International Journal of One Health
Available at www.onehealthjournal.org/Vol.1/2.pdf

REVIEW ARTICLE
Open Access

Status of *Taenia solium* cysticercosis and predisposing factors in developing countries involved in pig farming

Joseph M. Kungu[1,2,3], Michel M. Dione[4], Michael Ocaido[3] and Francis Ejobi[1]

1. Department of Biosecurity, Ecosystems and Veterinary Public Health, College of Veterinary Medicine, Animal Resources and Biosecurity Makerere University, P.O. Box 7062, Kampala, Uganda; 2. Animal Health Program, National Livestock Resources Research Institute, P.O.Box 96, Tororo, Uganda; 3. Department of Wildlife Animal Resources Management, College of Veterinary Medicine, Animal Resources and Biosecurity Makerere University, P.O. Box 7062, Kampala, Uganda; 4. International Livestock Research Institute, P.O.Box 24384, Kampala, Uganda.
Corresponding author: Joseph M. Kungu, e-mail: kungu@live.com,
MMD: mocaido@vetmed.mak.ac.ug, MO: M.Dione@cgiar.org,FE: francisejobi@gmail.com
Received: 21-12-2014, **Revised:** 01-04-2015, **Accepted:** 08-04-2015, **Published online:** 01-05-2015

How to cite this article: Kungu JM, Dione MM, Ejobi F, Ocaido M. Status of *Taenia solium* cysticercosis and predisposing factors in developing countries involved in pig farming. Int J One Health 2015;1:6-13.

Abstract

Taenia solium cysticercosis is a disease of pigs and humans populations considered endemic in many developing countries of Latin America, Africa, and South East Asia having serious impact on public health and agriculture. We conducted an in-depth comparative analysis of literature on the disease situation and predisposing factors in selected countries known to be at the interface of poverty-emerging livestock systems-zoonoses and with a growing small holder pig industry. Transmission, methods of diagnosis and employed control strategies of *T. solium* infection in pig and human populations in these countries are also discussed. Limited knowledge on porcine cysticercosis (PC) by various stakeholders expected to be key players in its control has undermined efforts for eliminating this potentially eradicable condition. Poor pig production practices, poor hygiene, and sanitation habits have also been important in the maintenance of the *T. solium* life-cycle. The major gaps identified in this review include scanty current information on PC prevalence in pigs with hardly any reports on the condition in humans in most developing countries. Factors affecting pattern of the infection and how they interact at the different levels of the pig value chain have not been exhaustively studied. Information on socioeconomic and public health impact is inadequate and not current.

Keywords: Cysticercosis, developing countries, eradication, risk factors, *Taenia solium.*

Introduction

Taenia solium cysticercosis, a parasitic zoonosis caused by larval cysts of pig cestode, *T. solium* has received little attention for decades despite its traumatizing health and socio-economic impact [1,2]. In countries where this condition occurs, every case of cysticercosis in pigs has been estimated to result in a monetary loss of 194 Euro and 9 Disability Adjusted Life Years per 1000 persons per year are averagely lost [3]. With minimal or no constraints due to porcine cysticercosis (PC) experienced in the developed world, the condition remains a problem of the poor. About 70% of the world's rural poor are known to depend on livestock as their source of livelihood and have been reported to be the most prone to prevailing endemic zoonoses of today [4]. *T. solium* cysticercosis has been ranked third of the 13 identified endemic zoonoses implicated for causing most illnesses of poor livestock keepers [5]. With many health challenges affecting the rural-poor communities, priority has been given to the continuously emerging epidemics, leaving the condition uncontained [6]. In many developing countries, pig-keeping is undergoing rapid expansion in response to the "livestock revolution" that is, the rapidly increasing demand for animal source foods driven by urbanization, changing dietary preferences, and increasing incomes [4,7,8]. These changes could be anticipated to influence the epidemiology of the disease. The objective of this review was to present recent information on cysticercosis epidemiology in the context of rapidly expanding pig systems in developing countries.

Methodology of the Review

In this review, a detailed comparative analysis of literature from recent studies conducted in pig keeping communities of countries from Latin America, Asia, and Africa has been done. Except The People's Republic of China, the countries described here are among those defined by the World bank as developing [4]. The review focused on information outside of the conventionally used databases. The search strategy involved entering key terms like "*T. solium* cysticercosis and taeniosis in developing countries, diseases of pigs communicable to man, parasites of public health importance, neglected tropical diseases, prevalence of epilepsy due to neurocysticercosis (NCC)" in Google scholar, Mendeley, and Wikipedia internet search engines. Websites hosted by animal and human disease surveillance agencies such as WHO, FAO, OIE, and Centers for Disease Control and Prevention (CDC) were browsed for the latest updates posted regarding the *T. solium* condition. Figure-1 describes details of the search strategy used [9].

