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Overview of *Taenia solium* cysticercosis in West Africa

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Abstract

Human and porcine cysticercosis is endemic in West Africa, where epilepsy is relatively common, but rarely reported due to fear of stigmatization. Neurocysticercosis, caused by *Taenia solium*, tends to affect the poor in developing countries and control is hampered by inadequate infrastructure and financial resources coupled with lack of adequate information about its significance and distribution. The risk factors for human cysticercosis are closely associated with the characteristics of smallholder or backyard pig farming systems prevalent in this region. Poverty, ignorance and lack of political will militate against successful eradication, while tools for effective diagnosis, prevention and treatment, including vaccines for pigs, are not yet available in many countries. Cysticercosis was targeted for control by The World Health Organization global plan for 2008-2015; however, measures for control are yet to be undertaken in a coordinated manner in West Africa. Diagnostic tools, including neuroimaging facilities, should be strategically situated and made accessible to rural populations in West Africa. Community education in combination with a multipronged approach consisting of vaccination of pigs using TSOL18 vaccine and treatment with oxfendazole along with mass chemotherapy of humans with praziquantel could eliminate taeniasis and should be considered. In-depth and extensive epidemiological studies are required in West Africa in order to fully elucidate the prevalence of *T. solium* and to support more coordinated and effective control of human and porcine cysticercosis.

Keywords: *Taenia solium*; poverty; food safety; backyard pig farming; epilepsy; West Africa.

1. Introduction

Taenia solium is a tapeworm of humans whose larval stage is normally found in pig muscle, but can also invade the human central nervous system to cause neurocysticercosis (Lightowlers, 2013; Garcia *et al.,* 2014b), and is thus a significant cause of acquired preventable epilepsy (Winkler, 2013; WHO 2016a). Ndimubanzi *et al.* (2010) reported that neurocysticercosis causes 29% of acquired epilepsy in endemic countries, and epilepsy in less developed countries is responsible for mortality rates 3–6 times higher than in developed nations (WHO, 2016a) due to inadequate infrastructure and poor access to hospitals. This zoonotic tapeworm therefore constitutes a serious, but preventable, public health problem, as well as impacting on agriculture (Ngowi *et al.,* 2013; Braae *et al.,* 2016a), and is considered a neglected parasite (WHO, 2016a; Johansen *et al.,* 2016). The disease is an emergent and persistent problem in most under-developed areas of sub-Saharan Africa, Asia and Latin America; except for in areas mainly populated by Muslims, who do not eat pig meat (Fleury *et al.,* 2015).

Although *T. solium* has been considered an eradicable disease since 1993 by the International Task Force on Disease Eradication (ITFDE), to date none of the endemic countries has been able to eradicate this disease. Despite the advances made in the development of appropriate tools for diagnosis, treatment and prevention, neurocysticercosis still persists at disturbingly high levels in endemic areas of Africa (Johansen *et al.,* 2016). Control of the disease in such regions is hampered by poverty, inadequate infrastructure, financial resource constraints, and unsanitary conditions (Lightowlers *et al.,* 2015; Johansen *et al.,* 2016). Furthermore, in Africa, ignorance surrounding the presence, magnitude and impacts of the parasite by stakeholders and political authorities have led to the disease being often unrecognized and under reported (Assana *et al*., 2013; WHO 2016a). This is further complicated by scarcity of information due to lack of overt

disease manifestation in many cases in both humans and pigs (Fleury *et al.,* 2015; Ron-Garrido *et al.,* 2015).

In recent years, the number of studies on *T. solium* in Africa has increased (Gabriël *et al.,* 2016; Assana *et al.,* 2013). The purpose of this review, following a brief introduction to the parasite and disease, is to summarise new information from West Africa in the context of existing knowledge on the parasite, and to apply it to identify gaps and opportunities in research and control of this potentially devastating parasitic disease.

2. Life cycle and disease

Taenia solium has a two-stage life cycle. The adult tapeworm lives in the human small intestine after eating viable cysticerci ("pork measles") in raw or under-cooked pork resulting in taeniasis. The life cycle is completed when the proglottids become gravid, harboring thousands of the infective onchospheres, and are shed from the tapeworm and ingested in the faeces of infected individuals. Oncospheres (=eggs) are then dispersed and contaminate the environment.

Humans can act as accidental dead-end intermediate hosts and develop cycticercosis following ingestion of tapeworm eggs. Auto-infection can also occur when proglottids reach the stomach by reverse peristalsis, resulting in massive infection. The hatched larvae penetrate the intestinal mucosa and migrate throughout the body, forming cysticerci, which commonly lodge in skeletal muscles, eyes and subcutaneous tissues, but have a particular predilection for the central nervous system (CNS), causing neurocysticercosis (NCC) (Gal'an-Puchades, 2016).

Pigs are the main intermediate hosts and ingest *T. solium* eggs contained in infected human feces or through ingestion of contaminated water or feed. After ingestion, the oncospheres evaginate and the hatched larvae penetrate the intestinal walls into the bloodstream and develop to

metacestodes, forming cysticerci throughout the body but mostly in the striated muscles of the pigs (WHO 2016a).

2.1 Clinical signs in pigs

Infected pigs are most often asymptomatic, but can rarely show neurological signs, which can manifest as dullness, sluggishness, loss of consciousness, and in some cases hypersensitivity to sound, and seizures, as in humans. Quivering, paralysis of the ear, ataxia, dribbling saliva, circling movement, decreased production performance and social isolation have also been reported (Mkupasi *et al.,* 2014; Trevisan *et al.,* 2016, 2017).

