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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.

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.

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41 **Contents**

42	1. Introduction	4
43	2. Factors favouring <i>T. solium</i> cysticercosis in Africa	5
44	2.1. Pig production systems.....	5
45	2.2. Limited research interest and investments in pig production	6
46	2.3. Low priority afforded to the control of cysticercosis	7
47	3. Epidemiology and disease burden	8
48	4. Tools for the control of <i>T. solium</i> cysticercosis	10
49	5. Conclusions and prospects	12
50	References	13

51

52

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 taeniocidal 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 et 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 et 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.

References

- Ajala, M.K., Adesehinwa, A.O.K., Mohammed, A.K., 2007. Characteristics of Smallholder Pig Production in Southern Kaduna Area of Kaduna State, Nigeria. Am.-Eur. J. Agric. & Environ. Sci. 2, 182-188.
- Afonso, S.M., Vaz, Y., Neves, L., Pondja, A., Dias, G., Willingham, A.L., Vilhena, M., Noormahomed, E.V., 2011. Human and porcine *Taenia solium* infections in Mozambique: identifying research priorities . Anim. Health Res. Rev. 12, 123-129.
- Allan, J.C., Craig, P.S., Pawlowski, Z.S., 2002. Control of *Taenia solium* with emphasis on treatment of taeniasis. In: Singh, G., Prabhakar, S. (Eds.), *Taenia solium* Cysticercosis from Basic to Clinical Science. CABI Publishing, Wallingford, pp.411–420.

303

304 Andriantsimahavandy, A., Ravaoalimalala, V.E., Rajaonarison, P., Ravoniarimbinina, P.,
 305 Rakotondrazaka, M., Raharilaza, N., Rakotoarivelo, D., Migliani, R., 2003. The current
 306 epidemiological situation of cysticercosis in Madagascar. Arch'Inst Pasteur Madagascar 69,
 307 46-51

308

309 Assana E. , Amadou, F., Thys, E., Lightowlers, MW., Zoli, A.P., Dorny, P., Geerts , S.,
 310 2010a. Pig farming systems and porcine cysticercosis in the Far North region of Cameroon. J.
 311 Helminthol. 84, 441-446

312

313 Assana, E., Kyngdon, C. T., Gauci, C. G., Geerts, S, Dorny, P., De Deken, R., Anderson, G.
 314 A., Zoli, A. P., Lightowlers, M.W., 2010b. Elimination of *Taenia solium* transmission to pigs
 315 in a field trial of the TSOL18 vaccine in Cameroon. Int. J. Parasitol. 40, 515-518

316

317 Assana, E., Zoli, P.A., Sadou, H.A., Nguekam, Voundou, L., Pouedet, M.S.R., Dorny, P.,
 318 Brandt, J., Geerts, S., 2001. Prévalence de la cysticercose porcine dans le Mayo-Danay (Nord-
 319 Cameroun) et le Mayo-Kebbi (Sud-Ouest du Tchad). Rev'Elev Méd Vét Pays Trop 54,:123-
 320 127.

321

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

325

326 Boa, M.E., Mahundi, E.A., Kassuku, A.A., Willingham, A.L., Kyvsgaard., 2006.
 327 Epidemiological survey of swine cysticercosis using ante-mortem and post-mortem
 328 examination tests in the southern highlands of Tanzania. *Vet Parasitol* 139, 249-255.
 329

330 Carabin, H., Krecek, R.C., Cowan, L.D., Michael, L., Foyaca-Sibat, H., Nash, T.,
 331 Willingham, A.L., 2006. Estimation of the cost of *Taenia solium* cysticercosis in Eastern
 332 Cape Province, South Africa. *Trop. Med, Int. Health* 11, 906-916.
 333

334 Carabin, H., Millogo, A., Praet, N., Hounton, S., Tarnagda, Z., Ganaba, R., Dorny, P.,
 335 Nitiema, P., Cowan, L.D., 2009. Seroprevalence to the antigens of *Taenia solium*
 336 cysticercosis among residents of three villages in Burkina Faso: a cross-sectional study. *PLoS*
 337 *Negl. Trop. Dis.* 3, e555.
 338