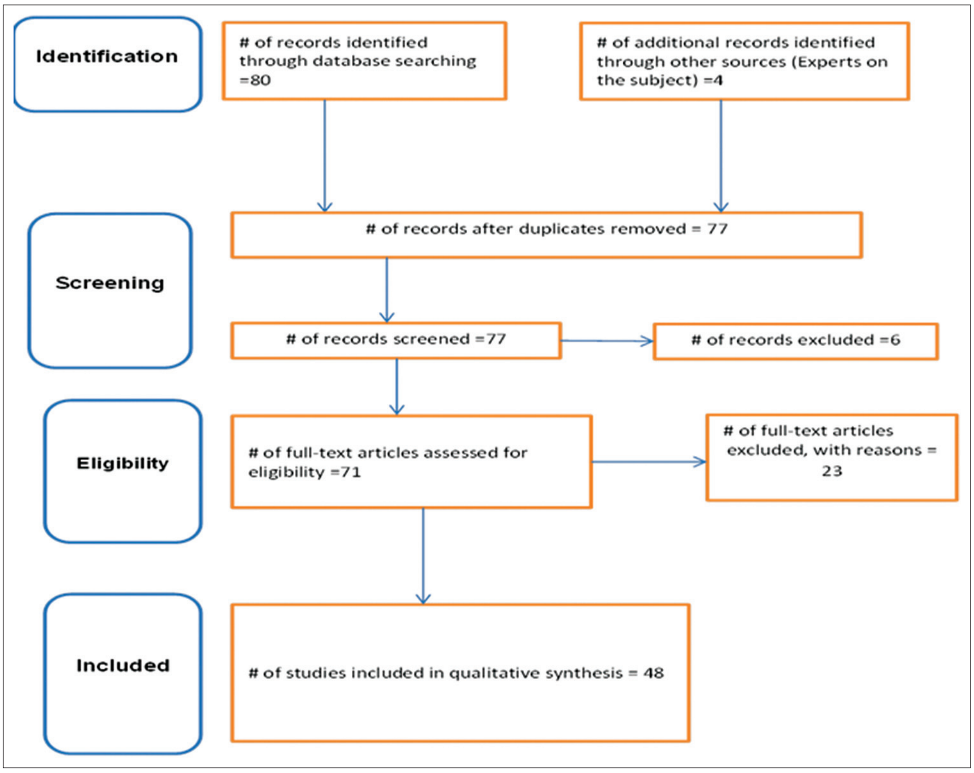

Figure-1: A flow chart showing methodology used to review the status of porcine cysticercosis in developing countries (Adopted from PRISMA flow diagram by Moher *et al*. [9]).

Findings

T. solium cysticercosis, a globally recognized public health concern, remains a serious yet neglected condition among the world's poverty stricken populations. The condition caused by metacestode of *T. solium* (previously referred to as cysticercus cellulosae) affects pigs and humans [10]. The pig is the known primary intermediate host (causing PC) and humans the definitive host (resulting in taeniosis) for this larval infection. Dogs have been reported as secondary intermediate hosts for the metacestode. Possibility of humans acting as accidental intermediate hosts (leading to human cysticercosis) and pigs as secondary final host of this tapeworm infection has been described [11]. Human cysticercosis becomes a life threatening situation when the metacestodes invade the brain tissues resulting in NCC that is the leading known cause of epilepsy in human populations of the developing countries [2]. Prevalence findings of the condition in both pigs and humans in countries described here are presented in Table-1.

The transmission cycle and risk factors

The role of pigs in the transmission cycle

Pigs are infected when they ingest *T. solium* eggs in food and water, hatching into oncospheres (embryos) that penetrate the intestinal lumen. These migrate through the blood circulatory system and lymphatics to different body tissues where they form cysts (cysticerci) [7,9]. Cysticerci (larvae) establish preferably in active tissues like the brain, skeletal and cardiac muscles. This process takes about 8 weeks, with the cysticercus remaining viable for at least 1 year, and inflammatory reactions around the cysticerci sets in after [13,14]. This probably explains why *T. solium* does not develop into a clinical condition in pigs since with the exception of sows; they are not usually kept for longer than a year before slaughter. All age groups can be affected however prevalence is significantly higher in pigs that are more than 4 months old [1].

PC is amplified by factors that lead to environmental contamination with the *T. solium* eggs and those that expose pigs to this contamination. Such causal factors include open air defecation by human carriers, use of human waste as manure in horticulture, careless disposal of untreated sewerage. Exposure factors such as free range pig rearing, unprotected water, and food sources as well as lack of awareness of the disease and its implications have been key in maintaining the condition [15]. Presence of these risk factors correlates with poverty levels of pig farming communities. This explains the global trend of PC discussed here, with the prevalence being highest in Africa, South East-Asia and least in Latin America [4]. The rural small holder pig keeping communities of many developing countries where pigs roam freely are the most affected [8,16,17]. The detrimental effects here are experienced as losses due to condemnation of infected carcasses in a few areas where meat inspectors are strict and high taeniosis infestation in humans who ingest poorly cooked pork [18,19].

Table-1: Prevalence findings on *T. solium* cysticercosis of studies conducted from 2002 to 2013 in selected developing countries.