2.2 Disease in humans

The clinical manifestations of NCC differ, varying from asymptomatic to severe (Winkler, 2013; Trevisan *et al.,* 2016). Seizures are the most common presentation (Carpio and Romo, 2014) occurring in about 60-90% of symptomatic infections (Rodrigues *et al*., 2012; Carpio *et al.,* 2013), although incidence varies in different regions according to socioeconomic and cultural practices (Del Brutto, 2013b; Winkler, 2013). Headache (Carabin *et al*., 2011; Johansen *et al*., 2016), focal neurological signs (Fleury *et al*., 2011; Flisser, 2013) and generalized weakness associated with muscle pseudohypertrophy (Fleury *et al*., 2015) are also common.

It has been estimated that between 2.6 and 8.3 million individuals are affected globally by symptomatic and asymptomatic NCC, and that 0.76-2.46 million of the NCC-related epileptic individuals and 0.95-3.08 million of the asymptomatic NCC individuals are in sub-Saharan Africa (Winkler, 2013), resulting in the loss of 2–5 million lost disability-adjusted life years (WHO, 2015b).

3. Diagnosis

3.1 Diagnosis of porcine cysticercosis

Diagnosis of porcine cysticercosis is essential for control, to prevent taeniasis in humans and further onward infections in pigs as well as NCC in humans (Gilman *et al*., 2012).

3.1.1 Tongue and carcass inspection

The simplest and most common diagnostic methods for porcine cysticercosis are visual inspection of the surface of the tongue, which has a sensitivity ranging from 16-70% (Phiri *et al*., 2006), and carcass inspection (Lightowlers *et al*., 2015). Most epidemiological studies on

porcince cysticercosis in West Africa have used tongue or carcass inspection (Onah and Cheinjina 1995; Gweba *et al.,* 2010; Goussanou *et al*., 2014; Edia-Asuke *et al.,* 2014; Attawalna *et al*., 2015; Idiaka *et al.,* 2017).

Tongue and carcass inspection are commonly applied to check meat safety in West Africa, but is poorly sensitive and can inadvertently lead to the entrance of a large amount of pork infected with cysticercosis into the human food chain, both by passing undetected through the checks and by sale of detected infected meat at a reduced price (Goussanou *et al*., 2014). Onah and Cheinjina (1995) observed 5.5% (72/1300) of pigs were infected with cysticercosis infection based on tongue inspection, and carcass inspection also showed that all 72 were infected, as well as a further 8.5% (104) that were negative by tongue inspection. Gweba *et al*. (2010), also in Nigeria, observed a prevalence of 5.85% (n = 205) and 14.40% (n = 118) by lingual palpation and postmortem examination, respectively. Studies by Lightowlers *et al*. (2015) indicate that slicing the tongue, masseter muscle and heart is highly specific and detects natural infection in pigs with 80% sensitivity at a low cost, especially because these are convenient anatomical sites which will not affect the carcass value; this technique should be practised in West Africa. Infected meat could be a source of infection to the public if mechanisms are not in place for its proper disposal (Gonzalez *et al*., 1990).

3.1.2 Serology in pigs

Serological tests for the detection of specific antibodies or specific antigens use enzyme-linked immunosorbent assay (ELISA) and electro-immuno transfer blot (EITB) (Lightowlers *et al*., 2016). Most of the few serological studies of pigs in West Africa have used B158/B160 Ag-

ELISA (Secka *et al*., 2010a; Ganaba *et al.,* 2011) and studies by Weka *et al*. (2009) used IgG antibody ELISA.

Lack of serological diagnostic kits in West Africa especially due to cost is a serious obstacle to providing detailed epidemiological data hence, availability of serological kits in the region will help in diagnosis of porcine cysticercosis. However, detection of antibodies does not necessarily imply active infection as serologically positive pigs may not have cysticerci at necropsy (Jayashi *et al*., 2012; Devleesschauwer *et al* 2013; Lightowlers *et al*., 2016). Moreover, false positive or transient positive reactions might arise from exposure to *T. solium* eggs that did not develop to cysticerci to be detected at carcass inspection (Lightowlers *et al*., 2016). Generally, antigen detection methods are far superior to antibody detection techniques since they indicate the presence of viable cysts. Although at population level, antibody detection results can nevertheless give a useful indication of infected areas where the life cycle of the parasite is ongoing (Thomas, 2015). Serological test interpretation in individual animals is limited by test sensitivity and specificity (Lightowlers *et al.,* 2016) and should be confirmed by necropsy where possible, although purchasing pigs for necropsy can be expensive.

3.2 Diagnosis in humans

3.2.1 Serology in humans

Serological studies for diagnosis of human cysticercosis have been carried out in West Africa, including the use of Ag-ELISA (Nitiéma *et al.,* 2012; Carabin *et al.,* 2015), Ab- ELISA (Edia-Asuke *et al*. 2015; Weka *et al*. 2013) and EITB (Secka *et al.,* 2010a; 2011). ELISA kits for antibody detection in human cysticercosis are commercially available (Rodriguez *et al*., 2012) but they are reported to have low sensitivity and frequent cross-reactions (Garcia *et al*., 2018);

hence, the results should be interpreted with caution. The EITB assay developed by Tsang *et al*. (1989), although about 20 times more expensive than ELISA, is highly specific (near-100%) and sensitive (70-90%). Antigen-ELISA is similarly highly sensitive, and more cost effective and technically simpler to implement in resource limited settings, and is a valuable tool for hospital diagnosis, particularly in the absence of imaging facilities. Although both Ag-ELISA (Nitiéma *et al.*, 2012; Carabin *et al.*, 2015) and EITB have also been used in studies in West Africa in humans (Secka *et al.*, 2010a, 2011), the financial burden of running the EITB precludes its routine use. Antibody seropositive individuals, moreover, might have been exposed to the parasite or naturally cured and do not necessarily have an established infection; hence, results should be interpreted in line with the clinical presentation (Gilman *et al*., 2012). Enhanced capacity in West Africat to diagnose exposure and infection in humans would support epidemioloigical studies and an improved evidence base for interventions.