339 Cruz, M., Davis, A., Dixon, H., Pawlowski, Z.S., Proanol J., 1989. Operational studies on the
 340 control of *Taenia solium* Taeniasis/cysticercosis in Ecuador. *Bull. WHO* 67, 401-407.
 341

342 Deca, R., Thorpe, W. M., Lapar, L., Kumar, A., 2007. Assam's pig sub-sector: current status,
 343 constraints and opportunities. Project Report. ILRI, 2007.
 344

345 Dorny, P., Phiri, I.K., Vercruysse, J., Gabriel, S., Willingham, A.L., Brandt, J., Victor, B.,
 346 Speybroeck, N., Berkvens, D., 2004a. A Bayesian approach for estimating values for
 347 prevalence and diagnostic test characteristics of porcine cysticercosis. *Int. J. Parasitol.* 34,
 348 569-576.
 349

350 Dorny, P., Brandt, J., Geerts S., 2004b. Immunodiagnostic approaches for detecting *Taenia*
 351 *solium* (letter). Trends Parasitol. 20: 259-260.
 352
 353 Engvall, E., Perlman, P., 1971. Enzyme-Linked Immunosorbent Assay (ELISA), Quantitative
 354 Assay of immunoglobulin G. Immunochem. 8, 871-874.
 355
 356 Flisser, A., Rodrigues-Canul, R., Willingham, A.L., 2006. Control of taeniosis/cysticercosis
 357 complex: Future development. Vet. Parasitol. 139, 283-292.
 358
 359 Flisser, A., Gauci, C.G., Zoli, A., Martinez-Ocana, J., Garza-Rodriguez, A., Dominquez-
 360 Alpizar, J-L., Maravilla, P., Rodriguez-Canul, R., Avila, G., Aguilar-Vega, L., Kyndon, C.,
 361 Geerts, S., Lightowers, M.W., 2004. Induction of protection against porcine cysticercosis by
 362 vaccination with recombinant oncosphere antigens. Infect. Imm. 72, 5292-5297.
 363
 364 Ganaba, R., Praet, N., Carabin, H., Millogo, A., Tarnagda, Z., Dorny, P., Hounton, S., Sow,
 365 A., Nitie'ma, P., Cowa, L. D., 2011. Factors Associated with the Prevalence of Circulating
 366 Antigens to Porcine Cysticercosis in Three Villages of Burkina Faso. PLoS Neg.Trop. Dis. 5,
 367 e927.
 368
 369 Garcia, H.H., Gonzalez, A.E., Gilman, R.H., Moulton, L.H., Verastegui, M., Rodriguez, S.,
 370 Gavidia, C., Tsang, V.C.W., The Cysticercosis Working Group in Peru, 2006. Combined
 371 human and porcine mass chemotherapy for the control of *T. solium*. Am. J. Trop. Med. Hyg.
 372 74, 850-855.
 373

374 Geerts, S., Zoli, A., Nguekam, J.P., Brandt, J., Dorny, P., 2004. The taeniasis-cysticercosis
 375 complex in West and Central Africa. *Southeast Asian J. Trop. Med. Public Health* 35, 262-
 376 265.

377
 378 Gonzalez, A.E., Gilman, R.H., Garcia, H.H., Lopez, T., 2002. Use of a simulation model to
 379 evaluate control programmes against *Taenia solium* cysticercosis. In: Singh G, Prabhakar S,
 380 (Eds). *Taenia solium* cysticercosis from basic to clinical science. CABI Publishing,
 381 Wallingford, p 437-448.

382
 383 Gonzalez, A.E., Gavidia, C., Falcon, N., Bernal, T., Verastegui, M., Garcia, H., Gilman, R.H.,
 384 Tsang, V.C.W., The Cysticercosis Working Group in Peru, 2001. Protection of pigs with
 385 cysticercosis from further infections after treatment with oxfendazole. *Am. J. Trop. Med.*
 386 *Hyg.* 65, 15–18.

387
 388 Gonzalez, A.E., Falcon N., Gavidia, C., Garcia, H.H., Tsang, V.C.W., Bernal, T., Romero,
 389 M., Gilman, R.H., 1997. Treatment of swine cysticercosis with oxfendazole: a dose-response
 390 trial. *Vet. Rec.* 141, 420–422.

