Veterinary Parasitology
Manuscript Draft

Manuscript Number: Vetpar-D-12-6113

Title: Taenia solium cysticercosis in Africa: risk factors, epidemiology and prospects for control using vaccination

Article Type: Review articles

Keywords: Taenia solium; Cysticercosis; Control; Africa, Treatment; Vaccination.

Abstract: Poor sanitary conditions, free-roaming of domestic pigs and lack of awareness of the disease burden play an important role in the perpetuation of the Taenia solium cysticercosis in Africa. Traditional pig production systems known as the source of T. solium taeniosis-cysticercosis complex are predominant in the continent, representing 60 % to 90 % of pig production in rural areas. It has been reported that T. solium cysticercosis is the main cause of acquired epilepsy in human population and results in considerable public health problems and economic costs to the endemic countries. Although the socioeconomic impact and public health burden of cysticercosis has been amply demonstrated, up to now no large-scale control program has been undertaken in Africa. Most disease control trials reported in the literature have been located in Latin America and Asia. This review discusses the risk factors and epidemiology of T. solium cysticercosis in Africa and critically analyzes the options available for implementing control of this zoonotic disease in the continent.

Taenia solium cysticercosis in Africa: risk factors, epidemiology and prospects for control using vaccination

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ABSTRACT

Poor sanitary conditions, free-roaming of domestic pigs and lack of awareness of the disease burden play an important role in the perpetuation of the *Taenia solium* cysticercosis in Africa. Traditional pig production systems known as the source of *T. solium* taeniosis-cysticercosis complex are predominant in the continent, representing 60 % to 90 % of pig production in rural areas. It has been reported that *T. solium* cysticercosis is the main cause of acquired epilepsy in human population and results in considerable public health problems and economic costs to the endemic countries. Although the socioeconomic impact and public health burden of cysticercosis has been amply demonstrated, up to now no large-scale control program has been undertaken in Africa. Most disease control trials reported in the literature have been located in Latin America and Asia. This review discusses the risk factors and epidemiology of *T. solium* cysticercosis in Africa and critically analyzes the options available for implementing control of this zoonotic disease in the continent.

Keywords: *Taenia solium*; Cysticercosis; Control; Africa; Treatment; Vaccination.

Contents

1. Introduction

Taenia solium (Linnaeus, 1758) has a life cycle involving two hosts (pig and human). The adult tapeworm establishes in the small intestine of humans, causing taeniosis. The tapeworm is composed of segments (proglottids). Gravid proglottids, containing infective eggs, detach from the worm and are released with the human faeces. When eggs are ingested by a pig, the larvae (oncospheres) are released; these penetrate the intestinal mucosa and migrate via the circulatory system to a suitable tissue location, particularly striated muscles, heart and the brain, where they develop into cysticerci causing porcine cysticercosis. Further transmission of the parasite (taeniosis) occurs when raw or uncooked meat from infected pigs is eaten by humans. Humans may also be infected by the cysticerci (human cysticercosis) following accidental ingestion of *T. solium* eggs through inadequate sanitation. In humans, cysticerci may establish in the brain, causing neurocysticercosis (NCC). *T. solium* taeniosis/cysticercosis complex constitutes an important public health problem and a serious socioeconomic obstacle for pig breeders in many African countries (Zoli et al., 2003; Willingham et al., 2006; Carabin et al., 2006). During the 1990s there was optimistic opinion on the control of cysticercosis in developing countries (Cruz et al., 1989). The assumption was based on characteristics of *T. solium* which suggest it could be eradicated (Schantz et al., 1993; Krecek and Waller, 2006). The failure to control taeniosis/cysticercosis using taeniacidal drug administration (Sarti et al., 2000) and health education through large scale eradication programs in Latin America (Sarti et al., 1997; Allan et al., 2002) has shown that global elimination of this zoonosis is difficult to achieve in the context of persistence of free-roaming pig production, poor hygiene and inadequate sanitation in the endemic countries. New strategies for controlling cysticercosis have been suggested by Flisser et al. (2006) who argue that intervention measures for control of cysticercosis might involve the international agencies and institutions, such as the World Health Organization, the Food and Agriculture

Organization, as well as the commitment of policymakers, scientists and field workers as key means for a sustainable control. Considering the many problems faced by endemic countries and the understandable priority focused on diseases such as malaria, tuberculosis and AIDS, and also the limited resources available in these countries, *T. solium* is often not provided the attention it deserves and is a particularly neglected disease. In this situation, some researchers suggest that control of *T solium* should be focused to the areas with high risk of infection (Molyneux et al., 2004; Ngowi et al., 2010). The objective of this review is to present the predisposing factors and the epidemiological data on *T. solium* cysticercosis available on the endemic areas of Africa including a critical comparison of various options for the control of this zoonotic disease.