3.2.2 Diagnosis of NCC

Diagnosis of NCC is mainly pursued by imaging techniques, including computerised tomography (CT) and magnetic resonance imaging (MRI) (Gilman *et al*., 2012; Fleury *at el*., 2013). Neuroimaging can detect the presence of parasitic lesions, and provide a sensitive and accurate diagnosis of NCC (Nash and Garcia, 2011; Gilman *et al*., 2012). Calcified cysts and parenchymal lesions are better visualized by CT and MRI respectively (Nash and Garcia, 2011). Only few surveys in West Africa have used imaging techniques (Secka *et al.,* 2010b; Milogo *et al.,* 2012). Neuroimaging facilities are expensive and not easily available for studies in West Africa; where possible, such diagnostic facilities should be made available in research institutes or government hospitals in the region where they can easily be assessed by researchers.

3.2.3. Diagnosis of taeniasis

The presence of adult *T. solium* tapeworms may be detected by stool microscopy, and observation of *Taenia* sp. tapeworm eggs or sometimes adult tapeworm segements (Lightowlers *et al*., 2016). Coproscopy has been used in human surveys in West Africa (Gweba *et al.,* 2010; Secka *et al*., 2011), but has poor sensitivity (Lightowlers *et al*., 2016), and misses 60-70% of cases (Mayta *et al*., 2000). Moreover, it is not possible to differentiate between *T. solium* and *T. saginata* eggs, which are morphologically similar (Garcia *et al*., 2003; Lightowlers *et al*., 2016). Therefore, results of stool microscopy should be interpreted with caution and more sensitive diagnostic techniques should be developed and made available in the region.

Coproantigen detection is more sensitive than stool microcopy, as reported by Allan *et al*. (1996), where the detection rate was 5% and 1%, resepectively. A species-specific coproantigen ELISA developed by Guezala *et al*. (2009) has a reported sensitivity of 96.4% and specificity of 100% for *T. solium* carriers, but is no longer commercially available. Studies of Edia-Asuke *et al.* (2014) in West Africa used coproantigen ELISA, applying polyclonal antibodies to identify antigens in feaces; wider use of this method by researchers in West Africa will give a better picture of the prevalence of taeniais in the region.

Other diagnostic methods include a polymerase chain reaction (PCR) and restriction enzyme analysis (REA) test developed by Mayta *et al*. (2000), which has several advantages: it avoids the use of scarce, expensive and radioactive reagents and specialized equipment and uses only two steps to differentiate the tapeworms. A multiplex PCR for differential diagnosis of *T. solium*, *T. saginata* and *T. asiatica* was also developed by Yamasaki *et al*. (2004). More recently, loop-mediated isothermal amplification (LAMP) for *T. solium* DNA, which does not need complicated equipment, was developed (Nkouawa *et al*. 2010). This method could differentially

diagnose *T. saginata*, *T. solium* and *T. asiatica* in 37 of 43 (86%) parasitologically diagnosed cases of taeniasis (Nkouawa *et al*., 2010; 2012).

These tests, however, are technically demanding and most of them have not been used in studies carried out in West Africa. Greater availability and use by researchers in the region would improve data availability and reduce under reporting and under-estimation of prevalence.

4. Current status of *Taenia solium* infections in West Africa

4.1 Human taeniasis and NCC

Taenia solium cysticercosis is present in most West African countries since favorable conditions for parasite transmission in both humans and pigs occur widely in the region, such as defecation in the open field, illicit slaughtering of pigs and unqualified meat inspectors (Gweba *et al.,* 2010; Weka *et al*., 2013; Carabin *et al*., 2015). The prevalence of cysticercosis / NCC and taeniasis in humans is shown below (Tables 1 and 2). Stubbornly persistent high prevalence of neurocysticercosis has been reported in countries such as Burkina Faso and Senegal (Fleury *et al.,* 2013). In Burkina Faso, NCC is common, with 12-17 % of people suffering from epilepsy testing positive for *T. solium* (Millogo *et al*., 2012; Nitiéma *et al*., 2012). In Nigeria, a study by Edia-Asuke, *et al.* (2015) showed an association between epilepsy and cysticercosis, such that individuals with epilepsy were twice as likely to test seropositive compared to non-epileptics. Cases of taeniasis have also been widely reported in the region (Table 2). There are important gaps in knowledge of prevalence, for example no recent published data on human cysticercosis in some countries susch as Guinea-Bissau and Liberia.

Country	Prevalence (%)	Diagnosis		Test method	Subjects	References
Burkina Faso	0 - 11.5 (120/3609)	B158/B60 ELISA	Ag-	NS	Villagers	Carabin *et al.,* 2015
	17 (10/60)	B158/B60 ELISA	Ag-	NS	PWE	Milogo *et al.,* 2012
	29.4 (20/68)	CT-Scan		Specific	PWE	Milogo *et al.,* 2012
	12.8 (5/39)	B158/B60 ELISA	Ag-	NS	PWE	Nitiéma *et al.,* 2012
Nigeria	9.6 (12/125)	ELISA (IgG)		NS	Villagers	Weka *et al.,* 2013
	14.3 (43/300)	ELISA (IgG)		NS	Butchers	Edia-Asuke *et al.,* 2015
Senegal	7.7 (31/403)	B158/B60 ELISA	Ag-	NS	Villagers	Secka *et al.,* 2011
	7.7 (31/403)	EITB		Specific	Villagers	Secka *et al.,* 2011
	23.3 (10/43)	CT-scan		Specific	Seropositive	Secka *et al.,* 2011
Gambia	0 (0/630)	EITB, CT-Scan		Specific	PWE and controls	Secka *et al.,* 2010b

