferation of NC patients	(37,59,60)
Cystic wall		Diagnostic	Antibody detection in serum of active NC patients	(37)
Membrane antigens		Diagnostic	Antibody detection in CSF of NC patients. Specific PBMC proliferation of NC patients	(35,51,59)
Secretion antigens	E/S	Diagnostic	Detection of circulating parasite antigens in serum and CSF of NC patients	(19,41,61–75)
	HP10		Detection of circulating parasite antigens in serum of epileptic patients and persons with teniosis	
	66 kDa		Antibody detection in CSF of NC patients	
	190, 230 kDa		Correlation with parasite stage	
Glycoproteins	Ts18var1	Diagnostic physiopathology characterization	Detection of antibodies in saliva, serum and CSF of NC patients	(25,30,32,41,42, 50,52,53,76–92)
	LLPG		Detection of teniosis	
	GP10, 13		Detection of parasite-exposed persons	
	GP24		Localization of antigenic glycoproteins during different parasite stages and during inflammation	
	GP39-42		Specific PBMC proliferation of NC patients	
	GP50		Evaluation of carbohydrates contribution to antigenicity	
	Ag1V1		Description of biochemical components from different glycoproteic fractions	
	Ag2 12, 16, 18, 32 kDa 30, 53, 64 100 kDa 200 kDa			

Table 2 summarizes the types of antigens from cysticerci that react with the human immune system and their possible use for prevention and control of cysticercosis in humans. A few of the antigens are specific to *T. solium*, but many others cross-react with other helminths tested including *T. saginata* (beef tapeworm), *T. crassiceps* (dog/canid tapeworm), *Echinococcus granulosus* (dog tapeworm), *E. multilocularis* (small fox tapeworm) and *Hymenolepis nana* (dwarf tapeworm). Several peptide antigens are significant markers and some have been identified as potential vaccine candidates [11]:

Antigen B:

- Frequently recognized by patients with NCC;
- Binds factor C1q from the complement system, reducing the potential toxicity of antibody-mediated parasite damage;

Glycoproteins:

- Binds to lentil lectin and in the parasite's structures in contact with the host, as well as on the cells of the inflammatory response surrounding the cysticercus, possibly modulating the host immune response;

HP10:

- Originally identified in *T. saginata* and is shared by *T. solium* is a valuable marker in the diagnosis of NC in the cerebrospinal fluid (CSF) and in sera of NC patients, and likely modulates the host immune response;

TSOL18:

- An oncosphere antigen peptide of *T. solium* and *T. saginata* which confers high levels of protection to healthy pigs against a single controlled exposure to *T. solium* eggs under experimental conditions;

Peptide antigens GK1, KETc1 and KETc12:

- Originally found in *T. crassiceps* but also present in all developmental stages of *T. solium* (112,113), greatly reduce parasite loads and lowers prevalence of porcine cysticercosis by 50%–70% when used as a vaccine against natural infection in feral pigs living in highly endemic areas of Mexico;

The epidemiological evolution of *T. solium* in Madagascar is a unique example of the interrelationship between culture and disease for porcine cysticercosis as assessed by mitochondrial haplotype analysis. A haplotype is a grouping of DNA polymorphisms, which occur together. Yanagita et al. conducted a study of *T. solium* haplotypes originating from Madagascar (8), China (2), Indonesia (2), India (1), Nepal (2). Thailand (1), Brazil (1), Cameroon (1), Ecuador (1), Mexico (3) and Tanzania (1). They found that the major mitochondrial haplotype of *T. solium* in Madagascar is most closely related to those from the Indian Subcontinent. Parasitological evidence presented and human genetics previously reported support the hypothesis of an Indian influence on Malagasy culture coinciding with periods of early human migration onto the island. Overall, 77% (84/109) of the Madagascan haplotypes were the Asian genotype. Among 52 pigs in which two cysts were examined, the

different haplotypes were simultaneously obtained in three (3) hosts; Asian and Afro-American haplotypes (MDG1 and MDG7) were identified from two hosts, and the different Asian haplotypes (MDG1 and MDG4) were obtained from one host. They also found evidence of nuclear-mitochondrial discordance in single tapeworms, indicating that cross-fertilization between the two separate lineages of *T. solium* was likely. Figure 6 presents a spatial-genetic map of the different mitochondrial genotypes from this study in Madagascar [12].

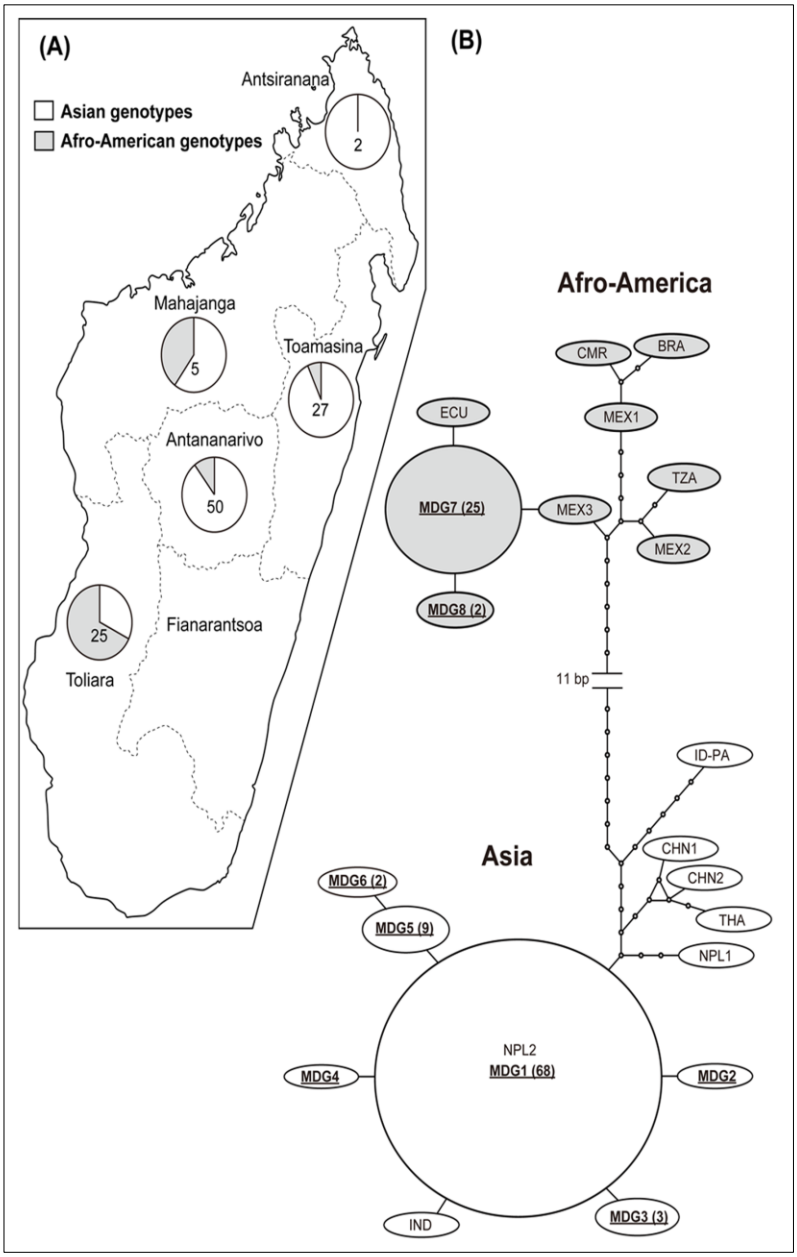


Figure 6: Spatial (A), Genetic (B) and cultural distribution of *T. solium* mitochondrial DNA genotypes

Host Factors

The OIE identifies the following factors associated with transmission of *T. solium* both within and among primary (humans) and secondary hosts (pigs) [1]:

- Proglottid segments are often passed in chains and flies are unimportant in dissemination;
- Eggs are immediately infective when passed;
- Animals acquire infection from ingestion of food or water contaminated with sticky eggs, ingestion of segments or faeces containing eggs;
- Pigs also acquire *T. solium* by coprophagy of the faeces of pigs that have eaten segments;
- Humans may be infected with *T. solium* by eggs on vegetables, in water, etc., that have been contaminated by faeces, or food contaminated by dirty hands, by faecal-oral transmission or through retroperistalsis and hatching of eggs internally;
- Human disease clusters where a human carrier exists.

There is very limited understanding concerning the mechanisms underlying the parasite's high specificity for pigs and humans. Carnivores and coprophagic mammals are only occasionally affected by *T. solium*. Hamsters and chinchillas may become tapeworm carriers especially if they are rendered immunosuppressed with corticosteroid injections. Likewise, *T. solium*'s tissue tropism towards the central nervous system (CNS) of humans (NCC) is more frequent in Latin America, while in India, the subcutaneous cysticerci are more frequently observed. Although the life cycle of *T. solium* is generally considered to involve only humans and pigs, dogs have also been found to harbor *T. solium* cysts and may possibly play a role in transmission in areas of the world where dog meat consumption is practiced such as in parts of Southeast Asia [13]. Host metabolism as well as genetic, antigenic and pathogenic diversity also may play a role in determining the outcome of infection [9]. Noteworthy, the cysticerci of *T. asiatica* of humans in South-East Asia occur in the liver of pigs [1].

With respect to the secondary pig host, Arriola et al. found a strong positive association between the presence of nematodes and cysticercosis infection and exposure in 326 village pigs. They defined a cysticercosis infection as the presence of at least one cysticercus in pig muscles, and cysticercosis exposure as seropositivity to anti-cysticercus antibodies with the presence of 0–5 cysticerci. Pigs infected with the nematode *Ascarops strongylina* were significantly associated with the presence of cysticerci (OR: 4.30, 95%CI: 1.83–10.09). Additionally, pigs infected with the nematode *Physocephalus sexalatus* were more likely to have cysticercosis exposure (OR: 2.21, 95%CI: 1.50–3.28) [14].

This and other findings should be carefully considered when interpreting or assessing serological tests due to the possibility of cross-reaction and the lack of specificity. Esquivel-Velázquez et al. found a large diversity among the proteins and antigens contained in each of the nine vesicular fluids of cysticerci from pigs (n=9). The serum IgG antibody responses of the nine pigs showed that none of their 2 Dimensional immunoblot images exhibited

the same number of spots and resembled each other in only 6.3% to 65.3% of their features. They conclude that such large individual immunological diversity of the cysticercal antigens and of the infected pigs IgG antibody response should be carefully considered in the design and interpretation of immunological tools for diagnosis and prevention of cysticercosis [15].

Sikasunge et al. assessed risk factors associated with *T. solium* transmission in humans and pigs in the rural areas of Eastern and Southern provinces of Zambia using a snowballing sampling method and a questionnaire that was administered in 788 households from 155 villages [15]. Tongue examination and Ag-ELISA were defined outcome variables for a positive finding for the 800 pigs sampled, however the sensitivity and specificity in this study is not stated and conclusions cannot be extrapolated to the population as a whole since subject enrollment was not randomly assigned. The main risk factor associated with *T. solium* infection in this cross-sectional prospective study was the use of a free-range husbandry system (OR = 1.68; 95% CI = 1.36–2.07) for porcine cysticercosis in the surveyed areas. The authors hypothesize that semi-intensive husbandry systems may have permitted them to have access to eating human feces that could be contaminated with tapeworm eggs. The following possible risk factors and percentages also considered, but which were not statistically associated with the outcome variables in this study due to a limitation of the snowball sampling design (lack of proper controls) are as follows:

- Lack of pork inspection at slaughter (96.7%);
- Consumption of pork with cysts (20.1%);
- Selling of pork infected with *T. solium* cysticerci (18.3%);
- Free-range husbandry system for pigs (83.2%);
- Absence of latrines for humans (58.0%).

Furthermore, the failure to control taeniosis/cysticercosis using taeniacidal drug administration and health education through large scale elimination programs in Latin America and Asia has shown that global eradication of this zoonosis is difficult to achieve due to the persistence of free-roaming pig production particularly important in peri-urban areas where meat demand and income are growing [16]. Pig rearing and management systems in Africa are further briefly characterized in Table 3 [16].

Table 3: Systems of pig production in Africa

	Characteristics			
	Housing	Ownership	Feeding	Breeding
Scavenging	None	Often communal	None	Uncontrolled
Herded	None	Individual	Seasonal diet	Uncontrolled
Semi-intensive	Semi-permanent construction from local materials	Individual smallholders	Household waste and sometimes specially grown cassava	Uncontrolled or use of local stud boars
Intensive	Modern pens made of concrete with zinc roofing	Urban-based entrepreneurs and businessmen	Agro-industrial by-products	Only selected boars used for stud

Source: Blench, R.M., 2000. A history of pigs in Africa. In: Blench, R.M., MacDonald, K.C (eds.), The Origins and Development of African Livestock. Archaeology, Genetics, Linguistics and Ethnography, UCL Press, pp. 355-367.

Human immigration and travel are associated risk factors for human cysticercosis. Zammarchi et al. demonstrated that out of 846 cysticercosis cases described in the literature for Europe, 522 cases were autochthonous and 324 cases were imported. The majority (70.1%) of the autochthonous cases were diagnosed in Portugal from 1983 to 1994. There were 242 (74.7%) cases of diagnosed in migrants and 57 (17.6%) in European travellers, showing an increasing trend. Most of imported cases were acquired in Latin America (69.8% of migrants and 44.0% of travellers). The majority of imported cases were diagnosed in Spain (47.5%), France (16.7%) and Italy (8.3%). One third of neurosurgical procedures were performed because the suspected diagnosis was cerebral neoplasm. Sixty-eight autochthonous and 5 imported *T. solium* taeniasis cases were reported [7].

The persistence of *T. solium* in the pig host as a factor in the epidemiology of porcine cysticercosis is largely undefined as the following evidence demonstrates [17]:

- Cysticerci establish primarily in skeletal and cardiac muscle, as well as in the brain of pigs, a process that takes approximately eight weeks and remain viable for at least one year, when pigs are usually sent to slaughter. In older pigs the inflammatory reaction surrounding cysticerci becomes evident with time.
- Most pigs are slaughtered in the six to 12 month period after birth and older animals such as sows and boars could represent important risks for humans;
- Cysticerci can survive for long periods, somehow avoiding the hosts immune response, through several possible ‘immunological sequestration or avoidance mechanisms;
- Cysticerci may not be completely protected from an immunological attack, and repeated reinfection can induce an inflammatory attack against the previously established cysticerci.