391
 392 Gyapong, J.O., Gyapong, M., Yellu, N., Anakwah, K., Amofah, G., Bockarie, M., Adjei, S.,
 393 2010. Integration of control of neglected tropical diseases into health-care systems: challenges
 394 and opportunities. *Lancet* 375, 160-165.

395
 396 Kagira, J.M., Kanyari, W.N., Maingi, N., Githigia, S.M., N'gang'a, J.C., Karuga, J.W., 2010.
 397 Characteristics of the smallholder free-range pig production system in Western Kenya. *Trop.*
 398 *Anim. Health Prod.* 42, 865-873.

400 Kama, K.L., 1998. Les cysticercoses porcines et bovines dans le sud de l'Angola. Abstract
 401 Book of the Ninth International Conference of Association of Institutions of Tropical
 402 Veterinary Medicine, Harare, 14-18 September, 1998, 62.
 403
 404 Kanobana, K., Praet, N., Kabwe, C., Dorny, P., Lukanu, P., Madinga, J., Mitashi, P., Verwijs,
 405 M., Lutumba, P., Polman, K., 2011. High prevalence of *Taenia solium* cysticercosis in a
 406 village community of Bas-Congo, Democratic Republic of Congo. Int. J. Parasitol. 41, 1015-
 407 1018.
 408
 409 Koussou, M.O., Duteurtre, G., 2002. Les facteurs de compétitivité de la filière porcine dans le
 410 bassin du Logone. Conference report, October 2002: *Systèmes agro-alimentaires localisés –*
 411 *Syal*», Cirad, Montpellier, France.
 412
 413 Krecek, R.C., Michael, L.M., Schantz, P.M., Ntanjana, L., Smith, M.F., Dorny, P., Harrison,
 414 L.J.S., Grimm, F., Praet, N., Willingham, A.L., 2008. Prevalence of *Taenia solium*
 415 cysticercosis in swine from a community-based study in 21 villages of the Eastern Cape
 416 Province, South Africa. Vet. Parasitol. 154, 38-47.
 417
 418 Krecek, R., Waller, P., 2006. Towards the implementation of the “basket of options”
 419 approach to helminth parasite control of livestock: Emphasis on the tropics/subtropics. Vet.
 420 Parasitol. 139, 270–282.
 421
 422 Lightowlers, M.W., 2010. Eradication of *Taenia solium* cysticercosis: A role for vaccination
 423 of pigs. Int. J. Parasitol. 40, 1183-1192.
 424

Lightowlers M., 2011. A mountain higher than Everest. *Microbiol. Aust.* 32, 120.

International Task Force for Disease Eradication II. 2003. www.cartercenter.org/documents/1367.pdf.

Mafojane, N.A., Appleton, C.C., Krecek, R.C., Michael, L.M., Willingham, A.L., 2003. The current status of neurocysticercosis in Eastern and Southern Africa. *Acta Trop.* 87, 25–33.

Michel, P., Callies, P, Raharison, H., Guyon, P., Holvoet, L., Genin, C., 1993. Epidemiology of cysticercosis in Madagascar. *Bull. Soc. Exotic Path.* 86, 62-67.

Molyneux, D. H., Hopkins, D.R., Zagaria N., 2004. Disease eradication, elimination and control: the need for accurate and consistent usage. *Trends Parasitol.* 20, 347-351.

Mopate, L.Y., Koussou, M.O., Kabore-Zoungana, C.Y., 2006. Consumers and consumption of pork outside homes in the city of N'Djaména (Tchad). *In* : Parrot L., Njoya A., Temple L., Assogba-Komlan, F., Kahane, R., Ba Diao, M., Havard, M. (eds), “*Agriculture and urban development in West and Central Africa*”, proceedings of International workshop. IRAD, INRAB, ISRA and CIRAD, 31 October to 03 november 2005, Yaoundé, Cameroun. pp. 135 – 140.

Mutua, F., Arimi, S., Ogara, W., Dewey, C., Schelling, E., 2010. Farmer Perceptions on Indigenous Pig Farming in Kakamega District, Western Kenya. *Nordic J. African Stud.* 19, 43–57.

449 Mwape, K.E., Phiri, I.K., Praet, N., Muma, J.B., Zulu, G., Van den Bossche, P., De Deken
 450 R., Speybroeck, N., Dorny, P., Gabriël, S. 2012. *Taenia solium* Infections in a Rural Area of
 451 Eastern Zambia-A Community Based Study. PLoS Negl.Trop. Dis. 6 , e1594.