Table 1. Prevalence of cysticercosis in both people with epilepsy (PWE) and general villagers in West Africa by serology and imaging methods. *Prevalence is given in percent, followed by positive cases / sample size in brackets). Ag-ELISA = Antigen ELISA=Enzyme linked immunosorbent assay; CT = Computed Tomography. NS = method is not specific for T. solium.*

Country	Prevalence % (N)	Target group	Test	References
Ghana	0 (1080)	Schoolchildren	Stool microscopy	Nkrumah and Nguah, 2011
	1.1 (3/292)	Villagers	Stool microscopy (Kato-Katz)	Humphries *et al.,* 2011
	13 (65/494)	Villagers	Stool microscopy (Kato-Katz)	Bimi *et al.,* 2012
Nigeria	30 (3/10)	Adult butchers	Copro-Ag-ELISA (*T. solium*)	Edia-Asuke *et al.,* 2014
	8 (4/50)	Villagers	Stool microscopy (*Taenia* spp.)	Gweba *et al.,* 2010
Gambia	4.7 (2/43)	Villagers	Stool microscopy (*Taenia* spp.)	Secka *et al.*, 2011

Table 2. Prevalence of taeniasis in human faecal samples in West Africa. Prevalence is given in percent, followed by positive cases / sample size in brackets. Of the tests used, only copro-antigen ELISA is specific for *T. solium*.

4.2 Porcine cysticercosis

Reports indicate that the West African region has the largest pig population on the African continent (Ngowi *et al*., 2013), having increased by 23 % between 1985 and 2005 (FAO, 2012). Available data on the current status of porcine cysticercosis in West Africa, determined by serological or carcass inspection, is presented in Table 3. Although there are no recent data on porcine cysticercosis in several countries, e.g. Togo (Dumas *et al*., 1989, 1990), *T. solium* is highly prevalent in others, including in Senegal, Gambia (Secka *et al*., 2010a,b; Secka *et al*., 2011) and Nigeria (Gweba *et al.,* 2010). There is a need for more epidemiological studies using suitable diagnostic technologies and neuroimaging to produce a more comprehensive picture.

Country	Prevalence % (sample size)	Diagnostic method	Test method	Reference
Burkina Faso	32.5- 48.2 (336)	B158/B60 Ag-ELISA	NS	Ganaba *et al.,* 2011
Gambia	4.8-13.2 (1705)	B158/B60 Ag-ELISA	NS	Secka *et al.,* 2010a
Ghana	2.3 (4121)	Carcass inspection	Specific	Atawalna *et al.,* 2015
	18.8 (117)	Carcass inspection	Specific	Bimi *et al.,* 2012
	11.7(60)	Carcass inspection	Specific	Permin *et al*., 1999
Nigeria	2.4 (379)	Carcass inspection	Specific	Idiaka *et al.,* 2017
	5.9 (205)	Tongue inspection	Specific	Gweba *et al.,* 2010
	14.4 (118)	Carcass inspection	Specific	Gweba *et al.,* 2010
	20 (2358)	Carcass inspection	Specific	Onah and Cheinjina 1995
	9.3 (43)	Carcass inspection	Specific	Edia-Asuke *et al.,* 2014
	46 (115)	IgG antibodies	NS	Weka and Ikeh, 2009
Senegal	6.4-13 (1334)	B158/B60 Ag-ELISA	NS	Secka *et al.,* 2010a

Table 3. Prevalence of porcine cysticercosis in pigs in West Africa. Prevalence is given in percent, followed by sample size in brackets. AgELISA = Antigen Enzyme linked immunosorbent assay; IgG = Immunoglobulin G. NS = not specific for *T. solium.*

4.3 Economic burden of human disease

Neurocysticercosis resulting in epilepsy is a significant health problem in many developing countries (Carabin *et al.,* 2015; Johansen *et al.,* 2016), leading to disproportionate economic suffering in underprivileged populations (Ferrer and Garate 2014; Gabriël *et al.,* 2016; WHO 2016a). Reports from most parts of West Africa show that epileptics suffer discrimination, stigmatization, joblessness and disability (Nitiéma *et al*., 2012; Komolafe *et al.,* 2012; Osakwe *et al.,* 2014). Negative attitudes and behaviours toward epileptics by the general population are due to ignorance and mistaken perceptions. In Nigeria some people believe that epilepsy is caused by witchcraft or evil spirits or that it is directly contagious, and sufferers therefore often seek treatment from herbalists, faith healers or witch doctors (Osakwe *et al.,* 2014). Hence detailed epidemiological surveys in order to generate data on communities' perception of epilepsy especially in relation to prevalence of epilepsy in NCC patients should be carried out in the region. Such a study will be used to serve as a guide in community treatment and social intervention packages (Osakwe *et al.,* 2014) to help change negative perceptions towards epileptics, and which impede effective treatment, surveillance and control.

4.4 Economic impacts of porcine cysticercosis

Porcine cysticercosis significantly impacts pig production in sub-Saharan Africa (Gabriël *et al.,* 2016; Trevisan *et al.,* 2017), resulting in nutritional and financial losses for smallholder farmers (Johansen *et al.,* 2016; Ngowi *et al.,* 2013). Previous studies by Zoli *et al*. (2003) estimate that annual losses resulting from porcine cysticercosis in 10 West and Central African countries are 25 million Euro. Atawalna *et al*. (2015), working at an abattoir that processed 7,622 pigs per annum, estimated annual direct losses of 104,528 Ghana Cedis (c.19,000 Euros) from (mainly whole carcass) condemnation for porcine cysticercosis.