Environmental Factors

The survival of taeniid eggs, including *T. solium* ranges from several days up to at least 419 days dependent upon temperature and moisture as summarized in Table 4 [17].

Table 4: Survival characteristics of *T. solium* under experimental and field conditions

Environment	Viability or infectivity assay used	Storage conditions	Maximum reported survival (days)
Laboratory	*in vivo* infectivity	2°C -5°C	95
Laboratory	*in vivo*	In silage, 10°C	60-80
Field	*in vivo*	On pasture	101
Field	*in vivo*	On pasture, Kenya	413
Field	*in vivo*	On pasture, winter	159
		Summer	58
Field	*in vivo*	In stored hay	21
Field	*in vivo*	On pasture, Denmark	164-194

Environmental factors are considered in terms of both the natural ecology and the more human-specific environments (environmental health). Several reviews of risk factors for *T. solium* taeniosis/cysticercosis complex in Africa and Asia are summarized in Table 5 (References noted in [13][18]).

Table 5: Natural and human environmental risk factors identified for porcine cysticercosis

Risk Factors	References
Limited use or absence of latrines are prevalent in rural areas of Africa where pigs are raised	Assana et al., 2001; Zoli et al., 2003; Sikasunge et al., 2008a; Gweba et al., 2010
In North Cameroon, more than 40% of households keeping pigs in the rural areas have no latrine facility and almost 80% of the pig owners and the members of the house- hold use open field defecation	Assana et al., 2010
Tapeworm carriers can disseminate the parasite eggs in the environment leading to the contamination of soil, water, vegetables and other food resources	Gweba et al., 2010

Poverty is not necessarily the source of reluctance to use latrines since latrines are often not used	[18]
The absence of latrines is found associated with the occurrence of porcine cysticercosis	Ngowi et al., 2004; Sikasunge et al., 2007; Kagira et al., 2010a; Krecek et al., 2012
90% of pigs are reared under scavenging/free range and semi-intensive in Western and Central African countries; poor sanitary conditions play an important role in the circulation of *T. solium* infection	Porphyre, 2009; Zoli et al., 2003
A free-range production system for pigs combined with open field defecation by humans are the conditions in which the animals can gain access to human faeces	Ngowi et al., 2004; Sikasunge et al., 2007; Ganaba et al., 2011
Intensive pig production systems do not always eliminate *T. solium* transmission because in Cameroon for instance some farmers are known to defecate directly in the pigsties	Shey-Njila et al., 2003
Lack of veterinary inspection and most often the infected carcasses are consumed and marketed	Zoli et al., 2003
Pork consumption is increasing in African sub-Saharan countries; specific niche restaurants or places for pork consumption, especially in the cities of West and Central Africa including “porc braisé” (grilled or fried pork) in Cameroon, “porc au four” (pork from oven) in Burkina Faso	Porphyre, 2009; Koussou and Duteurtre, 2002; Porphyre, 2009
Food preference of consumers: in N’Jamena city (Chad) that the majority of them ate fried pork	Mopate et al., 2006
In Asia, infected pork/pigs may be rejected in formal marketing channels, it is/they are usually sold at lower prices in informal markets, putting lower-income consumers at a high risk of infection.	[13]
Vegetarians in India have been found to be at high risk of infection from tapeworm infected food preparers	Rajshekar et al., 2003
People who neither raise pigs nor consume pork are also at risk of cysticercosis if they ingest *T. solium* eggs after coming into direct or indirect contact with tapeworm carriers.	Willingham et al., 2003
In Vietnam, there have been reports suggesting a link between cysticercosis and the use of human feces and “wastewater” for fertilizing crops	Willingham et al., 2003

The frequency of open defecation, backyard pig raising and pork consumption differed significantly (P < 0.005) among the different coexisting caste and ethnic groups in Nepal.	Devleesschauwer et al., 2012

Clinical Signs

The majority of adult and larval tapeworm infections in humans and pigs respectively, cause little or no signs of overt disease. Exceptions are severe, potentially fatal human NCC caused by *T. solium*, which may also occasionally cause muscle or ocular signs in humans. A summary of clinical signs of *T. solium* in pigs is presented in Table 6 under natural and experimental conditions [1][19].

Table 6: Clinical signs associated with *T. solium* in pigs

Body system	Clinical signs	Reference
General	Asymptomatic Variation of the parasite burden among animals suggests intrinsic differences in pigs such as breed or sex	[1][19] de Aluja et al., 1996
Digestive	Excessive salivation	[19]
Nervous	Blinking and tearing; motor neuron incoordination	[19]
Ocular	Subconjunctival nodules; the tongue examination is less sensitive than the orbital muscle and eyelid examination for diagnosis of cysticercosis	[19]; Subahar et al. 2001
Muscular	Cysticerci nodules on tongue; experimentally or naturally infected pigs harbouring less than 100 cysts, none of the animals could be detected by tongue inspection; Poor sensitivity (see below) Masseter and tricep muscle nodules	[17][19]; Dorny et al., 2004 Mendez et al. 1986

The incubation period of NCC is extremely variable and infected hosts may remain asymptomatic for years. The *T. solium* cysts are very effective at evading the hosts' immune system such that viable cysts with little or no inflammatory reaction are usually not associated with symptoms [13][17]. Visual examination and palpation for tongue nodules in pigs is the most widely applied technique for ante-mortem detection of cysticerci. However a study in Zambia using Bayesian analysis estimated the overall sensitivity of tongue inspection to be 21% (CI: 14-26%), a very low detection rate [17]. The specificity of the tongue inspection for cysticerci in pigs is considered to be 100%.

Diagnosis

The OIE specifies that the *"routine diagnosis of taeniosis continues to be mainly based on the morphology of the adult tapeworm and the presence of eggs or segments in the faeces of infected definitive hosts"* [1]. However, the eggs of *T. solium, T. saginata* and *T. s. asiatica* cannot be distinguished morphologically, particularly in field laboratories with limited capacity in developing countries [17]. Although it is theoretically possible to distinguish these three adult taeniids on the basis of morphological characteristics of the scolex or the mature proglottids, *T. solium* may not be readily detected after treatment with modern anthelmintics [17].

Differential Diagnosis

T. asiatica is the main cysticerci of pigs, which must be distinguished from *T. solium*, however other taenids can cross-react with *T. solium*. Methods for the differential diagnosis of *T. solium* cysticercosis in pigs (extra-intestinal) from clinical, post-mortem and environmental assessments of test utility are presented in Table 7 [1][17].

Table 7: Diagnostic methods and test details and test utility appropriate in developing countries for differential diagnosis of *T. asiatica* and *T. solium*

Diagnostic Methods	Test Details	Test Utility
Morphological microscopy	Scolex, mature and gravid proglottids	• Limited: requires preferably fresh or frozen material
Ante-mortem examination	Visual exam with tongue palpation	• Moderate to Variable: depending on experience of inspector • Limited: ante-mortem inspection is practiced in developing countries

Post-mortem examination	Location of lesions for *T. asiatica* include liver, lungs, omentum or serosa of the colon	• High: based on tissue tropism of cysticerci • Limited: post-mortem inspection is practiced in developing countries
Serological diagnosis	Antigens may be detected as early as one week post-infection but disappear soon after the cysticerci degenerate; Infection with as few as five *T. s. asiatica* viable cysticerci can be detected by Ag-ELISA; The antigen ELISA test is known not be specific for *T. solium*, cross-reacting with infection in pigs with *Taenia hydatigena* (Dorny et al. 2004a) and with *Taenia saginata asiatica* (Geerts et al. 1992).	• High: more sensitive than the tongue examination; relatively inexpensive and easy to perform on large numbers of serum samples • Variable: Low sensitivity may be due to expertise of laboratory staff • Low: Interpretation of results difficult: transient antibody response to a *T. solium* infection can occur, without the establishment of a patent infection; false positives due to maternal antibody for up to 7 months; cross-reactions with *Cysticercus tenuicollis* are the rule in China and Viet Nam

The Bayesian analysis of serology of Zambian village pigs estimated an overall sensitivity and specificity for one Ag-ELISA to be 87% (CI: 62-98%) and 95% (CI: 90-99%), respectively. For another Ab-ELISA (using crude somatic *Taenia crassiceps* antigen) the sensitivity was only 36% (CI: 26-41%) and the specificity 92% (CI: 85- 99%) [17]. The correct interpretation of the results requires both laboratory and epidemiological assessments.

Gross pathology

The procedures for the detection of *T. solium* cysticercosis using conventional meat inspection varies widely among countries. Using a Bayesian approach, the overall sensitivity of meat inspection in Zambia using visual examination of masseter muscles, triceps brachii, tongue and heart was estimated to be only 22.1% (CI: 15-27%) [17]. Cysticerci of *T. solium* found in pig masseter muscle detected through post-mortem examination are shown in Figure 7 [13].

Figure 7: Post-mortem detection of *T. solium* cysticerci in the masseter muscle of a slaughtered pig

Since pigs are also the most important intermediate hosts of *T. asiatica* it is important to recall that the cysts of *T. asiatica* are found in the liver (at the surface and/or in the parenchyma), the lungs, attached to the omentum or to the serosa of the colon [17].

Diagnostic Tests

Most of the techniques developed for the diagnosis of cysticercosis in humans have been adapted for analyzing pig sera, including the EITB, the Ab-ELISA using isoelectric focusing-purified glycoproteins, and the Ag-ELISA assays [17]. A summary of key limitations of existing tests for the detection and diagnosis of cysticercosis in pigs is presented in Table 8 [2][22][28][31][33].

Table 8: Limitations of existing tests for the detection and diagnosis

Limitations	References
Western immunoblot assay (designated or EITB) provides absolute specificity for *T. solium*; Attempts to date to convert the test from a Western blot assay to an ELISA format have not resulted in sensitivity and specificity comparable with that achieved using 2 native antigens	Rodriguez et al., 2012; Parkhouse et al., 1987; Tsang et al., 1989; Rodriguez et al, 2014; Sheel et al., 2005; Bueno et al., 2005

Tongue palpation is the simplest method for the detection of porcine cysticercosis. Estimates of the sensitivity of tongue palpation vary widely, from as low as 16% in some instances to 70%	Phiri et al., 2006; Gonzalez et al., 1990
Only 6% of *T. solium* cysts that were present in pigs could be identified in the organs that were examined at meat inspection.	Boa et al., 2002;
Pigs are likely to be exposed to many more species of taeniid cestode parasite than are humans, due to their foraging habit. For this reason, the potential for nonspecific positive serological reaction	Lightowlers et al., 2013
The great majority of rural pigs that are serologically positive for porcine cysticercosis are found to have no cysticerci at necropsy	Devleesschauwer et al., 2013; Gavidia, 2013; Gayashi, 2014
False-positive/transient positive reactions in serological tests for porcine cysticercosis could be due to exposure of the animals to *T. solium* eggs which did not lead to the establishment of cysticerci that could be found at necropsy	Lightowlers et al., 2013
No assessment has been made of the potential for cross-reactivity in tests for porcine cysticercosis due to exposure to T. saginata.	Lightowlers et al., 2013
Until data are available about serological responses in pigs following exposure to a variety of Taenia species, particularly T. hydatigena and T. saginata, none of the tests currently being employed has been adequately assessed for specificity.	Lightowlers et al., 2013
Interpretation of seropositive results in young pigs due to the presence of maternal antibodies transferred by colostrum from a seropositive sow to its piglet may persist for up to 7 months and should be considered in interpretation of seroprevalence studies;	[17]

The limitations noted above must be considered and incorporated in the OIE specifications for the following approved diagnostic tests related to *T. solium* in pigs [1].

Identification of the agent

1) *T. solium* (the pork tapeworm): *T. solium* is typically smaller than T. saginata being 1–5 metres and seems to survive for a shorter period, from a few months to 1 year. The scolex has an armed rostellum bearing two rows of hooks. Gravid segments have <14 uterine branches and do not usually leave the host spontaneously, but passively in chains with the faeces. Further detailed differential diagnosis of *T. solium* based on morphology of the important taenids is presented in Table 9.

Table 9: Differentiation of the morphology of important Taeniid species

Parasite species	Number of hooks	Length of hooks (µm)		No. testes	Layers of testes	Cirrus sac extends to longitudinal vessels	No. uterine branches	
		Large hooks	Small hooks					
T. hydatigena	28–36 (26–44)	191–218 (170–235)	118–143 (110–168)	600–700	1	Yes	6–10 that re-divide	Lobes of ovary unequal in size. No vaginal sphincter. Testes extend to vitellarium, but not confluent behind.
T. ovis	30–34 (24–38)	170–191 (131–202)	111–127 (89–157)	350–750	1	No	11–20 that re-divide	Lobes of ovary unequal in size. Well developed vaginal sphincter. Testes extend to posterior edge of ovary.
T. multiceps	22–30 (20–34)	157–177 (120–190)	98–136 (73–160)	284–388	2	Yes	14–20 that re-divide	Lobes of ovary equal in size. Pad of muscle on anterior wall of vagina. Testes extend to vitellarium, but not confluent behind.
T. saginata	– without rostellum	–	–	765–1200	1	No	14–32 that re-divide Ratio of uterine twigs to branches 2.3	Lobes of ovary unequal in size with small Well developed vaginal sphincter. Testes extend to vitellarium, but not confluent behind.
T. solium	22–36	139–200	93–159	375–575	1	Yes	7–14 that re-divide	Lobes of ovary unequal in size with small accessory lobe. No vaginal sphincter. Testes confluent behind vitellarium
T. asiatica	Vestigial hooks some with small rostellum	–	–	868–904		No	16–32 that re-divide Ratio of uterine twigs to branches 4.4	Ovary, vaginal sphincter and extent of testes as *T. saginata.* Posterior protuberances on some gravid segments

2) Diagnosis of adult parasites in humans or canids

   a) *T. solium* segments … may be found on the faeces, but are passed intermittently. Eggs are voided into the faecal mass but the migrating segments void about half their eggs in trails on the surface of faeces (to be eaten by flies) and surrounding area and on the ground after falling from the anus. Even if a segment has shed all its eggs, it can be identified as a cestode by the many concentric calcareous corpuscles contained within its tissues. Faeces, after mixing to reduce aggregation, can be examined for eggs. Various techniques are used throughout the world and include ethyl acetate extraction and flotation. For the latter, NaNO3 or Sheather's sugar solution (500 g sugar, 6.6 ml phenol, 360 ml water)… Faecal egg examination will be less sensitive for *T. solium* than the other species. Species cannot be determined by egg morphology. Cheesbrough (2005; 2006) reports that T. saginata eggs can be differentiated from T solium on staining with Ziehl–Neelsen as used for acid-fast bacilli: the striated embryophore of T saginata is acid fast (stains red), that of *T. solium* is not acid fast. DNA probes, the polymerase chain reaction (PCR) and PCR restriction fragment length polymorphism (RFLP), have proved useful for differentiation though largely used experimentally to differentiate faecal eggs of *T. solium*, T. saginata and T.asiatica (Gasser & Chilton, 1995; Gonzalez et al., 2004). While equally applicable to differentiation in dogs, the same examinations have not been done for Taenia spp.

   b) An Ag-ELISA to detect Taenia coproantigen is available from Cestode Diagnostics, University of Salford1 and can be developed independently if laboratory facilities are available (Allan et al., 1992). The technique, however, is only Taenia-genus specific. The test is a solid-phase, microwell assay with wells coated with polyclonal, rabbit anti-Taenia-specific antibody (TSA).