Country (area of study)	Prevalence in pigs % (sample size)	Seroprevalence in humans with epilepsy % (sample size)	References
Latin America			
Mexico (Tedzdiz, Mexico city)	35 (109)	12.2	[12]
Bolivia	38.9	17	[13]
Brazil	23.5	Unknown	[12]
Guatemala	14	17	[14]
Peru	75	24	[15]
South East Asia			
India	Unknown	4.64 (2500)	[16]
Vietnam	0.9	5.3 (303)	[17]
Indonesia (Papua-Jayawijaya)	77^{MI} (35)	29.2	[18]
Cambodia	10.9	10	[19]
P.R China	Unknown	0.58 (96,008)	[20]
Phillipines	Unknown	24.6 (497)	[20]
Africa			
The Gambia (Western region)	4.8 (371)	0	[21]
Senegal (Southern region)	6.4-13.2 (1,705)	Unknown	[21]
Burkina Faso (Batondo, Pabre', and Nyonyogo)	Unknown	10.3 (768)	[5]
Nigeria	20.5 (7,471,730)	0	[22]
Cameroon (Northern region)	26.6 (398)	5 (237)	[23,24]
Democratic Republic of Congo (Kinshasa; Bas-Congo province)	38.4 (498); 41.2 (158)	21.6	[25,26]
Rwanda (Southern region)	Unknown	21.8 (215)	[27]
South Africa (Eastern Cape Province)	57 (261)	32.6 (273)	[28]
Zambia (Eastern region)	Unknown	14.5 (817)	[13]
Mozambique (Angonia)	34.9 (661)	Unknown	[2]
Tanzania (Mbulu district)	7.3 (784)	Unknown	[29]
Kenya (Western region)	6.5^{TP} (33)	Unknown	[30]
Uganda (South-Eastern region)	8.5 (480)	Unknown	[31]

The tests in all the studies were serological ELISA tests except for Indonesia (MI) and Kenya (TP). MI: Meat inspection, TP: Tongue palpation

The role of humans in the transmission cycle

Taeniosis usually occurs when humans eat undercooked or raw pork infected with cysticerci [8]. Since *T. solium* cysticercosis has been reported to affect dogs, they could be playing a role in the transmission of human taeniosis in countries such as Korea, Vietnam, Indonesia and the People's Republic of China, where they are frequently eaten. Human populations in urban centers of developing countries who unknowingly consume dog meat disguised as beef are at risk too [15,20]. Availability of more hosts other than the pig and humans has increased the survival of the pig tapeworm and could complicate its eradication.

The adult development process of a tapeworm involves the scolex evaginating and attaching to the mucosa with its double row of hooks and its four suckers in the upper third section of the small intestine, which is the duodenum-jejunum. The adult worm develops and starts releasing gravid proglottids with its first expulsion taking place between eight to 12 weeks after infection. A few gravid proglottids are passed out in the host's feces daily or two to three times per week [3]. Although the tapeworm carriers may experience minimal clinical defects, they play a pivotal role in the *T. solium* transmission cycle by shading adult worm segments packed with eggs into the environment. A contaminated environment becomes a source of infection for other humans and pigs that ingest it from food and water. The carriers are also a source of infection to themselves by autoinfection which can be due to reverse peristalsis (endogenous) or ano-oral contamination (exogenous) [19,21].

Human cysticercosis clinically manifests depending on the tissues of the body affected, number of cysts, size of cysts and the immune response elicited in the affected body. The most significant clinical defects have been reported to occur when the cysts lodge in the brain and the eyes thereby manifesting as epileptic seizures and eye defects [22-24].

Generally, the pattern of human cysticercosis in a population is determined by the similar factors that influence the trend of PC, already described.

Risk factors associated with *T. solium* cysticercosis

Various factors have been identified to be responsible for the spatial distribution and occurrence of this condition in humans and pigs. These are discussed here in detail.

Poor hygiene and sanitation practices

Poor hygiene and sanitation have been reported to play a key role in the transmission of *T. solium* cysticercosis in both humans and pigs. Poor hygiene practices like lack of hand washing with soap following visits to the latrines and before eating food, eating unwashed fruits and vegetables, drinking unboiled/untreated water result in humans ingesting the eggs of *T. solium* and causing PC [13,16]. Poor sanitation in the households due to open air defecation, latrines in poor conditions allowing pigs to access feces increases the possibility of occurrence of the infection [25]. Feces deposited in the open environment are often washed into unprotected springs and wells contaminating the water sources hence posing a risk to both pigs and humans [16]. Such a risk of contamination of food and water is high especially in rural communities with over 60% none/poor latrine coverage.

Management systems

The traditional systems of pig rearing commonly practiced in rural communities like free range and tethering play a significant role in maintaining *T. solium* cysticercosis in humans and pig populations. This is because such systems of management allow pig's access to exposed fecal material, thereby enabling the continuity of the *T. solium* lifecycle [5,26].

Lack of knowledge

Community awareness about a disease is a crucial step in its control and eventual eradication. Lack of knowledge about the pork tapeworm transmission cycle by farmers, consumers and non-consumers of pork, medical and veterinary personnel, policy makers and implementers in developing countries has made control of the potentially eradicable condition difficult [27]. It causes reluctance among the communities in ensuring proper hygiene and sanitation, confinement of pigs as well as other practices that limit the spread of this condition [26].

Misperceptions by people in the disease endemic areas like "Tapeworm infections are only caused by eating of raw sweet potatoes and cassava" have made control of *T. solium* infection difficult. This has been the case in many East African communities. In Uganda, reports by media reporters with limited knowledge on transmission of *T. solium* cysticercosis alleging that "eating pork directly causes epilepsy" have left people misinformed.