5. Risk factors for transmission in West Africa

The human populations considered to be at the highest risk of infection are those who earn their livelihood wholly or partially through livestock rearing, including pigs, and have limited access to good sanitation (Carabin *et al*., 2015; WHO, 2016a). Here we discuss risk factors especially relevant to transmission of *T. solium* in West Africa.

5.1 Changing societal context

Increasing demand for meat and urbanization of populations in Africa are driving emerging livestock systems, including backyard pig rearing without sanitary precautions. The scenario is further complicated due to lack of potable water and poor sanitary conditions, which were reported as risk factors for taeniasis in a study conducted in Nigeria, in which *Taenia* spp. eggs were detected in soil and water (Gweba *et al.,* 2010). Unhygienic practices like dumping faecal matter in the surroundings, eating unwashed fruit and vegetables, and drinking unsafe (i.e. not boiled or otherwise treated) water contaminated with *Taenia* spp. eggs, are important risk factors for infection with *T. solium* in Burkina Faso (Carabin *et al*., 2015). Hence, potable drinking water should be provided to communities, which will prevent not only taeniasis but also other diseases, through improved sanitation and hygiene.

5.2 Animal husbandry systems

A strong link between various husbandry and sanitary practices and risk of infection in pigs and humans in West Africa has been established. The traditional system of pig management, where most of the pigs are confined or tethered at night and allowed to roam freely and scavenge during the day, is a common practice in West Africa and is likely to influence the prevalence of porcine or human cysticercosis, as observed in Burkina Faso (Ganaba *et al.*, 2011). In that study, porcine cysticercosis was associated with rearing practices, especially in the rainy season, in which pigs left to roam briefly during the rainy season were more likely to be seropositive than those kept confined in pens. Seropositivity for human cysticercosis in a village population in Senegal was also linked to free roaming pigs having access to human defecation sites (Secka *et al.*, 2011). In Nigeria, Gweba *et al.* (2010) observed that pigs had access to farmlands that were used as defecation sites by farmers. Weka *et al.* (2013), also in Nigeria, showed that extensively raised pigs had significantly higher seroprevalence of cysticercosis compared to those that were raised under more intensive management systems. The traditional system of pig management is therefore a risk factor for transmission of the disease; hence farmers should advised to confine their pigs if possible.

5.3 Human dietary behavior

Changing human behavior is a crucial component of solving the problem of cysticercosis in West Africa. For example, there is a lack of coordinated meat inspection and illegal slaughtering is commonly practised, resulting in infected carcasses being marketed and consumed even when under cooked, especially during festivities. In some instances, there are no abattoirs or slaughter slabs in the locality for meat inspection to be carried out, and if present are often unregistered.

This was a common scenario observed in studies conducted in Nigeria, Senegal and Gambia (Gweba *et al*., 2010; Secka *et al*., 2010a, Edia-Asuke *et al.,* 2014).

5.4 Butcher and inspector practices in abattoirs

Meat inspection regulations vary from one country to another (Dorny *et al*., 2005; Goussanou *et al*., 2014). Usually, butchers carry out basic visual inspection, sometimes supplemented by incisions of parasite preference sites, as for example in Benin (Goussanou *et al*., 2014). Butchers may allow only one incision to avoid disfigurement of meat, as reported in Nigeria (Gweba *et al*., 2010). A lack of multiple incisions renders the technique of low value, as cysts may be missed, thereby reducing sensitivity and observed prevalence (Goussanou *et al*., 2014). Some inspectors in Benin also allow butchers to sell meat from carcasses with immature cysts, with the recommendation to cook thoroughly before consumption (Goussanou *et al*., 2014). Confounding the issue also are the middle men who exert pressure to get the meat away from the slaughter slabs and quickly to the market place, thereby preventing thorough meat inspection, as observed in Nigeria (Gweba *et al*., 2010). Although existing legislation in many African countries requires that cysticercotic pig carcasses be condemned at meat inspection, this does not usually occur. Rather, infected pig carcasses are sold to consumers at reduced prices in Nigeria (Weka, personal observation) and in other African countries (Ngowi *et al*., 2013), which promotes spread of infection and further pushes the burden of disease onto the poor, who cannot pay the premium for safe meat.

5.5 Pork preparation and consumption

There are indications that pork consumption is increasing in sub-Saharan Africa, while preparation methods in the region often do not effectively kill the cysticerci (Assana *et al*., 2013). Heat resulting from boiling and frying the pork passes through the meat to a greater extent and is more likely to kill the cysts, compared to heat from roasting or barbecue grilling, as reported in Nigeria (Edia-Asuke, *et al.,* 2015). Studies conducted in Ghana, Nigeria and Burkina Faso indicated that those who ate pork with cysticerci and those who ate lightly cooked pork soups in the markets had higher probabilities of taeniasis (Bimi *et al.,* 2012; Weka *et al*., 2013; Carabin *et al.*, 2015). In Benin, pork is frequently eaten in form of a meat product named "kpete" (a kind of pudding), which is not always sufficiently heated to kill all cysticerci (Goussanou (2010). Consumers should be encouraged to cook meat thoroughly before consumption, and the factors preventing them from doing so further investigated, as these are likely to be strongly influenced by local contextual, *viz* cultural and socio-economic factors.

5.6 Hygiene practices

Open defecation, poor personal hygiene and low environmental sanitation including improper faecal disposal are common practices in West Africa and are habits that promote the spread of *T. solium* (Gweba *et al*., 2010; Secka *et al*., 2011; Weka *et al*., 2013). It has been reported that persons who do not use toilet facilities or did not wash their hands after defecation were 8.3 and 5.5 times respectively to test seropositive compared to those who used water closet toilet facilities and regularly washed their hands after defecation (Weka *et al*., 2013). A similar report had been made in Burkina Faso (Ganaba *et al*., 2011; Carabin *et al.,* 2015).