2. Factors favouring *T. solium* cysticercosis in Africa

2.1. Pig production systems

The management systems used by pig farmers in Africa is determined by various reasons including the source of feed, lack of financial resource for investment in housing and health care requirement (Ajala et al., 2007; Deca et al., 2007; Kagira et al., 2010; Mutua et al., 2010). In rural areas pig production can be classified into three main categories (Blench, 2000): scavenging/free range system where the pig finds most of its own food, and semi-intensive and intensive systems where the majority of the food consists of domestic kitchen waste (Table 1). About 90 % of pigs are reared under scavenging /free range and semi-intensive in Western and Central African countries (Porphyre, 2009). In these pig production systems, poor sanitary conditions play an important role in the circulation of *T. solium* infection (Zoli et al., 2003). A free-range production system for pigs combined with open field defecation by humans people 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). In the

intensive system where pigs are mainly confined, may not eliminate *T. solium* transmission because some farmers are known to defecate directly in the pigsties (Shey-Njila et al., 2003). The characteristics of traditional pig production systems favouring *T. solium* taeniosis-cysticercosis in Eastern and Southern African countries are largely similar to those reported in West and Central Africa (Kagira et al., 2010; Ngowi et al., 2010). Pig keeping is predominantly of the smallholder, traditional type, characterized by a free-range management system (Phiri et al., 2003; Kagira et al., 2010). South Africa is the country with the highest number of pigs in the region with at least 25 % of these pigs kept in free-range system and exposed to high risk of cysticercosis (Krecek et al., 2008).

2.2. Limited research interest and investments in pig production

One of the characteristics of pig production in Africa is the lack of interest from policy makers and funding agencies for this agricultural activity. For reasons unconnected to their economic importance, pigs are the least well known of all the major species of domestic livestock in Africa (Blench, 2000). It is observed that most research institutes in the continent and funding organisations for agriculture development exclude pig from their activities, even for African swine fever, the most devastating pig disease in Africa. This may be related to the questionable belief that pigs compete with human for food and probably also for religious reasons. Since Islam forbids Muslims to eat pork and the Muslim population is important in Africa, prejudice against pigs from the governments and potential donor agencies may explain the limited research and funding interest for pigs compared to other domesticated livestock (Blench, 2000). The consequence of this situation is that forgotten smallholders keep 60 % to 90 % of total pigs in Africa which are mostly reared under traditional semi-intensive and free range systems favouring the *T. solium* life cycle (Boa et al., 2006; Porphyre, 2009). These pig

production systems are increasing in Africa following the growing demand for meat, particularly in urban areas (Porphyre 2009). Recently, farmers' perceptions about pig farming practices were assessed (Mutua et al., 2010). Income generation and a faster growth rate compared to other livestock were mentioned by pig farmers as key reasons to keep pigs. Because these systems are becoming the source for high demand of pork in urban areas, the proportion of taeniosis and neurocysticercosis transmission occurring in these areas is probably progressing. However there has been little research undertaken on human neurocysticercosis in urban areas in Africa. Most of studies on *T. solium* transmission have been undertaken on pigs in rural areas.

2.3. Low priority afforded to the control of cysticercosis

T. solium cysticercosis is one of the neglected tropical diseases targeted for control by the World Health Organization (WHO) Global plan for 2008-2015 (WHO, 2007). However, up to now no control program has been undertaken in Africa. Poor sanitary conditions and free-roaming of pigs identified as important risk factors for swine cysticercosis (Sikasunge et al, 2007) are mostly related to the low level of education among the pig farmers that limits their knowledge on the management of pigs (Kagira et al., 2010). A nearly complete ignorance of the *T. solium* life cycle involving pigs (cysticercosis) and humans (taeniosis and neurocysticercosis) has been reported in studies carried out in Africa (Assana et al., 2010a; Pondja et al., 2010). Most farmers in endemic areas know about the cysts in infected pigs, but few are aware of how pigs get the infection. Little is done in endemic countries to improve the situation. Existing legislation in most or all countries requires infected pigs to be destroyed by the veterinary services, but there is lack of veterinary inspection and most often the infected carcasses are consumed and marketed (Zoli et al., 2003). This situation is increasingly