3) Diagnosis of metacestodes:

   a) *T. solium* or T. saginata metacestodes might be palpable in the tongue but, both in the living animal and on post-mortem examination or meat inspection, tongue palpation is of diagnostic value only in pigs or cattle heavily infected with metacestodes; these will also be difficult to differentiate from large sarcocysts.

   b) Meat inspection: Metacestodes are visible first as very small, about 1 mm, cysts, but detection of these requires thin slicing of tissues in the laboratory. Many young cysts are surrounded by a layer or capsule of inflammatory cells (mononuclear cells and eosinophils being prominent histologically). The parasites' abilities to evade the immune response mean that later in infection, as the cyst matures, few inflammatory cells are present in its vicinity and the cysticercus in its intermuscular location is surrounded by a delicate fibrous tissue capsule.

   c) In theory, cysts can be visualised or felt in tissues such as the tongue of heavily infected animals as early as 2 weeks after infection. Cysts are readily visible by 6 weeks and, when mature, are usually oval, about 10 × 5 mm or larger, with a delicate, fairly translucent, white parasite membrane and host capsule. Pale fluid within the cyst and the scolex, visible as a white dot within the cyst, usually invaginates midway along the long axis of the cyst. After treatment of T. saginata and *T. solium* in cattle and pigs with drugs such as albendazole and OFZ, the cysts may lose their fluid and collapse. The resultant lesion is smaller than lesions observed

following natural death but can take 3–6 months to resolve. However, cysts that died before treatment of the animal will remain large and visible.

d) The predilection sites [for *T. solium*] are as for T. saginata although there are reports of higher prevalence in shoulder and thigh. Commonly one or more cuts are required 2.5 cm above the elbow joint. This is said to detect some 13% of infected carcasses that would otherwise have been missed. In some countries, any lightly or heavily infected pigs and their viscera and blood are condemned. In areas where infection is common, lightly infected carcasses can be passed for cooking and pickling and occasionally freezing.

4) Detection of circulating antigens:

a) The development of an automated sensitive and specific diagnostic test would greatly reduce the costs of damage to the carcass and also the costs of labour at meat inspection. Sensitivity of serological tests for animals has not reached the stage where commercialisation for individual diagnosis or large- scale detection of infected carcasses in slaughter houses is possible. All assays tested – Ag-ELISA, antibody ELISA, EITB and tongue inspection – show low sensitivity in rural pigs infected naturally with low levels of *T. solium* (Dorny et al., 2005; Sciutto et al., 1998). This finding is also true for T. saginata infections in cattle (Van Kerckhoven et al., 1998). For example, only a small percentage (13–22%) of cattle carrying fewer than 30–50 viable cysticerci is detected by Ag-ELISA. Nonetheless, Ag-ELISAs do have a use in field-based epidemiological studies for indicating transmission. The detection of viable infections in cattle or pigs could indicate point sources of infection, season of transmission and age of animals at risk. The development of more sensitive and specific assays with recombinant antigens for diagnosis of NCC should improve immunodiagnosis of *T. solium* in pigs.

Serological tests for antibodies

1) Tests for circulating antibodies have little role in animals, except for epidemiological studies. A number of EITB and ELISAs for antibodies to *T. solium* in humans are now widely available. These were reviewed by Rodriguez et al. (2012) with comparisons of sensitivity and specificity.

The main challenge in using serological tests is the uncertainty posed by the dynamics of agent-host infection, the lack of sensitivity and specificity of the tests and the selection of controls in experimental trails. Even though good test antigens have been developed, a positive result could either be related to an established infection or to a resolved infection with different response profiles, which are difficult to differentiate. More specifically, the lack of a gold standard is a serious drawback for the optimization of ELISA tests [21].

Zoonotic disease

T. solium larval cysts infecting the brain, muscle, or other tissue of humans are a major cause of adult onset seizures in most low-income countries. Human taeniosis is an infection with the adult tapeworm of *T. solium* while infection of pigs with the cysts containing the larvae/metacestodes of *T. solium* is termed cysticercosis. The WHO and the US CDC classify Taeniasis as a Neglected Zoonotic Disease and a Neglected Parasitic Infection (NPI), respectively [20][22]. The life cycle of *T. solium* and other zoonotic taenids is unique among helminth zoonoses in that they are dependent upon humans as the sole definitive host [17]. A person can succumb to cysticercosis by the following mechanisms [22]:

- Autoinfection in the same person through reverse peristalsis;
- Swallowing eggs found in the feces of a person who has an intestinal tapeworm;
- People living in the same household with someone who has a tapeworm have a much higher risk of getting cysticercosis than people who don't.

In 1993 the ITFDE declared *T. solium 'a potentially eradicable parasite'* and recently, ITFDE called for a large demonstration project on effective control or elimination to be carried out and Brazil, Madagascar and China have undertaken to conduct such projects [22]. However, as yet no truly successful intervention programs has been completed anywhere at a national level to achieve this goal. The WHO/FAO/OIE Guidelines for the surveillance, prevention and control of taeniosis/cysticercosis provides a rich collection of synthesized knowledge of the human disease [17].

Among the taenids, only *T. solium* cysticerci become established in humans causing cysticercosis of the central nervous system, eye, striated and heart muscle and subcutaneous tissue. Two morphological types develop in humans [17]:

- *Cellulose type cysticercus is a small, spherical or oval, white or yellow vesicle that measures between 0.5 and 1.5 cm and has a translucent bladder wall, through which the scolex can be seen as a small solid eccentric granule. This type of cysticercus is generally separated from the host tissue by a thin collagenous capsule, within which it remains alive.*
- *The racemose type cysticercus appears either as a large, round or lobulated bladder circumscribed by a delicate wall, or resembles a cluster of grapes, and measures up to 10 or even 20 cm and may contain 60 ml fluid.*
- *Cellulose cysticerci may grow and transform into the racemose type if the area of localization is spacious. An important characteristic of this type of cysticercus is that the scolex cannot be seen, and in some cases only detailed histological studies reveal its remains* [17].

A key feature in immunoparasitology is the evasion of the host immune response by the parasite, thus explaining how cysticerci are capable of surviving in the human host for several years before they degenerate. Viable cysticerci are associated with little surrounding inflammation, which allows for the maintenance of the parasite. The mechanisms underlying the survival of parasites lodged in immunologically privileged sites (including the central nervous system) is complex and detection is difficult using standard immunological tests due to the following reasons [17][21]:

- Masking of cysticercus antigens by host immunoglobulins;
- Concomitant immunity;
- Molecular mimicry;
- Immune suppression or deviation of host responses;
- Low/variable test sensitivity of the available techniques in pigs with low levels of cyst burdens, although some studies were able to detect pigs harbouring one single cyst using an Ag-ELISA;
- When measuring antibodies, antigen exposure is measured rather than actual infection;
- Transient antibody response without patent infection;
- Cross-reactions with *C. tenuicollis* are rather the rule than the exception in most antibody and antigen detecting tests.

The epidemiology of Taeniasis in humans is inextricably linked to, yet distinct from pigs as noted previously. The prevalence of *T. solium* infection varies greatly according to the level of sanitation, pig husbandry practices and eating habits in a region and peri-urban areas where smallholder units are particularly at risk. Data on the prevalence of adult worm infections are generally considered very conservative for the following reasons:

- Coproscopical methods used for survey are inadequate and usually cannot differentiate between *T. solium* and *T. saginata* infections;
- Prevalence data based on serological methods may overestimate infection rates because presence of antibody may be the result of exposure to eggs and early but non-persisting infection.

The diagnosis of taeniosis in humans is complex and can be summarized as follows:

- Diagnosis of Taeniosis in humans:

    i. Clinical presentation: seizures are usually the most common presenting complaint; headaches are also frequent while focal neurological symptoms are decidedly less common and subcutaneous nodules are a common presentation (especially in South Asia);

ii. MRI and CT radiology: are the most helpful methods to diagnose NCC but this is not widely available in most developing countries;

iii. Western blot: patients with multiple viable or dying cysts should have serum antibodies present, usually in the range of 92% or greater;

iv. ELISA based assays: less well documented and standardized, and are less specific but in developing countries, ELISA is preferred because of its better availability, its simplicity and its lower cost compared to immunoblot; Ag-ELISA detects only cases of active cysticercosis;

v. Fundoscopic examination: Direct visualization of subretinal parasites

vi. Brain biopsy: Definitive histopathology;

vii. EITB: The current assay of choice for antibody detection using partially purified antigenic *Caveat*: results using the EITB assay need to be critically interpreted. This assay has a documented specificity approaching 100% and a sensitivity of 92% to 98% for patients with two or more cystic or enhancing lesions but results in false negatives in patients with a single intracranial cysticercus and in those with calcified cysticerci.

For prevention and control in humans, there is a consensus that, from the standpoint of disease transmission to humans and maintenance of the parasite's life cycle, controlling the adult tapeworm is the priority. Adequate sanitation and the adoption of safe animal husbandry practices, however, are very problematical in resource poor areas in developing countries, and therefore, prevention strategies must rely on multiple approaches, tailoring each to the special features of the particular endemic area. Figure 8 presents a graphical summary of prevention and control measures required for effective prevention and control of human taeniosis [17].

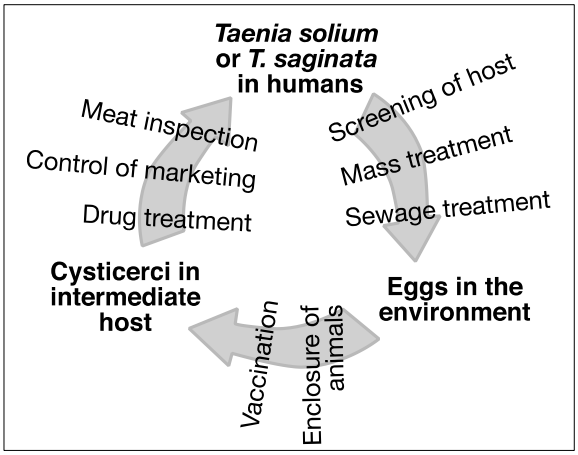


Figure 8: Interventions for the prevention and control of human taeniosis

Incidence and Prevalence in Selected Countries

Global

The WHO/OIE/FAO Guidelines state that the *T. solium* population consists of three distinct subpopulations: adult tapeworms in the definitive host (man), larvae (cysticercus or metacestode) in the intermediate host (pigs), and eggs in the environment. When assessing the epidemiology of *T. solium*, all three subpopulations must be taken into account and no part of the life cycle can be considered without reference to the other parts because all are interdependent [17].

The risk based on incidence and prevalence in 20 selected Africa and Asian countries considered under the LVIF are presented in Table 5 based on risk estimates conducted by the WHO/OIE/FAO [17]. Rwanda stands out among the hyper-endemic countries found in Central Africa. Nepal is also considered to have a very high prevalence based on published prevalence studies conducted by Joshi. In Asia, this zoonosis has been known to occur for the past several hundred years, but until recently, it has not received much attention. As a result, epidemiological information for Asia is not very extensive and data on taeniosis in humans are more available than than for cysticercosis in pigs [17]. Figure 9 illustrates the global distribution of porcine cysticercosis reported between January and June 2015.

Incidence data from the OIE and prevalence data for porcine cysticercosis from published studies are presented in Table 10 and Table 11, respectively. It is critical to consider the study design, the test methods and the case definitions, which influence both pig and human prevalence estimates.