5.7 Lack of knowledge

In endemic areas, poverty, ignorance and superstitious beliefs about *T. solium* are associated with increased risk of disease transmission and stakeholders in endemic areas may know about tapeworm infections in humans but be unable relate them to porcine cysticercosis and NCC (Thys *et al.,* 2015). In a study in Nigeria, 80 % of the butchers had poor knowledge of *T. solium* cysticercosis and its public health significance (Edia-Asuke *et al.,* 2014), a likely explaination for the persistently high-risk practices described above.

6. Treatment of *Taenia solium* infections

6.1 Treatment of neurocysticercosis/Taeniasis

There is no universally accepted gold standard for the treatment of NCC but several suggestions have been made (Winkler, 2013; Garcia *et al.,* 2014b). Pharmacological therapy succeeds in eliminating active cysts in only one third of patients (Carpio and Romo, 2014). Albendazole is one of the cysticidal drugs of choice because of its ability to penetrate the central nervous system (Garcia *et al*., 2014a). Another drug of choice is praziquantel, which is widely accessible in sub-Saharan Africa and is effective against cestodes and schistosomes (Evans *et al*., 2013; Braae *et al.,* 2015c). Mass praziquantel treatment has been used widely in schistosomiasis control in Africa. There are no data available yet on widespread treatment for *T. solium* infections in humans in West Africa; however, several countries in the region have carried out mass drug administration (MDA) against schistosomiasis using praziquantel (Garba *et al*., 2009; Evans *et al*., 2011; Leslie et *al*., 2012). The drug is very effective in the treatment of taeniasis at a single oral dose rate of 5–10 mg/kg and therefore can be used to treat against both parasites (Braae *et al*., 2015a). Integration with schistosomiasis control programmes might therefore be a good way

forward for control of *T. solium*, and will also control other co-endemic infections. Unfortunately, the recommended dose for the treatment of schistosomiasis (40mg//Kg); (WHO 2002) stimulates seizures in people with NCC (Johansen *et al*., 2016). The safety of praziquantel for MDA in West Africa is yet to be evaluated in the light of high prevalence of NCC. Niclosamide or praziquantel are drugs of choice for eliminating adult tapeworm burdens (Gilman *et al*., 2012), but must also be used with caution, especially in people with NCC. Adult worms eliminated by the patients constitute a serious hazard to the populace and the environment and must be safely disposed of. It may also be necessary to treat any newcomers to the region that might be carriers, and those returning from regions where transmission of *T. solium* is still ongoing (Geerts, 2016).

6.2 Treatment of cysticercosis in pigs

The benzimidazole drug, oxfendazole is very effective against muscle cysts and gastrointestinal helminths at a single dose of 30 mg/kg body weight, but has limited effect on brain cysts (Pondja *et al*., 2012; Mkupasi *et al.,* 2013a, b). An additional benefit of the use of oxfendazole in pigs is that it increases the growth rate and general condition by eliminating gastro-intestinal nematodes. The use of oxfendazole alone, however, is often unable to control *T. solium*, as shown in a highly endemic area in Mozambique (Pondja *et al*., 2012). This is because some animals are likely to get reinfected following the last treatment and prior to slaughter. The role of drug treatment in the development of immunity againt reinfection in endemic areas is also uncertain. Further, in heavily infected pigs, inflammatory reactions arise in reaction to the anthelmintic-mediated death of cysticerci in the muscles (Assana *et al*., 2010), and can make the meat unfit for marketing and subsequent consumption (Lightowlers, 2010). The prolonged treatment time needed to rid meat

of cysts, and long withdrawal period following the use of oxfendazole before the animals are sold for consumption, constitute major constraints to the effective control of *T. solium* in most rural communities where pigs are a major source of income for farmers. In Morocco, oxfendazole is marked under the trademark Paranthic[©] at a price of 0.5 US dollars per 30 kg pig, which is motivating to small-scale pig farmers (Lightowlers, 2013; Donadeu and Lightowlers, 2014; Geerts, 2016). Data on the availability, acceptability and affordability of the drug in West Africa are lacking.

7. Control

Taenia solium cysticercosis is still endemic in West Africa despite the availability of tools to disrupt the life cycle (Braae *et al.,* 2015b). The World Health Organization (WHO) included *T. solium* cysticercosis as one of the major neglected tropical diseases (NTDs), and has adopted a resolution for intensified control efforts (WHO, 2010; Braae *et al.,* 2016b). The resolution recommended a scaled-up control and eradication strategy in selected countries to last from 2016 to 2020 with the aim to control and eradicate the disease by 2020. However; no large scale taeniasis control programme has yet been implemented in sub-Saharan Africa (WHO, 2015c). Below, we consider the approaches available and how they might be more effectively applied in West Africa.

7.1 Use of latrines to reduce open defecation

The availability and use of toilets or latrines will decrease the spread of *Taenia* spp. eggs and other soil-transmitted helminths (STH) in the environment (Bethony *et al*., 2006; Pruss-Ustun *et al*., 2014). Moreso, emphasis should not be on the provision and use of latrines or access to

sufficient clean water only, but also on the proper management of such infrastructure by the population (Gabriël *et al*., 2016). Community-led total sanitation (CLTS) is an intervention measure that ought to assist in the control of porcine cysticercosis, but has not yet been fully evaluated as part of *T. solium* control in West Africa. Studies in The Gambia and Senegal reported that 93% of the residents had toilets and only 5% used open defecation, and that these 5% were therefore likely to be responsible for considerable environmental contamination with *Taenia* spp. eggs (Secka *et al*., 2010a). A study from Nigeria showed that although most households in the study location had toilets, the majority of people still defecated on farmlands, thereby contaminating the environment with *Taenia* spp. eggs (Gweba *et al*., 2010).