Some reports indicate that people are aware of the infection but are ignorant of how it can be transmitted and controlled. Although the change of behavior in communities is not automatic after acquisition of knowledge, it could be a key step in prevention of *T. solium* cysticercosis [28].

Lack of inspection of pork

PC has been shown to be prevalent in areas where inadequate, or none inspection of pork is practiced [28] (Table-2). This is the case in most communities in Africa whereby pigs are slaughtered in ungazetted areas, especially backyards. The uninspected pork is then sold locally or transported to urban centers for marketing. This poses a serious risk to pork consumers especially when they eat undercooked pork, increasing the incidence of taeniosis, and hence the possibility of PC occurring becomes high [8,13].

Diagnosis

Detection of occurrence of *T. solium* cysticercosis in human and pig populations in communities is important in forming the basis upon which control measures for the infection can be constituted [29]. In pigs, diagnosis of *T. solium* cysticercosis is done at antemortem using tongue examination and immunological tests. It is also undertaken at postmortem during meat inspection of predilection sites of cysts like the muscles, tongue, and heart [30]. Application of antemortem diagnostic tools in field conditions in developing countries is still limited, with lingual examination being the only used tool. This is because tools like serological tests for detection of antigens and antibodies for PC are expensive, limiting their use to research studies. Such tests include ELISA, lateral flow tests, and polymerase chain reaction [31,32]. Validating and making readily available under field conditions, the Dot blot test with a high sensitivity (86.4%) and specificity (93.2%) compared to lingual examination has been very helpful in detecting and hence control of PC in Latin America [33,34]. There is ongoing work by Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) to validate a lateral flow blot test developed by Australian scientists for use in Africa. Though lingual examination is highly specific, detection of the condition at ante-mortem where cysts have not manifested in the tongue is not possible [35]. Antibody ELISA and immuno-blot sero-diagnostic tests are also available for detecting both porcine and human cysticercosis, though they only indicate that the subject being tested has had previous exposure to infection by the parasite, and not necessarily has a current viable infection [31]. Researchers at the CDC in the USA have developed a serological test (immuno-blot) specific for human infection with adult *T. solium*. The test is based on excretory/secretory antigens and is very sensitive and specific [36]. This serological test has been suggested as a helpful tool in surveillance and control programs [32].

The use of antigen detection serological tests has been highly envisaged in recent studies of PC. The challenge however is that no concurrent confirmatory test has been employed to reduce the biasness due to false positive results. In humans, specialized tools like computerized tomography scans, magnetic resonance imaging, and X-rays are used to detect cysts in the brain. These are usually expensive, not widely available and are not appropriate for use in a large population-based studies [20,37]. Immunodiagnostic tests like immuno-blot and ELISA are also used to detect *T. solium* specific antibodies and antigens in serum and cerebral spinal fluid. These tests are helpful in demonstrating

Table-2: A summary of the status of *T. solium* cysticercosis in Latin America, South-East Asia, and Africa.

Item	Latin America	South-East Asia	Africa
Economic impact	In Mexico, estimated US $164 million [16] and 25,341 DALYS lost due to clinical NCC [17] In Peru up to $966 is estimated to be spent on treatment of a NCC patient for 2 years [23]	In China pig production loss of US $121 million occurs annually and 3-6 million people in the endemic areas are affected In the Indian sub-region, 4.2% of the economic worth of pigs is lost due to condemnation of affected carcasses [29]	In Cameroon pig production losses of €478,844 and €45,838.4 of DALYS [48] In South Africa, US $5Million production losses [20]
Risk factors	Free roaming of pigs, unprotected water sources and open air-defecation Tapeworm carriers, a possible source of infection in household clustering of this condition [15]	Improper sanitation Poor pig management practices and lack of pig meat inspection Sociocultural practices of the human populations whereby some communities have preference for pork to other meat products [14] Alternative hosts for *T. solium* cysticercosis such as dogs where they are a delicacy [49]	Poor hygiene and sanitation practices in humans, rearing pigs by free-range and tethering Lack of awareness about the disease and its transmission, non-inspection of pigs before or following slaughter, and age of pigs have been described to occur [3,13,49,19]
Diagnosis	Tongue examination Meat inspection Serology in pigs Neuroimaging and used in humans [50]	Meat Inspection in pigs Serological tests Neuro-imaging tests to confirm presence of the condition in humans and monitor progress of treatment in a few patients who can afford [25,51]	Tongue examination is rarely carried out by traders during buying of pigs Postmortem meat inspection of predilection sites of cysts like the muscles, tongue, and heart is also practiced on a non-routine basis in few formal slaughter places [20,28] The use of serological tests like ELISA, Lateral flow tests PCR for detection of antigens and antibodies for *T. solium* cysticercosis are expensive and have been limited to research studies [52] Neuroimaging and serology applied in humans during research studies [20]
Advances in control	Improved pig rearing practices Raising community awareness on the disease Massive chemotherapy against taeniosis and *T. solium* cysticercosis have been employed [53] Development and application of vaccines such as TSOL18, TSOL45-1A and S3PVAC to pig herds has been shown to be useful [33,35]. It is presumed that this has temporarily interrupted the transmission cycle of the condition	With the exception of China, not much progress has been made to reduce on the disease burden. Most affected countries are relying on meat inspection during post-mortem to hinder the transmission cycle by condemnation and disposal of infected pork [14] In China, surveillance and intervention measures such as mass-screening and treatment of taeniosis carriers, treatment of *T. solium* cysticercosis patients and pigs, meat inspection and raising public awareness are ongoing in the endemic areas [29]	Meat inspection in a few gazetted slaughter places [30]
Limitations	No reliable gold standard test for diagnosis of NCC No published reports on any extensive studies in recent years to estimate the level of such interventions	No large scale studies except in China and India. Limited interventions. No studies in humans	No large scale studies. Limited interventions. No studies in humans