452

453 Ndimubanzi, P., Carabin, H., Budke, C.M., Nguyen Hai, Qian Y-J., Rainwater, E., Dickey
 454 M., Reynolds, S., Stoner, J.A., 2010. A Systematic Review of the Frequency of
 455 Neurocysticercosis with a Focus on People with Epilepsy. PLoS Negl.Trop. 4, e870.

456

457 Newell, E., Vyungimana, F., Geerts, S., Van Kerkhoven, I., Tsang, V.C.W., Engels, D., 1997.
 458 Prevalence of cysticercosis in epileptics and members of their families in Burundi. Trans.
 459 Roy. Soc. Trop. Med. Hyg. 91, 389-391.

460

461 Ngowi, H., A., Kassuku, A.A, Carabin, H., Mlangwa, J.E.D., Malongo, R. S., Mlozi, M.R.S.,
 462 Mbilinyi, B.P., Willingham III, A.L., 2010. Spatial Clustering of Porcine Cysticercosis in
 463 Mbulu District, Northern Tanzania. PLoS Negl.Trop 4, e652.

464

465 Ngowi, H.A., Mlangwa, J.E.D., Mlozi, M.R.S., Tolma, E.L., Kassuku, A.A., Carabin H.,
 466 Willingham III, A.L., 2009. Implementation and evaluation of a health-promotion strategy for
 467 control of *Taenia solium* infections in northern Tanzania. Int. J. Health. Prom. Ed. 47, 24-34.

468

469 Ngowi, H.A., Carabin, H., Kassuku, A.A., Mlozi, M.R., Mlangwa, J.E., Willingham III, A.L.,
 470 2008. A health-education intervention trial to reduce porcine cysticercosis in Mbulu District,
 471 Tanzania. Prev. Vet. Med. 85, 52-67.

472

473 Ngowi, H.A., Kassuku, A.A., Maedab, G.E.M., Boa, M.E., Carabin, H., Willingham III, A.L.,
 474 2004. Risk factors for the prevalence of porcine cysticercosis in Mbulu District, Tanzania.
 475 Vet. Parasitol. 120, 275–283.
 476
 477 Phiri, I., Ngowi, H., Afonso, S., Matenga, E., Boa, M., Mukaratirwa, S., Githigia, S., Saimo,
 478 M., Sikasunge, C., Maingi, N., Lubega, G.W., Kassuku, A., Michael, L., Siziya, S., Krecek,
 479 R.C., Noormahomed, E., Vilhena, M., Dorny, P., Willingham, L., 2003. The emergence of
 480 *Taenia solium* Cysticercosis in Eastern and Southern Africa as a serious agricultural problem
 481 and public health risk. Acta Trop. 87, 13–23.
 482
 483 Pondja, A., Neves, L., Mlangwa, J., Afonso, S., Fafetine, J., Willingham, A.L., Thamsborg
 484 S.M., Johansen, M.V., 2010. Prevalence and Risk Factors of Porcine Cysticercosis in Angonia
 485 District, Mozambique. . PLoS Negl. Trop. Dis 4 , e594.
 486
 487 Porphyre, V., 2009. Enjeux et contraintes des filières porcines en Afrique de l'Ouest. Grain
 488 de sel, N° 46-47, 2009
 489
 490 Praet, N., Speybroeck, N., Manzanedo, R., Berkvens, D., Nsame Nforinwe, D., Zoli, A.,
 491 Quet, F., Preux, P.M., Geerts, S., 2009. The disease burden of *Taenia solium* cysticercosis in
 492 Cameroon. PLoS Negl. Trop. Dis 3, e406.
 493
 494 Praet, N., Kanobana, K., Kabwe, C., Maketa, V., Lukanu, P., Lutumba, P., Polman, K.,
 495 Matondo, P., Speybroeck, N., Dorny, P., Sumbu, J., 2010. *Taenia solium* cysticercosis in the
 496 Democratic Republic of Congo: how does pork trade affect the transmission of the parasite?
 497 PLoS Negl. Trop. Dis. 4, e817.