dangerous when it is considered that pork consumption is increasing in African sub-Saharan countries (Porphyre et al., 2009). This is clearly shown through the development of specific restaurants or places for pork consumption, especially in the cities of West and Central Africa: For example “porc braisé” (grilled or fried pork) in Cameroon, “porc au four” (pork from oven) in Burkina Faso (Koussou and Duteurtre, 2002; Porphyre, 2009). Very often cysticerci are not killed by these meat preparation methods, leading to a high risk for the infection of consumers and the spread of the *T. solium* taeniosis. The spread of these pork cooking methods is mostly related to the preference of consumers. It was shown in an assessment of the preference of consumers in N’Jamena city (Chad) that the majority of them ate fried pork (Mopate et al., 2006).

3. Epidemiology and disease burden

T. solium cysticercosis is probably widespread in most African countries where pigs are reared under scavenging /free range systems and pork is eaten. However, there are many countries from which no information is available on both human and porcine cysticercosis. Even though epilepsy is a major problem in African countries and may often be associated with neurocysticercosis (Quet et al., 2010; Ndimubanzi et al., 2010), few studies have been undertaken on human cysticercosis. More information is available about porcine cysticercosis. Table 2 presents the available epidemiological data on *T. solium* in African countries. The results are based mainly on classical diagnostic stools as tongue or meat inspection and serology for pigs and serology and presence of cysticerci for humans.

Serological assays used to assess the epidemiology of *T. solium* cysticercosis in Africa are mostly the enzyme-linked-immunosorbent assay (ELISA) for antigen or antibody detection as described by Engvall and Perlman (1971). Prevalence figures are affected by the

sensitivity and the specificity of the diagnostic tests (Dorny et al., 2004a). The ELISA for antigen detection has a high value with regard to sensitivity, but shows cross-reaction in animals infected with *Taenia hydatigena* (Dorny et al., 2004b). ELISA for antibody detection is less sensitive (Dorny et al., 2004a) and the presence of antibody may indicate the contact with the parasite and not always the disease. .Since there is not yet a perfect diagnostic test for *T. solium* cysticercosis, the epidemiological data obtained in Africa cannot be regarded as reflecting a perfectly accurate picture of disease prevalence.

In West and Central Africa *T. solium* cysticercosis has been studied in detail in few countries in both pigs and humans during the past decade, particularly in Cameroon, Zambia and Burkina Faso (Zoli et al., 2003; Sikasunge et al., 2008; Carabin et al., 2009; Assana et al., 2010a). Recently important foci of porcine and human cysticercosis have been identified in the Democratic Republic of Congo (Praet et al., 2010; Kanobana et al., 2011), Burkina Faso (Ganaba et al., 2011; Carabin et al., 2009) and Senegal (Secka et al., 2011). In Eastern and Southern African countries, *T. solium* has been reported as a serious public health and agricultural problem (Mafojane et al., 2003; Phiri et al., 2003; Carabin et al., 2006; Krecek et al., 2008). The epidemiological data on cysticercosis clearly indicates that, with the exception of Muslim countries in north Africa, *T. solium* cysticercosis is endemic in the all regions of Africa.

The financial burden caused by *T. solium* cysticercosis has been estimated for some African countries. For example, a comprehensive economic impact study of *T. solium* cysticercosis has been carried out in Cameroon and South Africa using Monte Carlo simulations based on combined research results and formal information (Carabin el al., 2006; Praet et al., 2009). In West Cameroon, the number of people with neurocysticercosis-associated epilepsy was estimated at 50,326 (1.0% of the local population), whereas the number of pigs diagnosed with cysticercosis was estimated at 15,961 (5.6% of the local pig

population). The total annual costs due to *T. solium* cysticercosis were estimated at 10,255,202 Euro (6,717,157,310 FCA, local currency), of which 4.7% were due to losses in pig husbandry and 95.3% to direct and indirect losses caused by human cysticercosis. However this estimation gives only an indication rather than an accurate determination of the economic and health impacts. Carabin el al. (2006) and Praet et al. (2009) recognize that the calculated economic costs were probably underestimated because the parameters which were taken into account in the studies were only epilepsy in humans and tongue examination of pigs. Other symptoms like chronic headache, hydrocephalus, encephalitis or ocular cysticercosis in humans were not considered. Besides the economic impact, the social impact due to neurocysticercosis such as stigma of epilepsy was not taken into account. Concerning porcine cysticercosis, losses in pig production are likely to be higher than were estimated.