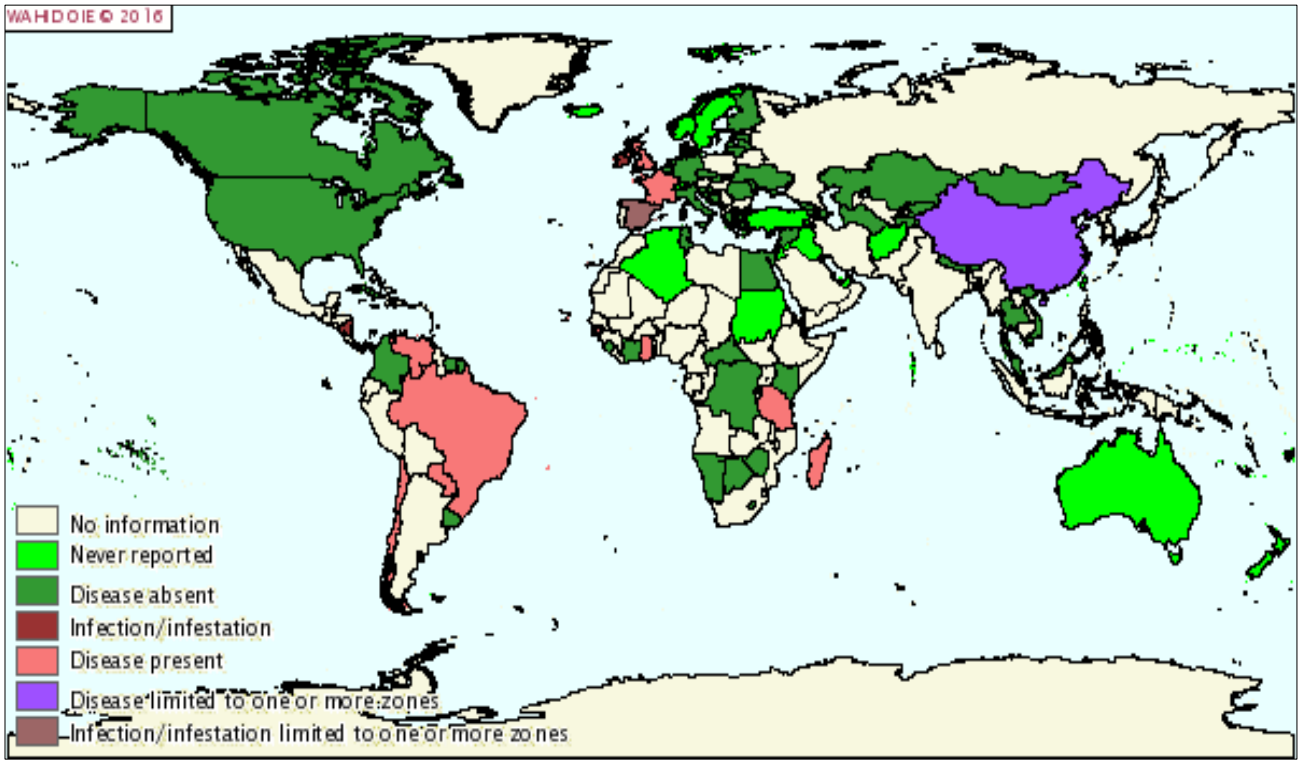


Figure 9: Official reports of porcine cysticercosis to OIE, January-June 2015

Regional

Incidence of Porcine Cystiercosis in 20 Selected Countries

Table 10: Reported incidence of porcine cysticercosis in 20 selected countries under the LVIF

Region/Country	Reported Incidence (OIE, WAHID) http://www.oie.int/wahis_2/public/wahid.php/Diseaseinformation/statusdetail# (Accessed 20 October 2015)															
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Sub Saharan Africa																
Burkina Faso	…	…	…	…	25	…+	…+	…+	…+	…+	…+	…+	…	…	…	…
Ethiopia	…	…	…	…	…	…	…	…	…	0	0	0	0	0	0	…
Ivory Coast	…	…	…	…	…	0	…	…	0…	0	0	0	0	0…	0	0…
Kenya	…	…	…	…	0	?	?	?	?	?	?	?	?	?	?	0…
Madagascar	…	…	44	…	13	10+…	3+…	3+	…+	…+	5	3	4	8	5	…
Malawi	…	…	…	33	4	…+	…+	…+	…+	…+	2…+	…+	0	?	…	…
Mali	…	…	…	0	0	0	0	…	…	…	…	…	…	…	…	…
Mozambique	0	0	…	0	0	0	0…?	3	6	2+	3	3…+	5	5	1+	…
Rwanda	…	…	…	5	…	…	0	?+	?+	?	?+	?+	2?	?+()	…	…

Senegal	0	…	…	0	0	…	…	…	…	…	…	…	…	…	…	…
South Africa	…	…	…	…	…	0	0	0	1	1	1	0	0	0	0	…
Tanzania	0	0	0	0	0	?()	?()	?()	?	?	?	?	?	?	?…+	…+
Uganda	…	…	0	0	0	0	…	…	…	…	…	…	…	…	…	…
Zambia	0	…	…	…	0	…	…	…	…	…+	0	0	0	0	0	0…
South Asia																
Bangladesh	…	…	…	…	…	…	…	0	0	0	0	0	0	0…	…	…
India	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	…
Nepal	0	0	0	0	0	0	…+	0	0	0	0	?+	0	0	0	…
Southeast Asia																
Indonesia	0	0	0	0	0	0	0	…	0	…	…	…	…	…	…	…
Myanmar	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	…
Vietnam	0	0	0	0	0	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	?	0	0…

WAHID Codes (2005-2015)

Legend	
…	No information available for this disease

0	Disease absent
?	Disease suspected
? +	Infection/infestation
...+	Disease present but without quantitative data
+	Disease present with quantitative data but with an unknown number of outbreaks
(+)	Disease limited to one or more zones
?()	Disease suspected but not confirmed and limited to one or more zones

HandiStatus II Codes (2000-2004)

...	No information available

Prevalence of Porcine Cysticercosis in 20 Selected Countries

Table 11: Reported prevalence of porcine cysticercosis in 20 selected countries under the LVIF

Region/Country	Apparent Prevalence (CI)	Study Method	Reference
Sub Saharan Africa			
Burkina Faso	**Pigs**: 0.6 %	Meat or tongue detection	Coulibaly and Yameogo, 2000

	Humans:		
Ethiopia	**Pigs:**		
	Humans: 1.4% among 419 school children and 1.8% in 384 food handlers	Not available	Terefe et al., 2011 Abera et al., 2010
Ivory Coast	**Pigs:** 2.5 %	Meat or tongue detection	Mishra and N'Depo, 1978
	Humans:		
Kenya	**Pigs:** 10-14%	Tongue examination of 407 pigs at slaughterhouse	Phiri et al, 2002
	17.2% for pigs (95% CI 10.2%–26.4%)	HP10 Ag-ELISA seroprevalence (suggestive of cysticercosis)	Wardrop et al, 2015
	Ag-ELISA (32.8%, 95% C.I. 26.8-39.2%), while by tongue inspection cysticerci were detected in 22/ 392 pigs (5.6% 95% C.I. 3.6-8.4%).	Cross-sectional survey using Ag ELISA and tongue examination	Eshitera, 2014
	Humans: 6.6% for humans (95% CI 5.6%–7.7%)	HP10 Ag-ELISA seroprevalence (suggestive of cysticercosis)	Wardrop et al, 2015
Madagascar	**Pigs:** Overall apparent prevalence was estimated at 4.6 % [4.2 – 5.0 %]. The corrected overall prevalence defined as the estimated prevalence after accounting for the sensitivity of meat inspection was 21.03 % [19.18- 22.87 %].	12-month monitoring in two urban abattoirs	Porphyre et al., 2015

	Indigenous pigs were 8.5 times [6.7 – 10.7] more likely to be infected than exotic improved pigs.		
	Humans:		
Malawi	**Pigs:**		
	Humans:		
Mali	**Pigs:**		
	Humans:		
Mozambique	**Pigs:** Slaughterhouse records indicate a countrywide occurrence of porcine cysticercosis, while studies have shown that 10–35% of pigs tested were seropositive for cysticercosis antibodies or antigen	ELISA found a 15% seroprevalence in swine (n=387) (Afonso et al., 2001), and an immunoblot and antibody ELISA serology in Inhambane province with the same antigen showed a 10% seroprevalence (n=20)	Afonso et al, 2011

	A total of 108 pigs from an endemic area in Mozambique were selected and followed for 8 months to estimate the prevalence and incidence of *T. solium* cysticercosis as indicators of ongoing transmission of the disease. The pigs were sampled and tested repeatedly for cysticercosis by Ag-ELISA at 4, 9 and 12 months of age. Porcine cysticercosis was diagnosed in 5.6% (95% CI: 2.1–11.7%), 33.3% (95% CI: 23.7–44.1%) and 66.7% (95% CI: 55.5–76.9%) of the animals, for the first, second and third sampling rounds, respectively, and varied by village. The mean incidence rate of the disease increased significantly from 6.2 cases per 100 pig-months between 4 and 9 months of age, to 21.2 cases per 100 pig-months between 9 and 12 months of age (incidence rate difference = 15.0; 95% CI: 6.8–23.3).	Repeat serosurveys using Ag ELISA	Pondja et al., 2015
	Two hundred thirty-one samples (34.9%) were found positive by the Ag-ELISA, while by tongue inspection on the same animals cysticerci were detected in 84 pigs (12.7%).	A cross-sectional survey was carried out in 11 villages in Angoʹnia district, Tete province in northwestern Mozambique. Between September and November 2007, a total of 661 pigs were tested serologically and examined by tongue inspection.	Pondja et al., 2010
	6.5-33.3%	Serological survey of 297 pigs	Phiri et al., 2002

	7,129 (95% CR, 6,401-7,879), which corresponded to 35% of the total adult pig population.	Socioeconomic survey	Trevisan, 2012
	Humans: 15-21% of apparently healthy adults were positive for cysticercosis antibodies or antigen, while in neuropsychiatric patients seroprevalence was as high as 51%.	ELISA	Afonsdo et al, 2012
Rwanda	**Pigs:** 20%	Meat or tongue detection	Chartier et al, 1990 Thienpont et al, 1959
	Humans: In CSF samples from NCC cases, anticysticercal antibodies were detected in 10% (definitive cases, 25%) and parasite DNA in 16% (definitive cases, 44%).	At three healthcare facilities in southern Rwanda, 215 people with epilepsy (PWE) and 51 controls were clinically examined, interviewed, and tested by immunoblot for cysticerci-specific serum antibodies. Additionally, CSF samples from PWE were tested for anticysticercal antibodies by ELISA and for parasite DNA by PCR.	Rottbeck et al., 2013

Senegal	**Pigs:** Porcine cysticercosis prevalence detected by tongue inspection at animal level per study area ranged from 0.1% to 1.0%. Using an antigen-detection ELISA the seroprevalence of cysticercosis at both community/village and animal levels for the four selected study areas is: Western region 80.0% (95%CI: 52.4%–93.6%) and 4.8% (95%CI: 3.4%–6.5%), Bignona 86.7% (95%CI: 59.8%–96.6%) and 8.9% (95%CI: 5.0%–15.5%), Kolda 82.4% (95%CI: 46.8%–96.1%) and 13.2% (95%CI: 10.8%–16.0%), and Ziguinchor 81.3% (95%CI: 43.5%–96.1%) and 6.4% (95%CI: 4.0%–10.1%), respectively.	During a stratified cross-sectional survey, 1705 pigs were sampled from 279 randomly selected households, 63 randomly selected communities and villages, from four study areas in The Gambia and Senegal during the period October 2007 to January 2008.	Secka et al., 2010
	Humans:		
South Africa	**Pigs:** In the absence of a gold standard true prevalence was obtained, using a Bayesian approach, with a model that uses both available data and prior information. Results indicate that the parasite is indeed present in the study villages and that true prevalence was 64.6%. The apparent prevalences as measured by each of the four tests were: 11.9% for lingual examination, 54.8% for B158/B60 Ag-ELISA, 40.6% for HP10 Ag-ELISA and 33.3% for EITB.	Community-based study of pigs owned by resource-poor, emerging pig producers from 21 villages in the Eastern Cape Province. Lingual examination (tongue palpation) in live pigs, two ELISAs, which detect parasite antigen (B158/B60 Ag-ELISA and HP10 Ag-ELISA) and an EITB assay, which detects antiparasite antibody, were used to verify endemicity and estimate apparent prevalence	Krecek et al., 2008
	0.5-25.1%	Post mortem slaughterhouse survey of >100,000 pigs	Phiri et al., 2002

	Humans:		
Tanzania	**Pigs:** The first survey revealed a cysticercosis seroprevalence of 15% (n = 822, 95% CI: 13-18%). The seroprevalence had significantly increased to 24% ($p < 0.001$, $\chi 2$-test, n = 812, 95% CI: 21-27%) at the time of the 6-month follow-up. At 14-months the seroprevalence had dropped to 20% ($p = 0.053$, $\chi 2$-test, n = 998, 95% CI: 18-23%). Overall, this was a reduction in seroprevalence compared with a study conducted in 2007 in the same area, where 31% (186/600) of pigs were found positive.	A longitudinal study composed of three cross-sectional surveys using Ag-ELISA	Braae et al. 2014
	600 male and female pigs of different age categories were randomly selected and examined for PC using lingual examination method and antigen Ag- ELISA. The overall pig level PC prevalence in Mbozi district was 11.7% (95% CI = 8.5–15.8%) and 32% (95% CI: 27–37.5%) based on lingual examination and Ag-ELISA, respectively. In Mbeya Rural district, the prevalence were 6% (95% CI: 3.8–9.3%) and 30.7% (95% CI: 25.8–36.1%) by lingual examination and Ag-ELISA, respectively. In Mbozi district 46% of the households were found infected (one or more infected pigs) and the corresponding figure was 45% for Mbeya Rural district. The agreement between lingual examination and Ag-ELISA was poor ($r < 0.40$).	Ag ELISA seroprevalence survey of 30 villages in high risk area of Tanzania	Komba et al., 2013

	Prevalence of 17.4% in the northern highlands district of Mbulu and a prevalence range of 5.1-16.9% in the southern highlands	Review: Community-based studies on porcine cysticercosis	Phiri et al., 2003
	Humans: 0.01%	PCR of Villagers (n = 1057)	Eom et al.,2011
Uganda	**Pigs:** Sera from 378 pigs were analysed with the HP10 Antigen Enzyme Linked Immunosorbant Assay (ELISA) and the prevalence was found to be 25.7% (95% confidence interval 21.0% to 30.0%). Previous serosurveillance in this region, using the B158/B60 Ag Elisa had indicated a prevalence of 8.6% in 2005 indicating a dramatic increase in prevalence within a 6-year period.	Prospective seroprevalence survey using an antigen detection ELISA	Nsadha et al., 2014
	33.7-44.5 %	Post mortem Slaughterhouse survey of 600 pigs	Phiri et al, 2002
	0-33.7%	Post mortem Slaughterhouse survey of 600 pigs	Phiri et al, 2003
	Humans:		
Zambia	**Pigs:** estimated prevalence of porcine cysticercosis was 0.642 (95% confidence interval 0.54–0.91); Cysticerci were found in 31 pigs (prevalence 0.477, 95% confidence interval 0.35–	Village pigs (n= 868) slaughtered in Lusaka (Zambia), were bled, and tongue and routine meat inspected; and serum antibody and parasite antigen concentrations were determined by ELISA.	Dorny et al., 2004