DALYS: Disability adjusted life years, NCC: Neurocysticercosis, PCR: Polymerase chain reaction, *T. solium: Taenia solium*

exposure and presence of active infection [33]. Use of these tools is however debatable because correlation between a positive serology and neurological symptoms/lesions indicative of NCC in neuro-imaging techniques is poor to fair in most studies due to unpredictable clinical outcome of the infection and the variable immunological response of the human host to the infection. There is also a lack of a gold standard for these tests [38].

Control and eradication

T. solium cysticercosis has been declared eradicable but remains an important neglected parasitic condition [21]. In Europe and USA, successful prevention of the condition has been achieved through maintaining high sanitary measures and strict inspection, as well as the elimination of affected carcusses in slaughter abattoirs. Control advances like vaccination of pigs, treatment of pigs and humans using anthelminthics on massive scale, public education of people have been demonstrated to be feasible in Latin America and China have caused a temporary disruption of the transmission cycle and thereby lowering the disease prevalence [26]. In Peru and Mexico, vaccination of pigs, use of massive chemotherapy and health education conducted by well-trained personnel has demonstrated a significant reduction of the condition [39]. In Brazil, health education campaigns through centers for control of zoonoses, schools, and local communities have played an important role in a reduction of *T. solium* condition. Most of all, organization of farmers into cooperatives with increased technical and financial support aimed at increased pork production for local market and export has significantly lowered the condition [40,41]. This has not been the case in the African countries and South. East Asian nations that have hardly taken such initiatives to combat the condition. This is probably because priority has been given to other emerging pandemics that affect these impoverished nations. In order for this disease burden to be reduced, combining effective, affordable and sustainable control strategies should be done [42]. Prior to initiation of intervention measures, there is need to carry out baseline epidemiological surveys to ascertain the status of the condition in humans and pigs of the communities suspected to be affected by use of field applicable diagnostic tools [29]. Screening of households to identify tapeworm carriers that act as transmission foci for PC is also important in eliminating the source of infection. Control measures are aimed at limiting continuity of the life cycle of *T. solium* in the intermediate hosts (pigs and humans) and definitive hosts [22].

In pigs, the condition can be combated by encouraging full-time confinement of pigs that prevents them from eating contaminated fecal materials. Although routine deworming with albendazole combined with ivermectin had earlier been suggested to minimize the occurrence of *T. solium*, recent studies have shown it is ineffective and have demonstrated that oxfendazole causes a significant reduction of the condition in pigs [43,44]. Since pigs are indispensable intermediate hosts, effective vaccination using developed vaccines like S3PVAC (98% efficacy), TSOL18, TSOL45-1A (with up to 100% efficacy) is expected to reduce transmission and form a basis for eradication of the condition [23,36]. Though vaccines have been developed and used in Latin American countries, feasibility of their production, affordability and effective usage in rural free-ranging pigs in other disease endemic countries remains a challenge [45]. Possible massive production and use of the TSOL18 vaccine is expected to start in Africa if the ongoing testing and validation process in the field by ASARECA is successfully completed.

The infection in human populations can directly be controlled by detection and massive chemotherapy against taeniosis and cysticercosis using drugs like oxfendazole, praziquantel and niclosamide [43]. Treatment of humans against adult tapeworms reduces the occurrence of cysticercosis in pigs [46].

This measure is being undertaken in vulnerable groups like children, pregnant mothers, and elderly people in some developing countries under the drive to combat neglected tropical diseases. The effectiveness of this effort in control of the condition has however not been evaluated.

Sustainable control can also be achieved by stopping the sale and consumption of infected pork through ensuring that slaughtering of pigs is done in gazetted areas where meat inspection can be undertaken, and infected meat is condemned. Except in Latin America and China, this is hardly implemented and slaughters are undertaken in backyards. In some countries that have gazetted pig slaughter places with meat inspectors, thorough inspection of pig carcasses is not guaranteed [1,13].

In communities where inspection is not carried out, cooking pork at ≥60°C and freezing it at ≤5°C could help interrupt the life cycle [44]. Reducing the risk of environmental contamination with the *T. solium* eggs by ensuring safe disposal of feces plays an integral part in the control of the infection [47]. Health education through raising awareness among the people in communities that rear pigs and consume pork about the zoonotic implications, and the transmission of the infection can be helpful in reducing the incidence of the infection [27]. The success of a PC control campaign can be evaluated by carrying out epidemiological surveys in pigs in the affected area. A lowered sero-prevalence of *T. solium* in pigs is indicative of a minimized incidence in humans [27]. The challenge in most of these developing countries however is that very few epidemiological surveys on PC in pigs exist, with no published findings available on the condition in humans. The studies already undertaken have used small sample sizes, non-confirmatory screening techniques making it difficult to generate reliable findings to draw conclusive remarks on the extent of *T. solium* cysticercosis in pig and human populations (Table-2).