4. Tools for the control of *T. solium* cysticercosis

Avoiding pigs to have access to human faeces, such as through confinement of the animals, is an obvious measure that would reduce *T. solium* transmission. However, it appears that this will not be realized in the short term in the areas where the free roaming system offers an economic advantage to pig breeders (Kagira et al., 2010). Health education is another approach for control, which has been evaluated in a rural community of Mexico. In a well designed experiment where the situation before and 6 months after an intensive educational intervention was compared, Sarti et al., (1997) showed that there were some changes in the behaviour of the villagers (less free roaming pigs, lower consumption of infected pork, use of latrine), but the long term sustainability of such an intervention is unclear. More recently, Ngowi et al. (2008, 2009) examined the effects of an intensive public education in an endemic area in Tanzania. The most important effect was a significant

decrease in the level of consumption of measled pork, but there were no significant changes in the knowledge about the transmission of cysticercosis. Approaches, such as the Community Led Total Sanitation (CLTS) (http://www.communityledtotalsanitation.org/page/clts-approach) aim at reducing open defecation by a participatory approach involving the whole village, but the efficacy has not yet been evaluated for the control of *T. solium.*

The impact of mass chemotherapy against human taeniosis using praziquantel was assessed in a rural community in Mexico (Sarti et al., 2000). A reduction of at least 50% of human taeniosis was seen after the treatment program. Obviously, the effect of chemotherapy against the human taeniosis is partial and cannot achieve the goal of elimination of the taeniosis/cysticercosis complex if the entire targeted population is not treated repeatedly. Oxfendazole (OFZ) is effective when used as a single-dose treatment for porcine cysticercosis at 30 mg/kg bodyweight (Gonzalez et al., 1997). The cysticerci survived only in the brain of treated pigs, but this is not considered a source of reinfection since the brain is usually not consumed. Moreover, as a result of concomitant immunity (Richard and Williams, 1982), it was demonstrated that up to 3 months after treatment with OFZ, pigs with cysticercosis did not acquire a new infection (Gonzalez et al., 2001). However, the problem of using mass treatment of pigs with OFZ as control measure arises from the fact that the prevalence of porcine cysticercosis in most endemic areas is lower than 50 %, indicating that the majority of pigs remain susceptible to *T. solium* infection after a mass treatment with OFZ. A combined human and porcine mass chemotherapy program has been undertaken in some Peruvian villages (Garcia et al., 2006). This approach was effective in reducing infection pressure, but did not eliminate the transmission of taeniosis/cysticercosis complex.

An attractive option is the use of a vaccine against pig cysticercosis combined with anthelmintic treatment of pigs to break the life-cycle of the *T. solium* in the endemic areas (Lightowlers, 2010). This approach was recently tested under field conditions in Cameroon

using TSOL18, a recombinant oncosphere vaccine (Flisser et al, 2004) and OFZ against porcine cysticercosis. The trial was an outstanding success, with parasite transmission being entirely eliminated through the use of 3 doses of TSOL18 vaccine and a single treatment of the animals with OFZ (Assana et al., 2010b) (Table 3). TSOL18 vaccine in combination with OFZ can be considered a novel disease control tool that could reduce human neurocysticercosis in endemic areas in Africa.

5. Conclusions and prospects

T. solium taeniosis-cysticercosis remains "an under-recognized but serious public health problem" in Africa. Seventeen years ago, this statement was a title of an article published in *Parasitology Today* (Tsang and Wilson, 1995). ~~Because *T. solium* cysticercosis can probably never be considered for national or international notification in Africa, it can now be highlighted as a "neglected disease but serious public health problem". As recently emphasized by Lightowlers (2011), developing a new control tool for a neglected disease that has no First World market is difficult.~~ However there is significant positive evolution in developing countries and farmers are able to invest money for livestock medicines. For example, in Cameroon, since the price paid for a pig decreases with at least 30% if it is found to have cysts in the tongue, the pig farmers are in search for a tool that can prevent their animals from cysticercosis (Assana, unpublished). What is needed is to have the vaccine manufactured on a commercial scale and registered for general use (Lightowlers, 2011).

