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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.

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

3

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23 **ABSTRACT**

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

36

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

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53 1. Introduction

54 *Taenia solium* (Linnaeus, 1758) has a life cycle involving two hosts (pig and human).
55 The adult tapeworm establishes in the small intestine of humans, causing taeniosis. The
56 tapeworm is composed of segments (proglottids). Gravid proglottids, containing infective
57 eggs, detach from the worm and are released with the human faeces. When eggs are ingested
58 by a pig, the larvae (oncospheres) are released; these penetrate the intestinal mucosa and
59 migrate via the circulatory system to a suitable tissue location, particularly striated muscles,
60 heart and the brain, where they develop into cysticerci causing porcine cysticercosis. Further
61 transmission of the parasite (taeniosis) occurs when raw or uncooked meat from infected pigs
62 is eaten by humans. Humans may also be infected by the cysticerci (human cysticercosis)
63 following accidental ingestion of *T. solium* eggs through inadequate sanitation. In humans,
64 cysticerci may establish in the brain, causing neurocysticercosis (NCC). *T. solium*
65 taeniosis/cysticercosis complex constitutes an important public health problem and a serious
66 socioeconomic obstacle for pig breeders in many African countries (Zoli et al., 2003;
67 Willingham et al., 2006; Carabin et al., 2006). During the 1990s there was optimistic opinion
68 on the control of cysticercosis in developing countries (Cruz et al., 1989). The assumption
69 was based on characteristics of *T. solium* which suggest it could be eradicated (Schantz et al.,
70 1993; Krecek and Waller, 2006). The failure to control taeniosis/cysticercosis using
71 taeniocidal drug administration (Sarti et al., 2000) and health education through large scale
72 eradication programs in Latin America (Sarti et al., 1997; Allan et al., 2002) has shown that
73 global elimination of this zoonosis is difficult to achieve in the context of persistence of free-
74 roaming pig production, poor hygiene and inadequate sanitation in the endemic countries.
75 New strategies for controlling cysticercosis have been suggested by Flisser et al. (2006) who
76 argue that intervention measures for control of cysticercosis might involve the international
77 agencies and institutions, such as the World Health Organization, the Food and Agriculture

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

88

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

90 *2.1. Pig production systems*

91 The management systems used by pig farmers in Africa is determined by various
92 reasons including the source of feed, lack of financial resource for investment in housing and
93 health care requirement (Ajala et al., 2007; Deca et al., 2007; Kagira et al., 2010; Mutua et al.,
94 2010). In rural areas pig production can be classified into three main categories (Blench,
95 2000): scavenging/free range system where the pig finds most of its own food, and semi-
96 intensive and intensive systems where the majority of the food consists of domestic kitchen
97 waste (Table 1). About 90 % of pigs are reared under scavenging /free range and semi-
98 intensive in Western and Central African countries (Porphyre, 2009). In these pig production
99 systems, poor sanitary conditions play an important role in the circulation of *T. solium*
100 infection (Zoli et al., 2003). A free-range production system for pigs combined with open
101 field defecation by humans people are the conditions in which the animals can gain access to
102 human faeces (Ngowi et al., 2004; Sikasunge et al., 2007; Ganaba et al., 2011). In the

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

112

113 *2.2. Limited research interest and investments in pig production*

114

115 One of the characteristics of pig production in Africa is the lack of interest from policy
116 makers and funding agencies for this agricultural activity. For reasons unconnected to their
117 economic importance, pigs are the least well known of all the major species of domestic
118 livestock in Africa (Blench, 2000). It is observed that most research institutes in the continent
119 and funding organisations for agriculture development exclude pig from their activities, even
120 for African swine fever, the most devastating pig disease in Africa. This may be related to the
121 questionable belief that pigs compete with human for food and probably also for religious
122 reasons. Since Islam forbids Muslims to eat pork and the Muslim population is important in
123 Africa, prejudice against pigs from the governments and potential donor agencies may explain
124 the limited research and funding interest for pigs compared to other domesticated livestock
125 (Blench, 2000). The consequence of this situation is that forgotten smallholders keep 60 % to
126 90 % of total pigs in Africa which are mostly reared under traditional semi-intensive and free
127 range systems favouring the *T. solium* life cycle (Boa et al., 2006; Porphyre, 2009). These pig

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

137

138 2.3. Low priority afforded to the control of cysticercosis

139

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

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

163

164 **3. Epidemiology and disease burden**

165

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

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

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

185 In West and Central Africa *T. solium* cysticercosis has been studied in detail in few
186 countries in both pigs and humans during the past decade, particularly in Cameroon, Zambia
187 and Burkina Faso (Zoli et al., 2003; Sikasunge et al., 2008; Carabin et al., 2009; Assana et al.,
188 2010a). Recently important foci of porcine and human cysticercosis have been identified in
189 the Democratic Republic of Congo (Praet et al., 2010; Kanobana et al., 2011), Burkina Faso
190 (Ganaba et al., 2011; Carabin et al., 2009) and Senegal (Secka et al., 2011). In Eastern and
191 Southern African countries, *T. solium* has been reported as a serious public health and
192 agricultural problem (Mafojane et al., 2003; Phiri et al., 2003; Carabin et al., 2006; Krecek et
193 al., 2008). The epidemiological data on cysticercosis clearly indicates that, with the exception
194 of Muslim countries in north Africa, *T. solium* cysticercosis is endemic in the all regions of
195 Africa.

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

203 population). The total annual costs due to *T. solium* cysticercosis were estimated at
204 10,255,202 Euro (6,717,157,310 FCA, local currency), of which 4.7% were due to losses in
205 pig husbandry and 95.3% to direct and indirect losses caused by human cysticercosis.
206 However this estimation gives only an indication rather than an accurate determination of the
207 economic and health impacts. Carabin et al. (2006) and Praet et al. (2009) recognize that the
208 calculated economic costs were probably underestimated because the parameters which were
209 taken into account in the studies were only epilepsy in humans and tongue examination of
210 pigs. Other symptoms like chronic headache, hydrocephalus, encephalitis or ocular
211 cysticercosis in humans were not considered. Besides the economic impact, the social impact
212 due to neurocysticercosis such as stigma of epilepsy was not taken into account. Concerning
213 porcine cysticercosis, losses in pig production are likely to be higher than were estimated.

214

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

216

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

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

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

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

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

259

260 **5. Conclusions and prospects**

261
262 *T. solium* taeniosis-cysticercosis remains “an under-recognized but serious public
263 health problem” in Africa. Seventeen years ago, this statement was a title of an article
264 published in *Parasitology Today* (Tsang and Wilson, 1995). ~~Because *T. solium* cysticercosis~~
265 ~~can probably never be considered for national or international notification in Africa, it can~~
266 ~~now be highlighted as a “neglected disease but serious public health problem”. As recently~~
267 ~~emphasized by Lightowers (2011), developing a new control tool for a neglected disease that~~
268 ~~has no First World market is difficult.~~ However there is significant positive evolution in
269 developing countries and farmers are able to invest money for livestock medicines. For
270 example, in Cameroon, since the price paid for a pig decreases with at least 30% if it is found
271 to have cysts in the tongue, the pig farmers are in search for a tool that can prevent their
272 animals from cysticercosis (Assana, unpublished). What is needed is to have the vaccine
273 manufactured on a commercial scale and registered for general use (Lightowers, 2011).

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

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

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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*
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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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570