Conclusion

Although the International Task Force for Disease Eradication (ITFDE) in 1993 declared *T. solium* a potentially eradicable parasite, no intervention programs have successfully been implemented at any national level to stump out this condition.[14] In most African and South East Asian countries, little effort has been envisaged in attempt to control or eliminate *T. solium* cysticercosis. The condition has remained a neglected infection with priority being given to emerging diseases with direct and immediate high mortality and morbidity effects in both human and livestock populations. The pig, an intermediate host playing a pivotal role in maintaining *T. solium* infection is not a priority animal in the developing countries' plan for development of the livestock industry. This implies that no financial and human resources have purposely been set aside by the governments to promote pig health and development of the pig industry despite the role it plays in the improvement of livelihoods of the rural poor.

Recommendations

In order for control efforts to be successful, the following strategies should be considered:

- Provide appropriate information about *T. solium* cysticercosis epidemiology to stakeholders along the pig value chain including farmers, consumers, government policy makers, committees involved in resource allocation and training institutions.
- Carry out extensive epidemiological surveys in pigs and humans in the different regions of the countries since they usually have varying socio-demographic patterns and possibly with different disease predisposing factors.
- As recommended by ITFDE and noted in the WHO/FAO/OIE guidelines,[14] medical and veterinary sectors should undertake joint national prevalence and economic impact studies, and surveillance reporting programs. These programs should involve use of up-to-date highly specific and sensitive diagnostic tools, and clinical management procedures.
- Since the use of anthelminthics for the treatment of humans and pigs is ongoing some countries, emphasis on the appropriate drug, dosage and period of protection as well as assessment of impact of this intervention must be ensured by the medical or veterinary practitioners.
- Government agencies for animal and human health should provide wide health education on the risks and prevention of taeniosis and *T. solium* cysticercosis.
- Establishment of high standards of meat hygiene and inspection, as well as provision of veterinary expertise on improved pig husbandry and slaughter practices will be very helpful in mitigation of *T. solium* cysticercosis.

Authors' Contributions

JMK: Designed, undertook study and compiled the manuscript. FE: Advised on the design and edited the manuscript. MO: Advised on the design and edited the manuscript. MMD: Advised on the design and edited the manuscript.

Acknowledgments

Special thanks to the Germany Academic Exchange Service (DAAD) Scholarship Scheme and International Livestock Research Institute (ILRI) for the financial support extended to undertake this review. Thanks to Dr. Delia Grace, ILRI for all the technical inputs in this work.

Competing Interests

The authors declare that they have no competing interests.

References

1. Boa ME, Mahundi EA, Kassuku AA, Willingham AL, Kyvsgaard NC. Epidemiological survey of swine cysticercosis using ante-mortem and post-mortem examination tests in the southern highlands of Tanzania. Vet Parasitol 2006;139(1-3):249-55.
2. Pondja A, Neves L, Mlangwa J, Afonso S, Fafetine J, Willingham AL 3rd, *et al.* Prevalence and risk factors of porcine cysticercosis in Angónia District, Mozambique. PLoS Negl Trop Dis 2010;4:e594.
3. Ngowi HA, Kassuku AA, Carabin H, Mlangwa JE, Mlozi MR, Mbilinyi BP, *et al.* Spatial clustering of porcine cysticercosis in Mbulu district, northern Tanzania. PLoS Negl Trop Dis 2010;4(4):e652.
4. The World Bank. Working for a World Free of Poverty, 2014. http://data.worldbank.org
5. Carabin H, Millogo A, Praet N, Hounton S, Tarnagda Z, Ganaba R, *et al*. Seroprevalence to the antigens of taenia solium cysticercosis among residents of three villages in burkina faso: A cross-sectional study. PLoS Negl Trop Dis 2009;3(11):7.
6. Grace D, Ogutu F, Akuku I, Thao BN, Phuc DP, Herrero M, *et al.* Mapping of poverty and likely zoonoses hotspots. zoonoses project 4. A report to department for international development, UK. Dfid Zoonoses Rep 2012;4:1-119.
7. Molyneux D, Hallaj Z, Keusch GT, McManus DP, Ngowi H, Cleaveland S, *et al*. Zoonoses and marginalised infectious diseases of poverty: Where do we stand? Parasit Vectors 2011;4:106.
8. Lekule FP, Kyvsgaard NC. Improving pig husbandry in tropical resource-poor communities and its potential to reduce risk of porcine cysticercosis. Acta Trop 2003;87(1):111-7.
9. Moher D, Liberati A, Tetzlaff J, Altman DG, Altman D, Antes G, *et al.* Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. PLoS Med 2009;6(7);e1000097
10. WHO. Neglected Tropical Diseases: Cysticercosis-Taeniasis, 2013.www.who.int>neglected tropical diseases. Last accessed on 15-12-2014.
11. Ito A, Putra MI, Subahar R, Sato MO, Okamoto M, Sako Y, *et al*. Dogs as alternative intermediate hosts of *Taenia solium* in Papua (Irian Jaya), Indonesia confirmed by highly specific ELISA and immunoblot using native and recombinant antigens and mitochondrial DNA analysis. J Helminthol 2002;76(4):311-4.
12. Sakai H, Barbosa HV Jr, Silva EM, Schlabitz FO, Noronha RP, Nonaka N, *et al*. Short report: Seroprevalence of *Taenia solium* cysticercosis in pigs in Bahia State, northeastern Brazil. Am J Trop Med Hyg 2001;64(5-6):268-9.
13. Assana E, Amadou F, Thys E, Lightowlers MW, Zoli AP, Dorny P, *et al.* Pig-farming systems and porcine cysticercosis in the north of Cameroon. J Helminthol 2010;84(4):441-6.
14. Conlan JV, Vongxay K, Fenwick S, Blacksell SD, Thompson RC. Does interspecific competition have a moderating effect on *Taenia solium* transmission dynamics in Southeast Asia? Trends Parasitol 2009;25(9):398-403.
15. Morales J, Martínez JJ, Rosetti M, Fleury A, Maza V, Hernandez M, *et al.* Spatial distribution of *Taenia solium* porcine cysticercosis within a rural area of Mexico. PLoS Negl Trop Dis 2008;2:e284.
16. Murrell KD, Dorny P, Flisser A, Geerts S, Kyvsgaard NC, Mcmanus DP, *et al*. WHO/FAO/OIE Guidelines for the Surveillance, Prevention and Control of Taeniosis/Cysticercosis.FAO Corporate Document Repository 2005. http//fao.org. Last accessed on 09-12-2014.
17. Willingham AL 3rd, Engels D. Control of *Taenia solium*