Porcine vaccination should be integrated in local or national programs through a simple strategy of short-term and long-term interventions, which can be carried out by existing services and structures. Recently it was argued that an elimination program for a neglected tropical disease may begin with a "vertical control program" as a pilot project

followed by sustainable long term “horizontal program” (Gyapong et al., 2010). This approach should be advisable for *T. solium* cysticercosis control. A program is called vertical when it is directed, supervised and executed by specialized services (Gyapong et al., 2010). The rationale for using a vertical strategy at the beginning of the control program is that it may provide rapid results. In the case of taeniosis/cysticercosis transmission, a pilot control program may reduce greatly the source of infection if the coverage is at least 90 % (Gonzalez et al., 2002). Re-emergence of the infection in pigs and new cases of taeniosis after the pilot program could be reduced by continued vaccination of pigs. Through the application of these new disease control measures it is hoped that more attention will be paid to the prevention of *T. solium* transmission in Africa so as to reduce the burden of neurocysticercosis on the continent.

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Table 1

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, 2000. A history of pigs in Africa. *In Blench R.M. and MacDonald K.C (editors)*, *The origins and the development of African livestock, genetic, linguistics and ethnology*. UCL Press.

Table 2

Prevalence of porcine and human cysticercosis in sub-Saharan Africa.

	Porcine Cysticercosis		**Human cysticercosis**	
Countries	Prevalence in pigs	Reference	Prevalence in man	References
Angola	0-6.8[b]	Kama, 1998	ND	
Benin	ND		1.3[c]	Geerts et al., 2004
Burkina Faso	32.5-39.6[a]	Ganaba et al., 2011	10.3[b]	Carabin et al., 2009
Burundi	2-39[a]	Newell et al.,1997	2.8[b]	Newell et al.,1997
Cameroon	24.6[b]	Assana et al., 2010a	0.7-4.6[b]	Zoli et al. 2003
Central Af. Republic	ND		2.4[b]	Geerts et al., 2004
Chad	40.8[b]	Assana et al., 2001	ND	
Côte d'Ivoire	2.5[a]	Geerts et al., 2004	ND	
DR Congo	38.8-41.2[b]	Praet et al., 2010	21.6[b]	Kanobana et al., 2011
Gambia	4.8	Secka et al., 2010	0	Secka et al., 2010b
Ghana	11.7[a]	Geerts et al., 2004	ND	
Kenya	10-14[a]	Phiri et al., 2003	ND	
Madagascar	ND		7-21[b]	Andriantsimahavandy et al., 2003
Mozambique	39.9[b]	Pondja et al., 2010	15-21[b]	Afonso et al., 2011
Nigeria	20.5[a]	Geerts et al., 2004	ND	
Rwanda	20[a]	Geerts et al., 2004	7[c]	Geerts et al., 2004
Senegal	6.4-13.2[b]	Secka et al., 2010	11.9[b]	Secka et al., 2011
South Africa	33.3[b]	Krecek et al., 2008	ND	
Tanzania	7.6-16.9	Boa et al., 2006	ND	
Togo	17[a]	Geerts et al., 2004	2.4[c]	Geerts et al., 2004
Uganda	34-45[a]	Mafojane et al., 2003	ND	
Zambia	23.3[b]	Sikasunge et al., 2008	5.8[b]	Mwape et al., 2012
Zimbabwe	28.6[a]	Phiri et al., 2003	ND	

[a] meat or tongue inspection; [b] serology; [c] based on presence of cysticerci; ; ND: no available data

Table 3

Proposed routine vaccination program against *Taenia solium* transmission in the north of Cameroon

Season*	**Interventions**
End of rainy season	Vaccination of all pigs (first dose)
Beginning of the dry season	Vaccination of previously vaccinated pigs (2nd dose) + Oxfendazole treatment
Dry season	-Vaccination of previously vaccinated (3rd dose), and unvaccinated piglets born in rainy season (1st dose) -Vaccination of previously vaccinated pigs born in rainy season (2nd dose) + treatment with OXF
End of rainy season	Third vaccination of previously vaccinated pigs