7.2 Personal and household hygiene

Individual and community hygiene should also be emphasized and encouraged in order to decrease the risk of NCC, including the availability of sufficient clean water, which is crucial to allow improved hygiene (Gabriël *et al.,* 2016). A study in Nigeria showed 31.7 times higher risk of exposure to taeniasis among respondents who did not wash their hands after each toilet use compared to those who washed their hands with soap and water (Weka *et al*., 2013). Enough water for washing of fresh foods such as fruit and vegetables is also necessary to reduce the spread of *Taenia* spp. eggs (Carabin *et al*., 2015).

7.3 Confinement of pigs

Traditional systems of pig management are commonly practised in West Africa and are likely to influence the prevalence of porcine or human cysticercosis (Ganaba *et al.*, 2011; Secka *et al*., 2011; Weka *et al.*, 2013). The ability of farmers to provide pig housing is hindered by poverty,

since the farmer is also expected to provide feed to the pigs under confined systems of management (Assana *et al*., 2013). This runs in opposition to the motives of the smallholder farmer, to keep pigs as a source of income without the need to invest in feed (Gilman *et al*., 2012), which renders pig confinement an unworkable approach to *T. solium* control in the short term; changes in pig management systems should therefore be considered a long term strategy (Thomas, 2015). Pig farmers should also be informed that, apart from the advantage of a decrease in porcine cysticercosis, confined pigs also have a reduced risk of acquiring African Swine Fever (Geerts 2016), and a decreased burden of other parasites (Gabriël *et al*., 2016). Changes in pig rearing system are likely to be driven by economic more than sanitary considerations, but research on the constraints and consequences of adopting different systems, and related trade-offs with time and funds available for other activities, resilience to internal and external disruptions, and animal welfare, remain largely un-studied in West Africa.

7.4 Meat and lingual inspection

Meat and tongue inspection are carried out in West Africa where slaughter slabs and abattoirs for pigs exist (Onah and Chiejina, 1995; Coulibaly and Yameogo, 2000; Gweba *et al*., 2010; Secka *et al*., 2010b; Edia Asuke *et al.,* 2014; Goussanou *et al*., 2014; Idiaka *et al.,* 2017). These techniques are relatively cheap, rapid and easy to conduct (Goussanou *et al*., 2013), but their sensitivity is low and lightly infected pig carcasses are likely to remain undetected and enter the food chain (see above, and Goussanou *et al*., 2014). Furthermore, farmers and traders in Benin frequently carry out tongue examinations to detect cysts prior to marketing in order to avoid condemnation, and then use the infected carcase for their own consumption or sell it illegally (Goussanou *et al*., 2013).

The lack of comprehensive and satisfactory meat inspection in West Africa is a significant risk factor for the transmission of cysticercosis to humans. In Nigeria, the situation is further complicated by the lackadaisical attitude of inspectors, apathy from the farmers, insincerity of policy makers, and consumers who prefer to buy infected carcasses at a cheap price without regard for the health implications (Weka, personal observation). Strict meat inspection and condemnation of infected carcases runs the risk of exacerbating the divide between safe but expensive meat and cheaper but riskier 'unofficial' meat, further pushing the burden of disease onto the poor. Research is urgently needed that encompasses the economic, social and behavioural context of meat safety as well as biological and veterinary processes.

7.5 Meat processing

Proper meat processing at household and community level is an important defence against NCC (Ertel *et al.,* 2015). Freezing for 10 days at −10 °C, gamma-radiation, cooking and salt pickling of pork meat infected with *T. solium* all decrease cyst viability (OIE, 2015; Geerts 2016). Implementation in rural areas, however, is often difficult due to cost and unavailability of equipment (Geerts, 2016). Lack of freezers, unreliable power supply, and impatience of consumers militate against prolonged freezing of meat as a control measure in West Africa. Although meat is normally well cooked in endemic areas (Geerts, 2016), and temperatures of 80 °C will kill *T. solium* cysticerci in infected meat (OIE, 2015), studies in including West Africa indicated that pork is frequently eaten in forms insufficiently heated to kill all cysticerci (Goussanou 2010; Edia-Asuke, *et al.,* 2015).

7.6 Anthelmintic treatment of pigs and humans

Treatment of cysticercosis in pigs and taeniasis in people can be usefully applied as MDA at population level using a single dose of 5 mg/kg praziquantel or nitazoxanide (2g) as an effective control measure. A 56% decrease of prevalence of taeniasis after 42 months was reported in Mexico while 1-3.5 % decrease in cases of taeniasis and a 7-55 % decrease in porcine cysticercosis in two villages in Guatemala was reported 10 months after evaluation (Allan *et al*., 1997). Studies using combined treatment of pigs and humans in West Africa have not yet been reported.