cysticercosis/taeniosis. Adv Parasitol 2006;61:509-66.
18. Carabin H, Budke CM, Cowan LD, Willingham AL 3rd, Torgerson PR. Methods for assessing the burden of parasitic zoonoses: Echinococcosis and cysticercosis. Trends Parasitol 2005;21:327-33.
19. Krecek RC, Mohammed H, Michael LM, Schantz PM, Ntanjana L, Morey L, *et al.* Risk factors of porcine cysticercosis in the Eastern Cape Province, South Africa. PLoS One 2012;7(5):e37718.
20. Foyaca-Sibat H, Cowan LD, Carabin H, Targonska I, Anwary MA, Serrano-Ocaña G, *et al*. Accuracy of serological testing for the diagnosis of prevalent neurocysticercosis in outpatients with epilepsy, eastern cape province, South Africa. PLoS Negl Trop Dis 2009;3(12):7.
21. Praet N, Kanobana K, Kabwe C, Maketa V, Lukanu P, Lutumba P, *et al. Taenia solium* cysticercosis in the Democratic Republic of Congo: How does pork trade affect the transmission of the parasite? PLoS Negl Trop Dis 2010 7;4. pii: E817.
22. Rottbeck R, Nshimiyimana JF, Tugirimana P, Düll UE, Sattler J, Hategekimana JC, *et al.* High prevalence of cysticercosis in people with epilepsy in southern Rwanda. PLoS Negl Trop Dis 2013 14;7:e2558.
23. Garcia HH, Gonzalez AE, Rodriguez S, Gonzalvez G, Llanos-Zavalaga F, Tsang VC, *et al.* Epidemiology and control of cysticercosis in Peru. Rev Peru Med Exp Salud Publica 2010;27(4):592-7.
24. Zammarchi L, Strohmeyer M, Bartalesi F, Bruno E, Muñoz J, Buonfrate D, *et al.* Epidemiology and management of cysticercosis and *Taenia solium* taeniasis in Europe, systematic review 1990-2011. PLoS One 2013;8(7):e69537.
25. Sreedevi C, Hafeez M, Kumar PA, Rayulu VC, Subramanyam KV, Sudhakar K. PCR test for detecting *Taenia solium* cysticercosis in pig carcasses. Trop Anim Health Prod 2012;44(1):95-9.
26. García HH, González AE, Del Brutto OH, Tsang VC, Llanos-Zavalaga F, Gonzalvez G, *et al.* Strategies for the elimination of taeniasis/cysticercosis. J Neurol Sci 2007;262(1-2):153-7.
27. Ngowi HA, Carabin H, Kassuku AA, Mlozi MR, Mlangwa JE, Willingham AL 3rd. A health-education intervention trial to reduce porcine cysticercosis in Mbulu District, Tanzania. Prev Vet Med 2008;85(1-2):52-67.
28. Maridadi AF, Lwelamira J, Simime FG. Knowledge and practices related to *T. solium* cysticercosis-taeniasis among smallholder farmers in selected villages in Kilolo District in iringa region in Southern Highlands of Tanzania. Int J Anim Vet Adv 2011;3(3):196-201.
29. Willingham AL 3rd, Wu HW, Conlan J, Satrija F. Combating *Taenia solium* cysticercosis in Southeast Asia an opportunity for improving human health and livestock production. Adv Parasitol 2010;72:235-66.
30. Ngowi HA, Kassuku AA, Maeda GE, Boa ME, Willingham AL. A slaughter slab survey for extra-intestinal porcine helminth infections in northern Tanzania. Trop Anim Health Prod 2004;36(4):335-40.
31. Dorny P, Brandt J, Zoli A, Geerts S. Immunodiagnostic tools for human and porcine cysticercosis. Acta Trop 2003;87(1):79-86.
32. Agudelo-Flórez P, Palacio LG. Dot blot for the diagnosis of porcine cysticercosis. Rev Sci Tech 2009;28:1077-84.
33. Sciutto E, Martínez JJ, Huerta M, Avila R, Fragoso G, Villalobos N, *et al*. Familial clustering of *Taenia solium* cysticercosis in the rural pigs of Mexico: Hints of genetic determinants in innate and acquired resistance to infection. Vet Parasitol 2003;116(3):223-9.
34. Schantz PM, Tsang VC. The US Centers for Disease Control and Prevention (CDC) and research and control of cysticercosis. Acta Trop 2003;87(1):161-3.