	0.60), overlapping with the estimated prevalence in the first study		
	Presence of antigens of the larval stages of *T. solium* by the B158/B60 Ag-ELISA. The associations between seropositivity and socio-demographic and pig management practices were estimated using logistic regression. Proportions of 32.5% (95% CI 25.4–40.3), 39.6% (31.9–47.8), and 0% of pigs, were found positive for the presence of circulating antigens of *T. solium*	clustered random sampling design was used.	Ganaba et al., 2001
	Out of the 1316 pigs examined at the slaughter slab, 143 (10.9%) and 271 (20.6%) were positive by lingual examination and meat inspection, respectively. Most of the pigs were very heavily infected with predominantly live cysts. The field surveys revealed that eight (8.2%) out of 98 pigs from Southern province and eight (5.2%) out of 151 pigs from Eastern province were positive for cysticercosis by tongue palpation. Using the Ag-ELISA 20 (20.8%) and 14 (9.3%) pigs were positive in Southern and Eastern provinces, respectively.	Slaughterhouse survey and field survey using Ag ELISA	Phiri et al., 2002

	Prevalence of households with pigs infected with *T. solium* on tongue examination by district ranged from 12.7% to 32.1% with Ag-ELISA having a range of 30.0–51.7%. Of the total number of households visited, 18.8% and 37.6% had at least one pig positive for porcine cysticercosis on tongue examination and Ag-ELISA, respectively.	Tongue examination and Ag-ELISA for the detection of circulating antigens of *T. solium* cysticerci were used to measure infection in pigs. A snowballing technique was utilised to select households with pigs.	Sikasunge et al., 2007
	Humans:		
South Asia			
Bangladesh	**Pigs:**		
	Humans:		
India	**Pigs:** A total of 175 pigs were examined for cysticercosis out of which 9 (5.14%) were found positive for porcine cysticercosis. Sex-wise prevalence of this infection in male and female was recorded as 4.82% (4/83) and 5.43% (5/92), respectively. The infection was higher (5.34%) in the young age group of 1-12 months as compared to the older stocks of 13-24 months of age group (4.54%). Prevalence of porcine cysticercosis was relatively higher in cross bred pigs (5.88%, 6/102) than in the non-descript local breed of pigs (4.11%, 3/73).	Local makeshift slaughter houses were visited weekly in Bareilly to explore the prevalence of the porcine cysticercosis in this area. 175 pigs were screened for cysticercosis and prevalence was correlated to age, sex and breed of pigs.	Saravanan t al., 2014

	8.0% from lingual palpation and 2.2% from meat inspection	Slaughter house post-mortem examination in Nagaland State	Fahrion, et al., 2014
	9.30%	Serosurvey	Rajshekhar et al., 2003
	Humans: A recent study in a pig-rearing community from the northern state of Uttar Pradesh reported that 17 of 72 (38%) members of that community had evidence of taeniasis. The prevalence of taeniasis is probably higher in northern than southern India. The prevalence of porcine cysticercosis has been studied in pig carcasses in slaughterhouses of north and east India and ranges from 7-12% although a recent study from the pig-rearing community in Uttar Pradesh placed the figure at 26%.	Review	Rajshekhar, 2004
Nepal	**Pigs:** Out of 250 pig carcass examined, 34 (13.6%) carcass were positive for taenia cysts.	Slaughter survey	Joshi et al., 2007
	Ante-mortem detection of *T. solium* infection of pigs in a Syangja District community indicated 32% (136/419) of pigs positive by lingual examination while 24% (48/201) was serologically positive by EITB and 6% (12/201) showed evidence of old infection or exposure	Ante-mortem, EITB	Joshi et al., 2004
	Porcine cysticercosis rates were estimated to be 14 and 32% by examination of carcasses and lingual palpation of live pigs, respectively.	Review	Rajshekhar, 2004

	Four were positive out of 400 and one was equivocal, giving a Trichinella seroprevalence of 1% (95% CI: 0.27 - 2.54).	The aim of the present study was to determine the Trichinella seroprevalence in slaughter pigs in Kathmandu Valley, Nepal. Serum samples were obtained from 400 pigs at 4 major slaughterhouses and tested for Trichinella antibodies by ELISA using larval excretory- secretory (E/S) antigen.	Sapkota et al., 2006
	32.50%	Serosurvey	Rajshekhar et al., 2003
	Humans: Out of 724 patients who presented with seizure at Kathmandu Model Hospital, 61% of all seizures and 72% of focal seizures were due to NCC.	Hospital survey	Joshi et al., 2008
	Taeniosis rates range from 10 to 50% amongst different ethnic groups in the Syangja and Tanahun districts of Nepal (Joshi et al., 2002, unpublished data). These are amongst the highest taeniosis rates reported from anywhere in the world.	Unpublished hospital records	Rajshekhar et al. 2003
Southeast Asia			
Indonesia	**Pigs:** 15.5% (2011) and 99 8.3% (2012) in humans and 19% in pigs (2012) were seropositive for cysticercosis	The recent field survey of cysticercosis in Jayawijaya Indonesia	Wandra et al., 2013
	0.02-2.63 %	Serosurvey	Rajshekhar et al., 2003

	Humans: Based on a positive serological test using ELISA, 10 of 74 (13.5%) patients with epilepsy in Bali were diagnosed to have NCC	ELISA	Margono et al., 2001
	81 (50.6%) were found to be positive by the immuno- blot	In a survey of 160 human sera samples from 18 villages in Jaywijaya District of Irian Jaya,	Subahar et al., 2001
	1.7-13%	Serosurvey	Rajshekhar et al., 2003
Myanmar	**Pigs:** the prevalence of porcine cysticercosis in meat inspection was 23.7%; seroprevalence was 15.9%	Slaughterhouse survey and ELISA antibody test of 364 pigs	Khaing et al, 2015
	Humans:		
Vietnam	**Pigs:** The infection rate of cysticercus cellulosae in pigs was 0.04% at Hanoi slaughterhouses, 0.03-0.31% at provincial slaughterhouses in the north, and 0.9% in provincial slaughterhouses in the southern region of Vietnam.	Slaughterhouse survey	Nguyen et al., 2014
	Humans: Vietnam, 633 cases of NCC were diagnosed out of 4017 patients (15.8%) managed there between 1996 and 1997	A study of patients attending the National Institute of Malariology, Parasitology and Entomology (NIMPE) in Hanoi,	Van De, 2002

	The seroprevalence in epileptic patient population was <10%.	To describe the occurrence of cysticercosis in patients living in rural areas of Northern Vietnam presenting clinical signs of NCC. Serological antigen detection, reflecting current infection with viable larval stages of *T. solium*, was used to estimate the prevalence of active cysticercosis in this patient population.	Trung et al., 2013

Conclusions

Reporting bias from animal health agencies regarding porcine cysticercosis incidence is very evident when comparing pig and human data (Figure 10 and Table 12).

Of the 207 official reports submitted among the 20 selected countries under the LVIF, 47% were reported in Madagascar and 97% of all events were reported from African countries, while only 3% were reported from Asia, in Myanmar. When comparing the incidence and prevalence estimates for porcine cysticercosis, the country event based incident reporting is very limited and does not coincide with high prevalence estimates derived from surveys, particularly in Nepal, Indonesia and Viet Nam which did not report any events between 2000-2015. However, Madagascar is actively reporting their outbreaks and this likely reflects the government policies and priorities.

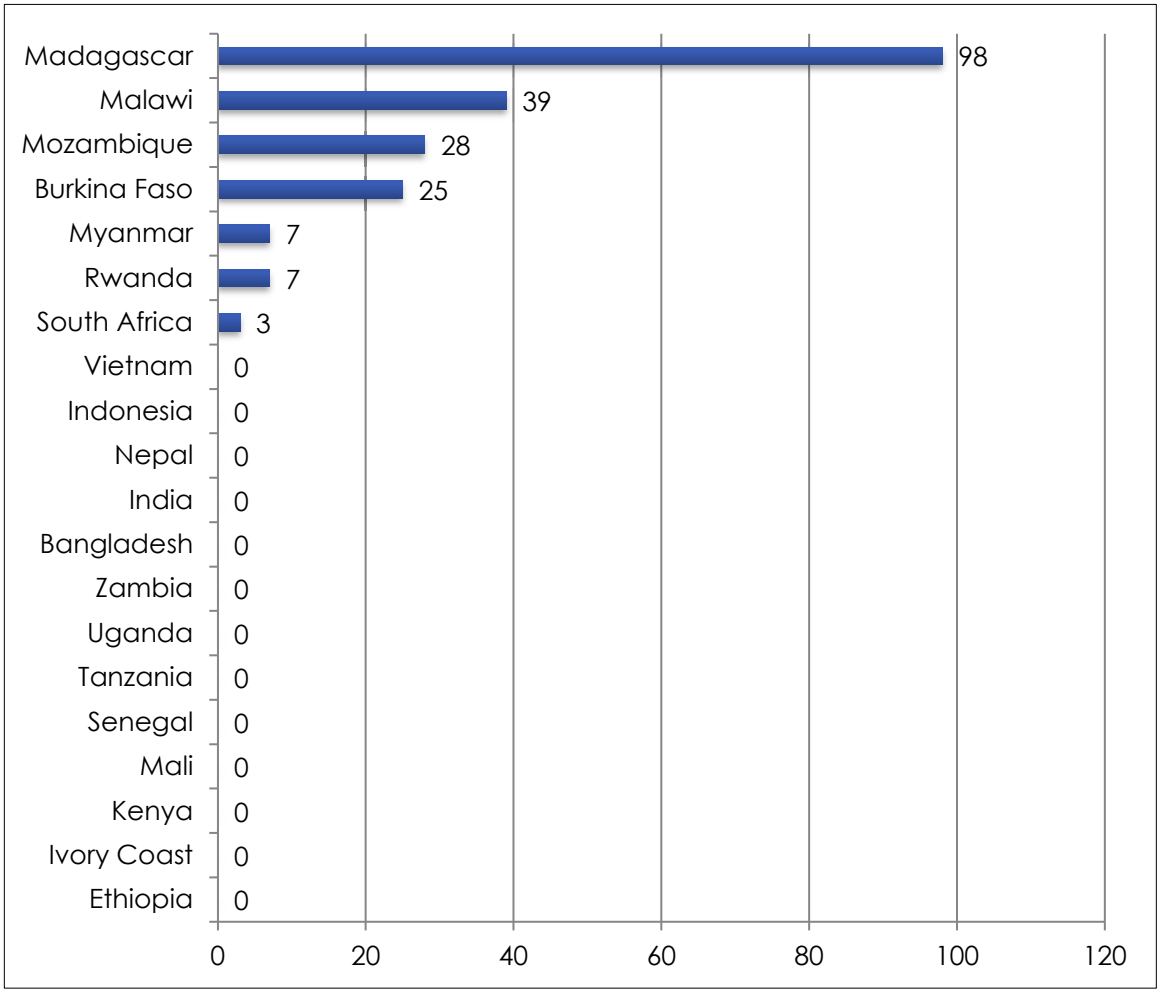


Figure 10: Number of reported cysticercosis events among 20 selected countries, 2000-2015

In addition, official reports of human cases and deaths provide additional discrepancies to support under-reporting of porcine cysticercosis in pigs as presented in the following Table based on OIE WAHIS Zoonosis data in Table 12. Coloured cells indicate both cases (C+) and deaths (D+), which were reported among the 20 selected countries between 2005 and 2014.

Table 12: Reported cases (C+) and deaths (D+) of cysticercosis in humans among 20 selected countries

Country	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Bangladesh										
India	C: +, D: +	C: +, D: +	C: +, D: +	C: +, D: +						
Indonesia										
Myanmar										
Nepal							C: +, D: +		C: +, D: +	C: +, D: +
Vietnam	C: +, D: +	C: +, D: +		C: +, D: +	C: +, D: +					
Burkina Faso	C: +, D: +	C: +, D: +								
Ethiopia										
Ivory Coast										
Kenya							C: +, D: +	C: +, D: +		
Madagascar	C: +, D: +			C: +, D: +	C: +, D: +	C: +, D: +	C: +, D: +	C: +, D: +	C: +, D: +	C: +, D: +

Malawi	C: +, D: +								C: +, D: +	
Mali										
Mozambique		C: +, D: +				C: +, D: +	C: +, D: +	C: +, D: +	C: +, D: +	
Rwanda		C: +, D: +	C: +, D: +			C: +, D: +	C: +, D: +		C: +, D: +	
Senegal										
South Africa						C: +, D: +	C: +, D: +	C: +, D: +	C: +, D: +	C: +, D: +
Tanzania										
Uganda										
Zambia										

In terms of the incidence in pigs reported by year among the 20 selected countries, the peak occurs 2002-2004 with a maximum of 44 (Figure 11).