498

499 Quet, F., Guerchet, M.I, Pion, S.D.S., Ngoungou, E.B., Nicoletti, A., Preux, P.M., 2010.
500 Meta-analysis of the association between cysticercosis and epilepsy in Africa. *Epilepsia*,
501 51:830–837.

502

503 Richard, M.D., Williams, J.F., 1982. Hydatidosis/cysticercosis: immune mechanisms and
504 immunization against infection. *Adv. Parasitol.* 21, 229–296

505

506 Sarti, E., Schantz, P.M., Avila, G., Ambrosio, J., Medina-Santillan, R., Flisser, A., 2000.
507 Mass treatment against human taeniasis for the control of cisticercosis: a population-based
508 intervention study. *Trans. Roy. Soc. Trop. Med. Hyg.* 94, 85-89.

509

510 Sarti, E., Flisser, A., Schantz, P., Gleizer, M., Loya, M., Plancarte, A., Avila, G., Allan, J,
511 Craig, P., Bronfman, M., Wijeyaratne, P., 1997. Development and evaluation of health
512 education intervention against *Taenia solium* in a rural community in Mexico. *Am. J.*
513 *Trop.Med. Hyg.* 56: 127-132.

514

515 Schantz, P.M., Cruz, M., Sarti, E., Pawlowski, Z., 1993. Potential eradicability of taeniasis
516 and cysticercosis. *Bull. PAHO* 27, 397-403.

517

518 Secka, A., Grimm, F., Marcotty, T., Geysen, D., Alassane, M., Niang, A.M., Ngale, V.,
519 Boutche, L., Marck, E.V., Geerts S., 2011. Old focus of cysticercosis in a senegalese village
520 revisited after half a century. *Acta Trop.* 119, 199-202.

521

522 Secka, A., Marcotty, T., De Deken, R., VanMarck, E., Geerts S., 2010a. Porcine Cysticercosis
 523 and Risk Factors in The Gambia and Senegal. J. Parasitol. Res. doi:10.1155/2010/823892
 524
 525 Secka, A., Grimm, F., Victor, B., Marcotty, T., De Deken, R., Nyan, O., Herera, O., Van
 526 Marck, E., Geerts, S., 2010b. Epilepsy is not caused by cysticercosis in The Gambia. TMIH
 527 15, 476-479.
 528
 529 Sikasunge, C.S., Johansen, M.V., Willingham, A.L., Leifsson, P.S., Phiri, I.K., 2008. *Taenia*
 530 *solium* porcine cysticercosis: viability of cysticerci and persistency of antibodies and
 531 cysticercal antigens after treatment with oxfendazole. Vet. Parasitol. 158, 57-66.
 532
 533 Sikasunge, CS, Phiri, I.K, Phiri, A.M, Dorny, P, Siziya, S, 2007. Risk factors associated with
 534 porcine cysticercosis in selected districts of Eastern and Southern provinces of Zambia. Vet.
 535 Parasitol. 143, 59–66.
 536
 537 Shey-Njila, O., Zoli, P.A., Awah-Ndukum, J., Nguekam, Assana, E., Byambas, P., Dorny, P.,
 538 Brandt, J., Geerts, S., 2003. Porcine cysticercosis in village pigs of North-West Cameroon. J.
 539 *Helminthol.* 77, 351-354.
 540
 541 Tsang, V.C., Wilson, M., 1995. *Taenia solium* Cysticercosis: An underrecognized but serious
 542 public health problem. Parasitol. Today 11, 124-126.
 543
 544 Willingham III, A.L., Engels D., 2006. Control of *Taenia solium* cysticercosis/taeniasis. Adv.
 545 Parasitol. 61, 509-566.
 546

547 World Health Organization, 2007. Global plan to combat neglected tropical diseases 2008-
548 2015. http://www.who.int/neglected_diseases/NTD20Global20plan_20January202007.pdf
549
550 Zoli, A.P., Shey-Njila, O., Assana, E., Nguekam, J.P., Dorny, P., Brandt J., Geerts S., 2003.
551 Regional status, epidemiology and impact of *Taenia solium* cysticercosis in Western and
552 Central Africa. Acta Trop. 87, 35-42.
553

554 Table 1

555 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

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

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560

561 Table 2

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

Countries	Porcine Cysticercosis		Human cysticercosis	
	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	

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

564

565 Table 3

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

567 Cameroon

568

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

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