35. Flisser A, Rodríguez-Canul R, Willingham AL 3rd. Control of the taeniosis/cysticercosis complex: Future developments. Vet Parasitol 2006;139(4):283-92.
36. CDC.Cysticercosis - Epidemiology & Risk Factors, 2010. CDC 24/7: Saving lives.Protecting people.Saving money through prevention.www.cdc.gov>parasites home. Last accessed on 09-12-2014.
37. OIE Terrestial Manual.Cysticercosis 2008. Chapter 2.9.5. www.oie.int/international-standard-setting/terrestrial-manual .Last accessed on 11-12-2014.
38. Sreedevi C, Pradesh A. Diagnosis of *Taenia Solium* metacestode infection in pigs : A Review. Int J Vet Health Sci Res (IJVHSR) 2013;I(3):1-8.
39. Jayashi CM, Kyngdon CT, Gauci CG, Gonzalez AE, Lightowlers MW. Successful immunization of naturally reared pigs against porcine cysticercosis with a recombinant oncosphere antigen vaccine. Vet Parasitol 2012;188(3-4):261-7.
40. Sarti E, Rajshekhar V. Measures for the prevention and control of *Taenia solium* taeniosis and cysticercosis. Acta Trop 2003;87(1):137-43.
41. Pawlowski Z, Allan J, Sarti E. Control of *Taenia solium* taeniasis/cysticercosis: From research towards implementation. Int J Parasitol 2005;35(11-12):1221-32.
42. Secka A, Marcotty T, De Deken R, Van Marck E, Geerts S. Porcine cysticercosis and risk factors in the gambia and senegal. J Parasitol Res 2010;2010:823892.
43. Pondja A, Neves L, Mlangwa J, Afonso S, Fafetine J, Willingham AL 3rd, *et al.* Use of oxfendazole to control porcine cysticercosis in a high-endemic area of Mozambique. PLoS Negl Trop Dis 2012;6:e1651.
44. Mkupasi EM, Sikasunge CS, Ngowi HA, Johansen MV. Efficacy and safety of anthelmintics tested against *Taenia solium* cysticercosis in pigs. PLoS Negl Trop Dis 2013;7(7):e2200.
45. Lightowlers MW. Vaccines for prevention of cysticercosis. Acta Trop 2003;87(1):129-35.
46. Iburg TM, Karlsson M, Spång F, Sikasunge CS, Johansen MV. The effect of oxfendazole treatment on muscle pathology in pigs infected with *Taenia solium* cysticercosis. Vet Parasitol 2012;190(3-4):442-6.
47. Mwanjali G, Kihamia C, Kakoko DV, Lekule F, Ngowi H, Johansen MV, *et al*. Prevalence and risk factors associated with human *Taenia solium* infections in Mbozi District, Mbeya Region, Tanzania. PLoS Negl Trop Dis 2013;7(3):e2102.
48. Praet N, Speybroeck N, Manzanedo R, Berkvens D, Nsame Nforninwe D, Zoli A, *et al.* The disease burden of *Taenia solium* cysticercosis in Cameroon. PLoS Negl Trop Dis 2009;3(3):e406.
49. Rajshekhar V, Joshi DD, Doanh NQ, van De N, Xiaonong Z. *Taenia solium* taeniosis/cysticercosis in Asia: epidemiology, impact and issues. Acta Trop 2003;87(1):53-60.
50. Garcia HH, Gonzalez AE, Gilman RH. Diagnosis, treatment and control of *Taenia solium* cysticercosis. Curr Opin Infect Dis 2003;16(5):411-9.
51. Singh AK, Singh SK, Prasad KN, Singh A, Bajpai A, Rahman M, *et al*. Evaluation of ELISA, neck muscle, tongue and eyelid examinations for the diagnosis of swine cysticercosis in a highly endemic area of north India. Exp Parasitol 2013;134(3):313-7.
52. Ramahefarisoa RM, Rakotondrazaka M, Jambou R, Carod JF. Comparison of ELISA and PCR assays for the diagnosis of porcine cysticercosis. Vet Parasitol 2010;173(3-4):336-9.
53. García HH, Cancrini G, Bartalesi F, Rodriguez S, Jimenez JA, Roldan W, *et al.* Evaluation of immunodiagnostics for toxocarosis in experimental porcine cysticercosis. Trop Med Int Health 2007;12(1):107-10.

****