7.7 Vaccination of pigs

Vaccination is a recently available intervention for the control and elimination of *T. solium* (Lightowlers, 2013; Gabriël *et al.,* 2016), and has conferred high levels of protection in both experimental and field trials (WHO, 2015a, 2016a). Three candidate vaccines currently exist, based on: a crude antigen developed by Molinari *et al*. (1993); a recombinant oncosphere antigen-based TSOL16 or TSOL18 vaccine by Lightowlers *et al*. (2010); and a peptide-based S3PVac developed by Huerta *et al*. (2001). The most effective vaccine produced to date is the recombinant protein TSOL18, which achieved 99.5–100% protection of vaccinated pigs in a field trial in Cameroon when combined with a single oxfendazole treatment (Assana *et al*., 2010). In the study, the first vaccine dose was given at 2-3 months of age, and a second vaccine dose given with oxfendazole 4 weeks later. A third vaccine dose was given 3 months later. The combination of TSOL18 vaccination and oxfendazole in pigs has the potential to control transmission in endemic areas and indirectly decrease new cases of NCC (Assana *et al*., 2010). The oxfendazole eliminates any *T. solium* infection that is already present in the vaccinated pigs,

prior to the animals being fully vaccinated and protected (Lightowlers, 2013). The regimen allows adequate time to pass after chemotherapy for any lesions in the pork arising from killed and necrotic cysticerci to be resolved prior to the animals being slaughtered. During this period, all animals (previously infected or otherwise) are protected against new *T. solium* infection by the vaccine. A smilar result was obtained in a field trial conducted in Peru (Jayashi *et al*., 2012). The effectiveness of *T. solium* taeniasis-cysticercosis elimination by combined vaccination (TSOL18) plus treatment of pigs with oxfendazole, combined with mass or targeted treatment of human tapeworm carriers (Geerts, 2016) led to marked reduction in *T. solium* transmission in the study populations (Garcia *et al*., 2010; Gilman *et al*., 2012). Challenges remain, however, in achieving optimal protection of traditionally managed pigs under field conditions (Lightowlers, 2013; Pawloski, 2016). The protocol requiring three vaccinations and oxfendazole increases costs to the farmer and likely decreases feasibility (Jayashi *et al*., 2012; Thomas, 2014). Therefore, the vaccine may be unaffordable for poor communities unless subsidized and supported by provision of infrastructure to deliver the vaccine, including an effective cold chain. Currently, the TSOL18 vaccine is produced commercially at scale by Indian Immunologicals (Thomas, 2015; Geerts, 2016). Although the vaccine has been available since May 2016, registration at national level requires investment, which in practice limits availability in Africa to date. Therefore, no data yet exist on impacts of vaccination in West African contexts, though the authors' personal interviews with farmers in north central Nigeria indicate their willingness to purchase the vaccine when available.

7.8 Health education

Health education is a significant part of control strategies for *T. solium* (Garcia *et al*., 2010; Fleury *et al*., 2013), informing consumers about the risks related to the consumption of infected pork. Subsequent refusal to purchase infected meat might assist in a change of management practices, as farmers acknowledge a clearer economic cost of high-risk practices (Thomas, 2015; Gabriël *et al*., 2016). Impact could extend through the meat supply chain and to health workers and the general population (Thomas, 2015), although like other interventions, education has limitations as a stand-alone approach (Gabriël *et al*., 2016). A free computer-based health education tool called "The Vicious Worm" was developed to support efforts to control *T. solium* infections in East Africa (Johansen *et al.,* 2014), targeting stakeholders across from all professions and sectors and providing information on transmission, diagnosis, risk factors, and prevention and control of the disease (Johansen *et al.,* 2016). In West Africa, a community-based (EFECAB) educational programme carried out in Burkina Faso showed a reduction in active cysticercosis (Carabin *et al*., 2018). Such approaches should be expanded regionally to better understand and enhance the role of health education in *T. solium* control.

7.9 Integrated approaches

Several predictive models have been developed to help design the most effective and feasible intervention strategies for the control of *T. solium* cysticercosis in both pigs and human populations (Braae *et al.,* 2016b; Winskill *et al.,* 2017). The recently developed CystiSim model indicated that combined intervention strategies in both pigs and humans, such as concurrent MDA in humans and vaccination and treatment of pigs, have a high likelihood of success, given a 75% coverage rate sustained for more than four years (Braae *et al.,* 2016b).

Collaborative networks for *T. solium* control already exist nationally and internationally among researchers, and this effort should be sustained for interaction and transfer of knowledge and findings (Gabriël *et al.,* 2016, WHO, 2016a). A multisectorial and One Health approach across all disciplines including agricultural, food and human health sectors comprising medical, veterinary, environmental, governmental, nongovernmental and social actors, is necessary for the control and eradication of cysticercosis and *T. solium* in both humans and pigs (Braae *et al.,* 2016a; Gabriël *et al.,* 2016). Furthermore, it is vital to integrate control of *T. solium* cysticercosis with other NTDs or within national primary health care systems (Bockarie *et al*., 2013; Nakagawa *et al.,* 2015) and this should be encouraged in West Africa. Efforts to improve scientific understanding and design of optimal control strategies should be cognisant of the fact that the success of any intervention is largely dependent on the level of societal and political acceptance, commitment and engagement of the stakeholders (Gabriël *et al.,* 2016).

8. Conclusions

Diverse intervention methods have been recommended and attempted in order to control *T. solium* cysticercosis (Fleury *et al*., 2013). A multipronged approach consisting of vaccination of pigs using TSOL18 vaccine and treatment with oxfendazole along with mass chemotherapy of humans is promising, and could eliminate taeniasis. Long-term and sustainable control should include combinations of methods that center on both human and animal hosts, and are appropriate to local and regaional contexts. Selected combinations will depend on practicality and economic cost (Mwape *et al.,* 2015). Alas, at present there is inadequate evidence for the best combinations for cost-effective intervention packages in endemic countries (Johansen *et al.,* 2016), thus integration of economics into disease control models might help to rectify this

important deficit. Identifying and addressing key obstacles to sustained control efforts, as set out in this review for West Africa, is an essential step in designing rational approaches suited to target regions, and making real progress towards elimination. Diagnostic tools, including neuroimaging facilities, should be strategically situated and made accessible to rural populations in West Africa. This will support efforts to more accurately estimate the burden of disease, highlight the problem to policymakers with competing priorities, and monitor the effectiveness of interventions.

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