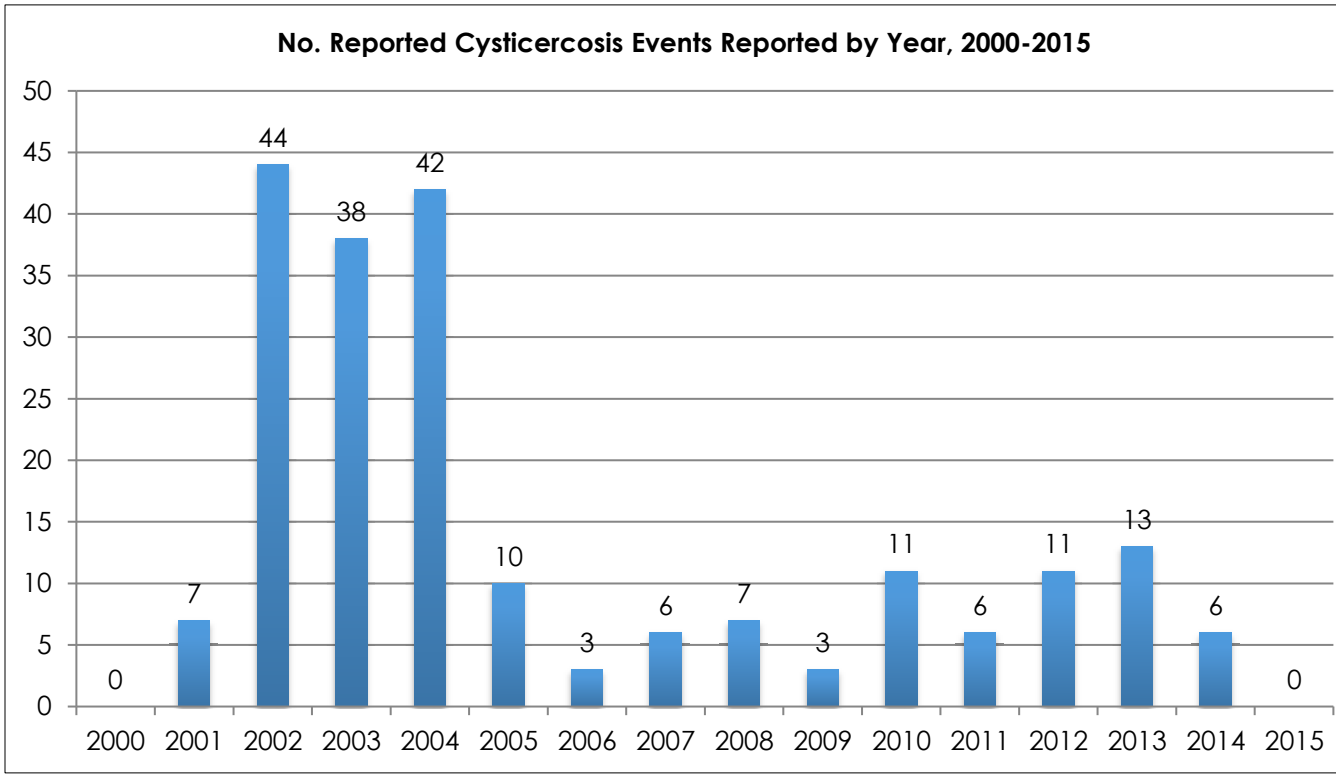


Figure 11: Number of reported cysticercosis events reported among 20 selected countries by year.

Economic and Social Impacts at Global and Regional Levels, and in Selected Countries

Losses of animals of different species are calculated as Livestock Unit (LSU) losses, using the definitions presented in Figure 12 [23]:

1 camel or "other camelid"	=	1.1 LSU
1 cattle	=	0.9 LSU
1 buffalo	=	0.9 LSU
1 horse or mule (equidae)	=	0.8 LSU
1 pig	=	0.25 LSU
1 sheep	=	0.1 LSU
1 goat	=	0.1 LSU
1 poultry bird (chicken, duck, guinea fowl or goose).	=	0.015 LSU

Figure 12: Definition of species-specific livestock units values based on the World Bank Livestock Disease Atlas

Porcine cysticercosis ranks as the 7th most economically significant disease of pigs globally measured in livestock units lost globally. Figure 13 presents a summary of the ranking of pig diseases in terms of reported Livestock Units (LSU) lost, 2006-2009 [23].

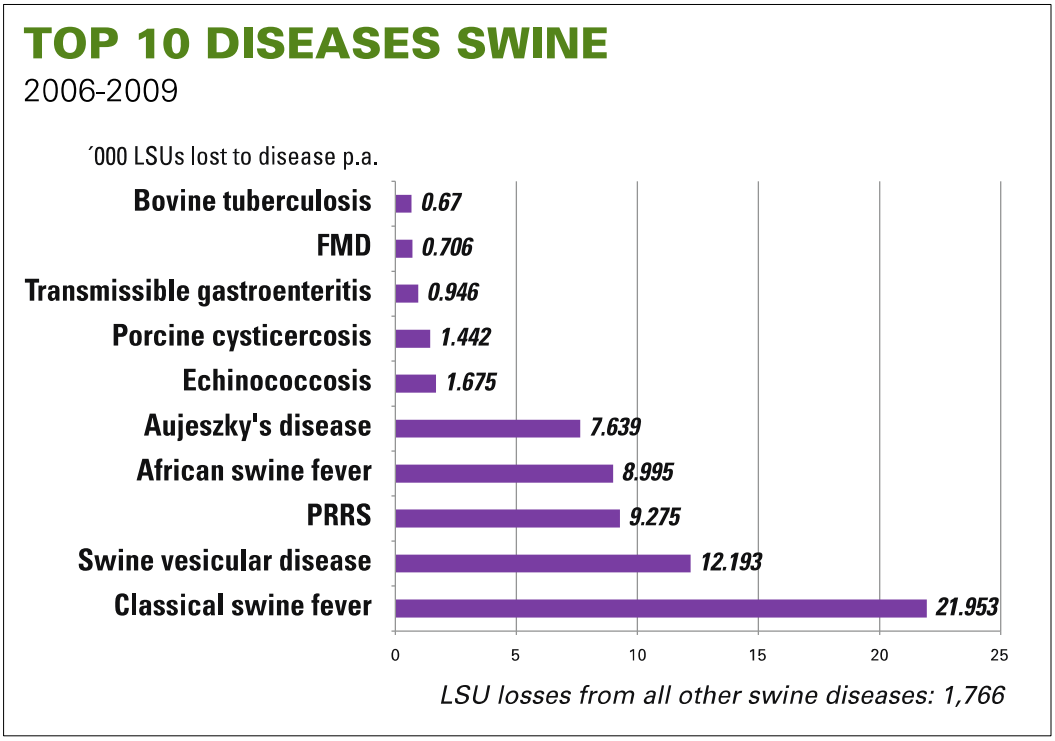


Figure 13: Ranking of the top 10 pig diseases in terms of Livestock Units lost, 2006-2009

Figure 14 further summarizes the geographic distribution of the top 10 countries impacted through LSU losses due to porcine cysticercosis, 2006-2009. Among the 20 selected countries, Rwanda (2006-2008) and Mozambique (2009) are noted to be among the top 10 economically affected countries globally [23].

The economic, social and health impacts to pigs and humans will be considered in the following section.

The International League Against Epilepsy has cited NCC as the main cause of epilepsy in the world (Anonymous, 1994) and the WHO estimates that throughout the world at least 50 million people are infected with the parasite that causes annually more than 50,000 deaths [17]. The CWGESA has developed a long-term control program, which aims to: 1) document the burden and impact of *T. solium* infections; and 2) encourage basic and applied research on cysticercosis/taeniosis, socioeconomics and potential interventions.

In Sub-Saharan Africa there is a growing recognition of the importance of NCC (larval infection of the central nervous system) in epilepsy, a disease that is now part of a global public health campaign ('Out of the Shadows'). In this region, the rapid expansion of smallholder pig production has led to a significant increase in cysticercosis in pigs and humans. Therefore the disease is a growing problem for governments seeking to increase livestock production and rural incomes sustainably [17].

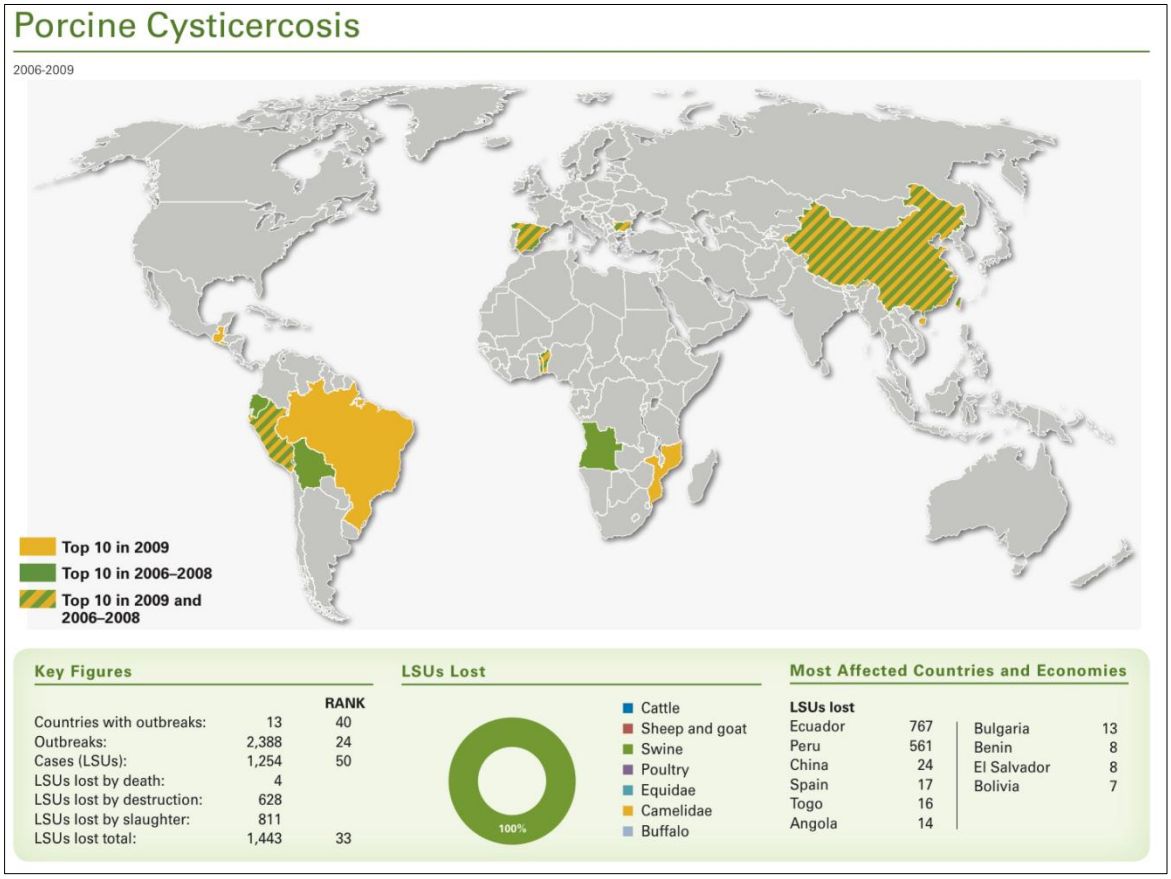


Figure 14: Geographic distribution of the top 10 countries impacted through lost LSU due to porcine cysticercosis, 2006-2009

NCC is an important cause of epilepsy globally and it places particular demands on health services results in severe social impact on humans affected due to the social stigmatization and discrimination surrounding this condition. The WHO has estimated the global burden of NCC based on four comprehensive studies for *T. solium* cysticercosis [25]. A global extensive systematic review of literature found that the frequency of NCC in people with epilepsy was consistent across endemic countries. The pooled estimate was 29.0% (95% CI: 22.9%–35.5%) [25].

The clinical manifestations of NCC vary, but seizures are by far the most common presentation, occurring in 66–90% of cases. Other central nervous system manifestations include asymptomatic infections, subarachnoid and ventricular involvement resulting in hydrocephalus, chronic meningitis and infarcts, and massive infection and encephalitis. In severe cases, NCC can be fatal. NCC is an important and preventable cause of epilepsy, especially in developing countries [24].

The social consequences of NCC include stigmatization, incapacitation and decreased work productivity [24]. In addition, measuring the long-term impact of, chronic endemic diseases are is difficult to quantify and communicate to policy makers [24].

The cost estimates for the pig sector have been entirely based on the prevalence of porcine cysticercosis and the economic loss of the pig's value due to the infection. The observed variation between countries has been primarily due to the differences in porcine cysticercosis prevalence and reduced values of the infected pigs in the different country settings. A study in the Eastern Cape Province of South Africa also reported different values due to different data analytical methods. Generally, the price of a finished pig is reduced by 20-60% because of infection with cysticercosis, however losses due to pig condemnations account only approximately 5% of the overall cost of the disease in pigs and humans [24].

Direct costs of cysticercosis infection in pigs will often result in the condemnation of the whole carcass at the slaughterhouse [25]. However, in poor countries most pigs are slaughtered without any meat inspection [26] and some parts of the infected animals may still be sold, usually at a lower price [25].

Porcine cysticercosis studies have also found evidence for the possible reduction of fertility in pigs naturally infected with cysticercosis, which would reduce the productive performance of the pigs [27]. Similar findings have been reported in humans infected with NCC. In both the pig and human studies, cysticercosis was found to significantly reduce serum level of testosterone while increasing significantly the level of follicle stimulating hormones in males [27]. The economic costs associated with pig infertility remains to be defined.

Table 13 summarizes the social, economic and human health impacts published in peer-reviewed studies on porcine cysticercosis/taeniosis among the 20 selected countries considered under the LVIF.

Table 13: Socioeconomic impact of porcine cysticercosis in pigs and taeniasis in humans

Region/Country	Economic Impact	Social Impact	Human Health	Reference
Sub Saharan Africa				
Burkina Faso	US$76,523 loss estimated			Zoli et al., 2003
Ethiopia				
Ivory Coast				
Kenya				
Madagascar				
Malawi				
Mali				
Mozambique	15% of the total = US$114,955		85% of the total annual cost due to *T. solium* cysticercosis were estimated at around US$1.2 million	Trevisan, 2012
Rwanda				
Senegal	US$83,432 loss estimated			Zoli et al., 2003

South Africa	The agricultural sector losses were estimated to an average of US$5.0 million (95% CI US$2.4–8.1 million).	Disability in persons infected with NCC is another potential factor that is likely to contribute to further economic losses in the agricultural sector through reduced manpower, some of which would be used in pig production in the countries.	Overall, there were an estimated 34 662 (95% CI: 17 167–54 068) NCC-associated cases of epilepsy in Eastern Cape Province in 2004; The overall monetary burden (in million of US$) was estimated to vary from US$18.6 (95% CI: US$9.0–32.9) to US$34.2 (95% CI: US$12.8–70.0) depending on the method used to estimate productivity losses	Carabin et al., 2006
Tanzania	A total of 365 randomly selected participants comprising of 306 pig farmers and 59 families with epileptic patients were involved in the survey. The findings indicated that the average selling price was USD 84 for mature pigs and ranged from USD 13 - 27 for piglets. The estimated annual monetary loss due to PCC was US$ 144,449.		The estimated monetary burden due to epilepsy management in hospitals and/or by traditional healers was USD 78,592 per annum.	Nkwengulila, 2014

	A community based health education intervention trial in Tanzania found out that over a period of 5 years, the health and pig management education intervention would have a significant financial benefit to a smallholder pig farmer receiving it [NPV: US $3507 (95% CI: 3421 to 3591); IRR: 370%].			Ngowi et al, 2012
		49.8% (Chi Sq = 0.003, DF = 1, p = 0.954) of pig keepers were aware of PC, whereas the remaining 50.2% were not aware (Chi Sq = 25.5, DF = 1, p < 0.001).		Chacha et al, 2014
Uganda				
Zambia				
South Asia				
Bangladesh				

India			Between 26 and 50% of all Indian patients presenting with partial seizures are diagnosed with a SCG on the CT scan The other unusual feature of the disease is the low proportion of pork eaters amongst Indian patients with NCC. Less than 1 / 2% of patients with NCC admit to eating pork. More than 95% of Indian patients with NCC are vegetarians or do not consume pork.	Wadia et al., 1987; Misra et al., 1994
			The societal monetary cost of T. soli- um cysticercosis was estimated to US$13.4 million (95% CI: US$45.3 million-US$262.3 million) in India,	Carabin et al., 2005
Nepal				
Southeast Asia				
Indonesia	Annual economic loss due to taeniasis (all species including Taenia asiatica) in Samosir island of Indonesia amounted to US$ 2.4 million			Fan and Chung, 1997

Myanmar				
Vietnam			30% of patients with NCC were found to have taeniosis. Several patients were reported to have subcutaneous cysts.	Van De, 2002

Disease Prevention and Control Methods

Although the socioeconomic impact and public health burden of cysticercosis have been demonstrated to some degree, thus far no large-scale control program has been undertaken in Africa or in Asia [15]. The amount of information available from Asia is severely lacking. Prevention and control options will be presented primarily from the pig point of view with relevant points for the human-pig interface.

Treatment (Control)

Sanitary Control Methods

Based on WHO/OIE/FAO Guidelines, components of long-term programs with a supportive value in short-term control projects include the following [17]:

- Improved sanitation (as noted under risk factors previously);
- Changes in pig husbandry (and marketing);
- Advocacy, awareness and community targeted education.

Medical Treatment

Potential strategies for the control of *T. solium* infections to meet short-term control goals include the following [17]:

- Anthelmintic treatment of human carriers (Albendazole should not be used in pregnant women but is now widely used against *T. solium* cysticerci only).
- Anthelmintic treatment of positive pigs, in high risk areas for cysticercosis with OFZ;
- Vaccination of pigs (see below).

OFZ is a safe and effective anthelmintic used for the treatment of *T. solium* in pigs. Key features of OFZ related to safety and efficacy are summarized in Table 14 [17][28].

Table 14: Feasibility of OIE recommended sanitary prevention measures in smallholder poultry settings

Features	Reference
A single dose of OFZ at 30mg/kg has been the most promising	Mkupasi et al., 2013
OFZ has not shown 100% efficacy against cerebral cysts	Gonzalez et al., 1998, Sikasunge et al., 2008
Reduces cyst viability quickly, with 50% of cysts found to be non-viable at 1 week post treatment	Sikasunge et al., 2008
At 12 weeks post treatment all muscle cysts appear to be non-viable	Gonzalez et al., 1998
Time period for: • Resolution of all muscle cysts following treatment by 10-12 weeks • Normal appearance reported at 12 weeks post treatment • 4/5 carcasses having meat fit for human consumption at 26 weeks post treatment	Gonzales et al., 1996 Gonzalez et al., 1997 Sikasunge et al., 2008
A withdrawal time of 17 days has been established for meat to be fit for human consumption	Moreno et al., 2012
OFZ-treated infected pigs were immune to reinfection for at least three months after treatment	Gonzalez et al., 2009

Work is progressing towards the standardization of the optimal dose and the registration of OFZ as a treatment for *T. solium* in pigs. A consortium of scientists from Argentina, Peru and the Global Alliance for Livestock Veterinary Medicines (GALVmed) has undertaken an assessment of OFZ and its metabolites [29]. A study by Lightowlers et al. is undergoing peer review for publication and the author has shared preliminary findings on the use of TSOL18 vaccine in combination with OFZ as an intervention approximately every 3 months. All pigs greater than 6 months old were vaccinated and pigs 2-6 months of age were given vaccination + OFZ. The researchers have modelled the outcome of this initial pilot study and predict that within 9 months of implementing this strategy all pigs older than 6 months of age would be free of cysticercosis and safe to eat (data is being submitted for publication).

Prophylaxis (Prevention)

Sanitary Prophylaxis

The feasibility of implementing the following sanitary procedures eligible for prevention and prophylaxis of porcine cysticercosis and taeniosis in developing countries are summarized in Table 15 [17].

Table 15: Draft of TPP for a porcine Antigen tests for screening and food safety use [34]

Sanitary Prophylactic Measures	Current Feasibility in Developing Countries
Incentives for smallholder farmers and traders to utilize officially licensed slaughter facilities with ante-mortem and post-mortem pig inspection	Limited: Informal/unofficial pig value chains exist and veterinary capacity is not sufficient to inspect all home slaughtered pigs
Isolated slaughter facilities away from human latrines	Limited: Very few well designed facilities exist in rural areas and are only being developed in peri-urban and urban areas
Prevent pigs from exposure to gravid proglottids while grazing and foraging	Limited: Free ranging pigs wander freely; farmers may be aware but do not prioritize food safety due to risk perception

Where is it best to focus control efforts? CLTS is an innovative community based sanitation programme being that aims at reducing open air defecation in rural communities [29]. The working hypothesis was that the success of CLTS could lead to control of poor sanitation related diseases including porcine cysticercosis. Bulaya conducted pre- and post-intervention assessments in the same villages to evaluate CLTS as an intervention measure for porcine cysticercosis in Katete District in the Eastern Province of Zambia. The study revealed that "*CLTS as an intervention did not lead to a decrease porcine cysticercosis infections in pigs ($p > 0.05$). It recommended that besides CLTS; health education, mass drug treatment and veterinary control of pigs be incorporated, particularly to pig farmers as an essential component of prevention and control programmes* [30]".

Interventions also require defined endpoints. Handali and Pawitan conducted a modeling study, suggesting that taeniasis and porcine cysticercosis antibody assays could be used to determine with a high statistical confidence whether an area is free of disease. Confidence would be improved by using secondary tests such as the taeniasis coproantigen assay and necropsy of the sentinel pigs [31].

Medical Prophylaxis

The OIE notes that a *T. solium* vaccine is undergoing the steps towards registration and commercial availability. A combination of TSOL18 vaccine and OFZ anthelmintic treatment has been demonstrated to be highly effective in experimental control of natural transmission to pigs [1]. A list of intervention strategies developed under the WHO/OIE/FAO Guidelines is presented in Figure 15 [17].

Intervention strategy	Advantages	Disadvantages
Elimination of infected pig carcasses (meat inspection)	• Known contribution to elimination of parasite from several developed countries • Relatively easy to integrate with meat inspection for several other important diseases	• Pigs in many endemic countries do not go to formal slaughter • Infected pigs can be diagnosed *ante-mortem* (tongue inspection) and slaughtered outside regulated system to avoid condemnation of carcasses
Improved sanitation, hygiene and pig husbandry	• Known contribution to elimination of parasite from several developed countries • Provides benefits beyond control of *T. solium*	• Economically difficult in many existing endemic areas
Health education	• Provides benefits beyond control of *T. solium* • New media now widely available	• Improved knowledge does not always result in change of practises • Inefficient as sole strategy
Treatment of intestinal taeniosis	• Highly efficacious drugs now available (some generically produced niclosamide may have low efficacy) • Demonstrated short-term benefits • Removes known significant transmission risk	• Would require repeated interventions for long-term control • Requires specific infrastructure; not self-sustainable • Praziquantel should be used with caution in cases of cysticercosis
Vaccination of swine	• Long-term protection • Possible to integrate with existing veterinary and/or pig husbandry practices • Provides economic benefit to end user (avoidance of carcass condemnation) • Compliance monitoring possible (serological testing)	• Many existing producers in endemic areas do not currently vaccinate against other diseases with high economic impact on swine production • Vaccines not available now (other than at experimental level)
Chemotherapy of infected swine	• Drugs available now • Highly effective • Producers have economic motivation (avoidance of carcass condemnation) • Other production benefits: can affect other economically important parasites of swine	• Producers often do not treat for other economically important parasites despite economic benefits • Existing systems of avoiding meat inspection reduce economic advantages

Figure 15: Matrix of intervention strategies for porcine cysticercosis/Taeniosis developed under the WHO/OIE/FAO Guidelines

Options and Strategies for Vaccination

Options

A critical finding from early studies is that immunity to re-infection plays an important role in the natural regulation of transmission of taeniids. This host-protective immune response is directed towards the oncosphere in the early developing embryo, a trait that can be used by scientists developing vaccines [32]. Three initiatives to develop a vaccine for *T. solium* in pigs are described below.

Sciutto et al. developed an S3Pvac vaccine against *Taenia crassiceps* infection in mice using peptide antigens, which was subsequently described as inducing immunity cross-reactive to *T. solium* in pigs. Three field trials have been reported using the vaccine. Huerta et al. (2001) achieved a 52% reduction in the prevalence of *T. solium* in vaccinated pigs compared with control pigs. In another field trial, the selection of controls was not appropriately done and the results were equivocal. In addition, this vaccine produced in Mexico has yet to be evaluated outside of Mexico.

Flisser et al. conducted a trial using the peptide antigen TSOL18 which achieved complete protection against the development of any cysticerci in the vaccinated pigs, compared with the presence of many cysticerci developing in the musculature of all control pigs [32]. Assana et al. also conducted a pilot field trial in Cameroon of the new peptide vaccine TSOL18 vaccine directed at the elimination of *T. solium* oncoshperes. Two hundred and forty 2–3 month-old piglets were distributed to 114 individual households in pairs. Vaccinated animals received three immunisations with 200 µg TSOL18 plus 5 mg Quil A and 30 mg/kg OFZ at the time of the second immunisation. Necropsies were undertaken when the pigs were approximately 12 months of age. Viable *T. solium* cysticerci were identified in 20 control pigs (prevalence 19.6%); no cysticerci were found in any of the vaccinated animals ($P < 0.0001$). Combined application of TSOL18 vaccination and a single OFZ treatment in pigs is a simple and sustainable procedure that has the potential to control *T. solium* transmission in endemic areas and indirectly reduce the number of new cases of NCC in humans [33].

DNA vaccines have also been developed in China. Vaccination trials were conducted in pigs immunized with DNA constructs expressing antigen B of *T. solium*. The pigs were challenged orally with *T. solium* eggs at 14 days and 4 months after vaccination and it was found that vaccinated pigs had 84-99% fewer cysticercosis than control pigs [32].

Strategies

The most promising vaccine model is the TSOL18 vaccine in pigs, together with OFZ treatment of young pigs to remove any *T. solium* infections that may have established in the animals prior to vaccination [32]. A vaccine is needed because there is a 21-day withholding time for anthelmintics and since *T. solium* cysts create muscle lesions when treated with anthelmintics, thus reducing carcass quality. Vaccination would prevent such cysts from being established. The use of both OFZ and vaccination to treat existing lesions and prevent future

infection has the potential to improve carcass quality and food safety which will encourage upward economic mobility marketing program/incentives for smallholder pig owners.

A holistic strategy for Porcine Cysticercosis vaccination inclusive of technical and non-technical considerations is therefore proposed:

Short-term

- Support the transition from research projects to country programs including policy, advocacy and community needs assessments;
- License the current vaccine formulation and optimize the TSOL18 for a single dose regimen;
- Initiate the development of a rapid pen side tests: one for surveillance purposes to identify highly endemic areas and one for slaughter decision making and carcass disposition (whole versus partial carcass condemnation);
- Support field trials to validate and optimize field application of TSOL18 plus OFZ under a variety of epidemiological conditions;
- Integrate animal health, public health and private industry to advance advocacy and technology transfer, respectively.

Medium- to long-term

- Develop a one dose formulation for TSOL18 to deal with challenges in revaccinating free range pig rearing;
- Develop bivalent/multivalent TSOL18 formulation models in combination with classical swine fever (Asia) and African swine Fever (Africa) under a One Health approach to provide incentives for smallholder farmers and public health agencies;
- Support the development of comprehensive joint intersectoral, country-specific and culturally specific intervention models for cysticercus (source reduction) and taeniosis (human mitigation) at the human-animal-environmental interface. (Madagascar, Viet Nam, Burkina Faso, Nepal).

Vaccines Available

There is currently no approved vaccine for the prevention and control of cysticercosis in pigs.

Commercial vaccines manufactured in Africa and Asia

The TSOL18 vaccine is currently in the form of a liquid pulse-release formulation that is in the process of being licensed for production and sale in India by Indian Immunologicals Limited, Hyderabad, India (February or March 2016). The vaccine is the result of a collaboration between Indian Immunologicals Limited and the following institutions:

- Faculty of Veterinary and Agricultural Sciences, The University of Melbourne, 250 Princes Highway, Werribee, Victoria 3030, Australia
- GALVmed, Doherty Building, Pentlands Science Park, Bush Loan, Edinburgh EH26 0PZ, United Kingdom

Commercial vaccines imported into Africa and Asia

None currently.

Characteristics of Ideal Vaccine Candidates for Smallholders

Target Product Profile: Vaccine (Cysvax) [35]

Attribute	Minimum (currently available candidate vaccine)	Ideal
Antigen	TSOL18	Same
Indication for use	Prevention and control of porcine cysticercosis	Same
Recommended species	Pigs	Same
Recommended dose	(TSOL18) ≥ 150 microgram (1ml)	As required for one-dose formulation
Pharmaceutical form	Recombinant monovalent liquid pulse-release formulation of *T. solium* oncosphere antigen	Same or may require lyophilized form for bivalent/multivalent construct with Classical swine fever (CSF) and/or African swine fever (ASF) antigens
Route of administration	Deep intramuscular	Same or oral
Regimen – primary vaccination	Day 60	Day 60 as one-dose regime with no need for booster
Regimen – booster	Day 80-90	None required
Epidemiological relevance and use for smallholders	Monovalent model is of limited perceived usefulness by pig	Bivalent formulation with either CSF or ASF would be highly desirable for

Attribute	Minimum (currently available candidate vaccine)	Ideal
	smallholders and animal health agencies	smallholder and animal health agencies
Recommended age at first vaccination	Day 60	Same
Onset of immunity	2 weeks following the second booster	2 weeks following the single booster for a one dose regime
Duration of immunity	6 months	Lifelong
Expected efficacy	>95%	Same
Expected safety	>99%	Same
Withdrawal period	None	Same
Special requirements for animals	Pigs approximately of two months of age and above. Generally corticosteroid therapy should be avoided 1-2 weeks before and after the vaccination for developing good immune response.	Same
Special requirements for persons	Not for human use.	No tissue or anaphylactic reaction
Package size	1, 5, 10 and 20 dose vials.	Same
Price to end user	US$0.50	Same or US$0.65 as bivalent formulation
Storage condition and shelf-life as packages for sale	Keep refrigerated 2-8^0 C	Same
In-use stability	Information not available	Stable within 4-8 hours

Seromonitoring to assess the possible circulation and effect of maternally derived antibodies must also be considered.

In December 2015, the WHO sponsored a Stakeholder Meeting on *T. solium* Taeniasis/Cysticercosis Diagnostic Tools and the following target product profile (TPP) was proposed for Antigen testing in pigs related to: 1) Screening the population; and 2) Food safety decisions in slaughterhouses. The ideal candidates for each purpose are described in Table 16 [34].

Table 16: Draft of TPP for a porcine Antigen tests for screening and food safety use [34]

Purpose/setting	Screening	Food safety
Specimen	Blood (serum, spots)	Blood
Test time	--	30 min
#Operator steps	--	1-3
Performance	Species: Se (for less than 50 cysts, 90%), Sp (98%), gold standard: necropsy	Se (for less than 50 cysts, 95-99%), Sp (90%)

Se: Sensitivity; Sp: Specificity

Key Conclusions Related to Vaccination and Diagnostic Tests

The following conclusions related to vaccines and diagnostics are submitted:

- *T. solium* is technically eradicable given the potential of TSOL18 vaccine;
- Vaccination for *T. solium* in pigs with TSOL18 must be pursued in a holistic way including technical and non-technical considerations for the communities in order to fully realize its benefit;
- Incentives are needed for animal health sector to develop affordable, sensitive and specific diagnostic tests;
- The combination of TSOL18 and OFZ in conjunction with intersectoral community and market interventions requires further study through operational research and socio-economic studies;
- Incentives for farmers will be the key for eventual adoption including the use of regionally appropriate bivalent vaccines such as African swine fever (ASF) and Classical swine fever (CSF).

Limitations

Methodology

All incidence and prevalence estimates must be regarded with additional scepticism due to reporting bias by OIE member countries and especially lack of test specificity and clear interpretation of positive antigen test results. Porcine cysticercosis is clearly still not a prioritized or reported disease due to the chronic and still as yet undefined economic losses it causes to smallholder farmers. Use of a bivalent vaccine with other important pig diseases of economic importance will likely impact interest in and reporting of porcine cysticercosis by animal health ministries.

Gaps in knowledge or capacity impacting strategic planning and effective adoption and implementation of vaccination for Porcine Cysticercosis:

- Optimization of the field application of TSOL18 plus OFZ based on local risk, needs, cultural preferences under a comprehensive One Health approach;
- Need for a cheap, highly sensitive and highly specific pen side antigen detection test for *T. solium* for 1) routine surveillance and for 2) carcass disposition at slaughter plants;
- Shifting from academic approach to a government-led (user-driven) policy and programmatic framework. A program driven approach using policy development is currently being developed in Peru and Madagascar and soon in Viet Nam.
- Work on *T. solium* in pigs should be synergized with related needs for Schistosomiasis and important pig diseases in order to identify high risk and high impact areas to promote complementary and synergistic interventions at the human-pig-environmental interface;
- Definition of the required market incentives related to the vaccination and treatment of pigs for *T. solium* The knowledge, attitudes and practices (KAP) of smallholders should be evaluated to evaluate what farmers can do with the slaughtered pigs who clear the infection due to vaccination;
- New, alternative-marketing options should be developed for acceptable products made from previously infected and healthy pigs including smoked processed meat products that can generate profits in niche markets.

Acknowledgements

The consultant gratefully acknowledges the opportunity to contribute to the International Development Research Centre, Livestock Vaccine Innovation Fund Project. Sincere thanks for guidance and support of Dr. Vincent Guyonnet, Dr. Victor Mbao, and Dr. Renee Larocque. This includes clear direction of the TOR and letters supporting for the survey and questionnaires developed. Thanks is also expressed to Shumin Li for her diligent work in researching Chinese vaccine information;

Many thanks to my colleagues Dr. Meritxell Donadeu, Dr. Fred Musisi and Dr. Baptiste Dungu for their collegiality and collaboration to share information and for their collaboration in conducting the vaccine survey with selected countries and vaccine companies. I am very grateful for the time taken by experts interviewed, particularly Dr. Marshall Lightowlers, Dr. Bernadette Abela-Ridder, Dr. Anna Fahrion, Dr. Hugo Garcia, Dr. Anand Kumar, Dr. Pierre Dorny, Dr. Kapil Maithal and Dr. Samson Mukaratirwa for their recommendations and information shared.

References

[1] OIE. 2014. OIE Terrestrial Manual 2014 Chapter 2.9.5. **http://www.oie.int/fileadmin/Home/eng/Health_standards/tahm/2.09.05_CYSTICERCOSIS.pdf** (Accessed 1/7/2016).

[2] Biology discussion. **http://www.biologydiscussion.com/parasites/the-structure-and-life-cycle-of-taenia-with-diagram/2727** (Accessed 1/7/2016).

[3] US Centers for Disease Control and Prevention. 2016. **http://www.cdc.gov/parasites/taeniasis/biology.html** (Accessed 1/7/2016).

[4] WHO Factsheet. Taeniasis/cysticercosis. Updated May 2015. **http://www.who.int/mediacentre/factsheets/fs376/en/** (Accessed 1/7/2016).

[5] Merck Medical Manual. 2016. **http://www.merckvetmanual.com/mvm/public_health/zoonoses/zoonotic_diseases.html** (Accessed 1/7/2016).

[6] García, H.H Gonzalez, A.E. Evans, C.A.W. Gilman, R.H. *Taenia solium* cysticercosis**.** THE LANCET • Vol 361 • August 16, 2003.

[7] Zammarchi L, Strohmeyer M, Bartalesi F, Bruno E, Muñ oz J, et al. (2013) Epidemiology and Management of Cysticercosis and Taenia solium Taeniasis in Europe, Systematic Review 1990–2011. PLoS ONE 8(7): e69537. doi:10.1371/journal.pone.0069537. (Accessed 1/7/2016)

[8] Sibat H.F. and de Fátima Ibañez Valdés L. Introduction to Cysticercosis and Its Historical Background. **http://dx.doi.org/10.5772/50318**. **http://cdn.intechopen.com/pdfs-wm/42403.pdf** (Accessed 8/1/2016).

[9] Hoberg, E. Alkire, N.L. de Quieroz, A. Jones, A. Out of Africa: The origin of the *Taenia* tapeworms in humans. Proceedings Royal Society of London. 2001. 268: 781-787. **http://royalsocietypublishing.org/content/royprsb/268/1469/781.full.pdf** (Accessed 1/8/2016).

[10] Sciutto, E. Fragoso, G. Fleury, A. Laclettea, J.P. Sotelo, J. Alujad, A. Vargasa, Larraldea, L.C. *Taenia solium* disease in humans and pigs: an ancient parasitosis disease rooted in developing countries and emerging as a major health problem of global dimensions. Microbes and Infection, 2, 2000, 1875−1890.

[11] Vega, R. Piñerob, D. Ramanankandrasan, B. Dumas, M. Bouteille, B. Fleury, A. Sciutto, E. Larralde, C. Fragoso, G. Population genetic structure of Taenia solium from Madagascar and Mexico: implications for clinical profile diversity and immunological technology. International Journal for Parasitology 33 (2003) 1479–1485.

[12] Yanagida T, Carod J-F, Sako Y, Nakao M, Hoberg EP, et al. (2014) Genetics of the Pig Tapeworm in Madagascar Reveal a History of Human Dispersal and Colonization. PLoS ONE 9(10): e109002. doi:10.1371/journal.pone.0109002 (Accessed 1/7/2016).

[13] Willingham, A.L. Combating Taenia solium Cysticercosis in Southeast Asia: An Opportunity for Improving Human Health and Livestock Production. **http://www.rnas.org.cn/upload/infile/2008-9-25160539-combating.pdf** (Accessed 1/8/2016).

[14] Arriola CS, Gonzalez AE, Gomez-Puerta LA, Lopez-Urbina MT, Garcia HH, et al. (2014) New Insights in Cysticercosis Transmission. PLoS Negl Trop Dis 8(10): e3247. doi:10.1371/journal.pntd.0003247.

[15] Marcela Esquivel-Velázquez, Carlos Larralde, Julio Morales and Pedro Ostoa-Saloma. Protein and Antigen Diversity in the Vesicular Fluid of *Taenia Solium* Cysticerci Dissected from Naturally Infected Pigs. International Journal of Biological Sciences 2011; 7(9):1287-1297.

[16] Sikasunge, C.S. Phiri, I.K. Phiri, A.M. Dorny, P. Siziya, S. Willingham III, A.L. Risk factors associated with porcine cysticercosis in selected districts of Eastern and Southern provinces of Zambia. Veterinary Parasitology 143 (2007) 59–66.

[17] WHO/FAO/OIE. 2005. WHO/FAO/OIE Guidelines for the surveillance, prevention and control of taeniosis/cysticercosis. **http://www.oie.int/doc/ged/d11245.pdf** (Accessed 1/10/2016).

[18] Assana, E. Lightowlers, M.W. Zolia, A.P. Geerts, S. Taenia solium taeniosis/cysticercosis in Africa: Risk factors, epidemiology and prospects for control using vaccination. Vet. Parasitol. (2013), http://dx.doi.org/10.1016/j.vetpar.2012.12.022

[19] Aluja, A.S. Villalobos, A.N.M. Plancarte, A. Rodarte, L.F. Hernfindez, M. Sciutto, E. Experimental *Taenia solium* cysticercosis in pigs: characteristics of the infection and antibody response. Veterinary Parasitology 61 (1996) 49-59.

[20] WHO. 2015. Taeniasis/cysticercosis Fact sheet N°376 Updated May 2015. **http://www.who.int/mediacentre/factsheets/fs376/en/** (Accessed 1/11/2016).

[21] Dorny, P. Brandt, J. Zoli, A. and Geerts, S. Immunodiagnostic tools for human and porcine cysticercosis. Acta Tropica 87 (2003) 79 /86 .

[22] US CDC. 2016. Cysticercosis. **http://www.cdc.gov/parasites/cysticercosis/** (Accessed 1/11/2016).

[23] World Bank. 2011. WORLD LIVESTOCK DISEASE ATLAS A Quantitative Analysis of Global Animal Health Data (2006-2009). **http://documents.worldbank.org/curated/en/2011/11/15812714/world-livestock-disease-atlas-quantitative-analysis-global-animal-health-data-2006-2009** (Accessed 2/12/2015)

[24] Carabin, H. Krecek, R. C. Cowan, L. D. Michael, L. Foyaca-Sibat, H. Nash, T.and Willingham. A.L. Estimation of the cost of Taenia solium cysticercosis in Eastern Cape Province, South Africa. Tropical Medicine and International Health. Volume 11 no 6 pp 906–916 june 2006 doi:10.1111/j.1365-3156.2006.01627.x

[25] Zoli, A. *et al*. (2003) Regional status, epidemiology and impact of *Taenia solium* cysticercosis in Western and Central Africa. *Acta Trop*. 87, 35-42

[26] Joshi, D. D. *et al*. (2003) Improving meat inspection and control in resource-poor communities: the Nepal example. *Acta Trop*. 87, 119-127

[27] Ngowi, H.A. Mukaratirwa, S. Lekule, F.P. Maingi, N. Waiswa, C. Sikasunge, C. Afonso, S. Sumbu, J. Ramiandrasoa, S. Penrith, M.L. and Willingham, A.L. Agricultural Impact of Porcine Cyisticercosis in Africa: A Review. Novel Aspects on Cysticercosis and Neurocysticercosis. **http://dx.doi.org/10.5772/51196** **http://cdn.intechopen.com/pdfs-wm/42398.pdf** (Accessed 1/8/2016).

[28] Thomas, L.F. Landscape analysis: control of Taenia solium. **http://apps.who.int/iris/bitstream/10665/164359/1/9789241508643_eng.pdf** (Accessed 1/13/2016).

[29] BULAYA, C. THE EVALUATION OF CLTS AS AN INTERVENTION MEASURE FOR THE CONTROL OF PORCINE CYSTICERCOSIS IN KATETE DISTRICT IN THE EASTERN PROVINCE OF ZAMBIA. Research Thesis: Master of Science in Epidemiology. **http://dspace.unza.zm:8080/xmlui/handle/123456789/3727?show=full** (Accessed 1/13/2016).

[30] Lightowlers, M.W. Control of Taenia solium taeniasis/cysticercosis: past practices and new possibilities. Parasitology (2013), 140, 1566–1577. 2013. doi:10.1017/S0031182013001005

[31] Handali, S. and Pawitan, Y. Verifying Elimination Programs with a Special Emphasis on Cysticercosis Endpoints and Postelimination Surveillance**.** Journal of Parasitology Research Volume 2012, Article ID 974950, 6 pages doi:10.1155/2012/974950.

[32] Lightowlers, M.W. Review article: Vaccines for prevention of cysticercosis. Acta Tropica 87 (2003) 129 /135.

[33] Assana, E. Kyngdon, C.T. Gauci, C.G. Geerts, S. Dorny, P. De Deken, R. Anderson, G.A. Zoli, A.P. Elimination of Taenia solium transmission to pigs in a field trial of the TSOL18 vaccine in Cameroon. Int J Parasitol. 40(5): 515-519.

[34] WHO. 2015. Stakeholder Meeting on *T. solium* Taeniasis/Cysticercosis Diagnostic Tools. Geneva.

[35] Kumar, A. Prevention of Epilepsy in India. PowerPoint presentation. 2016.