

RESEARCH ARTICLE

The epidemiology of human *Taenia solium* infections: A systematic review of the distribution in Eastern and Southern Africa

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Abstract

Background

Taenia solium is a tapeworm that causes taeniosis in humans and cysticercosis in humans and pigs. Within Eastern and Southern Africa (ESA), information on the presence of human taeniosis and cysticercosis seems scarce. This systematic review aimed to describe the current information available and gaps in the epidemiology of human *T. solium* infections in ESA.

Methods/Principle findings

Scientific literature published between 1st January 2000 and 20th June 2022 in international databases [MEDLINE (Ovid), Embase (Ovid), Global Health (Ovid), Scopus (Elsevier), African Index Medicus (via WHO Global Index Medicus), and Open Grey] was systematically reviewed for ESA. The study area included 27 countries that make up the ESA region. Information on either taeniosis, cysticercosis or NCC was available for 16 of 27 countries within the region and a total of 113 reports were retained for the review. Most case reports for cysticercosis and NCC were from South Africa, while Tanzania had the most aggregated cysticercosis reports. Eleven countries reported on NCC with seven countries reporting data on NCC and epilepsy. Unconfirmed human *T. solium* taeniosis cases were reported in nine countries while two countries (Madagascar and Zambia) reported confirmed *T. solium* cases. The cysticercosis seroprevalence ranged between 0.7–40.8% on antigen (Ag) ELISA and between 13.1–45.3% on antibody (Ab) ELISA. Based on immunoblot tests the Ab seroprevalence was between 1.7–39.3%, while the proportion of NCC-suggestive lesions on brain CT scans was between 1.0–76% depending on the study population. The

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human taeniosis prevalence based on microscopy ranged between 0.1–14.7%. Based on Copro Ag-ELISA studies conducted in Kenya, Rwanda, Tanzania, and Zambia, the highest prevalence of 19.7% was reported in Kenya.

Conclusions

Despite the public health and economic impact of *T. solium* in ESA, there are still large gaps in knowledge about the occurrence of the parasite, and the resulting One Health disease complex, and monitoring of *T. solium* taeniosis and cysticercosis is mostly not in place.

Author summary

Taenia solium is a tapeworm that causes three diseases, taeniosis in humans and cysticercosis in humans and pigs. Neurocysticercosis, which occurs when the central nervous system is involved has been associated with up to 57% of epilepsy cases in sub-Saharan Africa. Diagnosing neurocysticercosis among people with epilepsy is vital to prevent further morbidity and mortality from the disease as well as to reduce the negative socio-cultural beliefs associated with epilepsy. Within Eastern and Southern Africa, there are many countries in which information on the presence of human taeniosis, cysticercosis and neurocysticercosis seems scarce. This systematic review aimed to describe the current information available and gaps in the epidemiology of human *T. solium* infections in Eastern and Southern Africa. We found that information on either taeniosis, cysticercosis or NCC was available only for 16 of 27 countries within the region. We also found that most of the studies on *T. solium* taeniosis, cysticercosis and neurocysticercosis within the region have been done in Kenya, Madagascar, Mozambique, Rwanda, South Africa, Tanzania and Zambia. Understanding the epidemiology of *T. solium* infections is essential for monitoring, prevention and control of the disease complex in a One Health approach.

Introduction

Taenia solium is a tapeworm that causes taeniosis in humans and cysticercosis in humans and pigs. The life cycle of *T. solium* involves pigs as intermediate hosts (cysticercosis) while humans are definitive hosts (taeniosis). Humans may also act as accidental intermediate hosts when larvae of the parasite settle in muscles, subcutaneous or organ tissues causing human cysticercosis (HC). If they lodge in the central nervous system (CNS), including the brain and the spinal cord, the disease is called neurocysticercosis (NCC) [1,2]. An individual may also have cysticerci in the CNS as well as in other parts of the body, which is referred to as (neuro) cysticercosis. NCC may be asymptomatic, but it can also cause various neurological signs/symptoms such as epileptic seizures and epilepsy, chronic progressive headache, focal neurological deficits, signs and symptoms of increased intracranial pressure and in rare cases, death [3–5]. Globally, NCC is estimated to be responsible for 30% of cases of acquired epilepsy in endemic areas [6] and 22% in sub-Saharan Africa [7]. However, this proportion depends on the infection pressure of *T. solium* and thus may vary considerably.

T. solium is endemic in Africa, Asia and Latin America, especially in areas where pigs are reared under free-ranging conditions, where pork is eaten and where hygiene is limited [8–10]. Nevertheless, information on the endemicity of *T. solium* is limited and there are many countries from which no published information is available for either human or porcine

cysticercosis. Within the Eastern and Southern African region, information on porcine cysticercosis was recently published [11]. However, not much is known about the epidemiology of *T. solium* infections in humans. The purpose of this review was to gather all published information on human *T. solium* infections (*T. solium* taeniosis/(neuro)cysticercosis (TSTC)) in Eastern and Southern Africa (ESA) within the period 1st January 2000 and 20th June 2022 and describe the gaps in the epidemiology of TSTC in this area.

Methods

The systematic review was conducted following a pre-registered protocol and reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [12] (S1 Table). The review was registered with the International Prospective Register of Systematic Reviews (PROSPERO) (registration number: CRD 42022343072).

Search strategy

All published articles were searched using the electronic databases, MEDLINE (Ovid), Embase (Ovid), Global Health (Ovid), Scopus (Elsevier), African Index Medicus (via WHO Global Index Medicus), and Open Grey. The reference lists of included studies were also scanned to identify further eligible documents. The searches were conducted on 20th June 2022.

For all questions subject headings (where applicable) and text words describing *T. solium* taeniosis/cysticercosis/neurocysticercosis and prevalence, epidemiology, control, elimination, or eradication were searched. The search strategy was intended to obtain all available literature on human taeniosis, cysticercosis and neurocysticercosis in ESA conducted and published in the last 22 years. Grey literature was also searched for any relevant publications. The search terms for all databases can be found in (S1 File).

Procedures

Data management. Literature search results were uploaded to the bibliographic software Mendeley Desktop and Covidence. Duplicates were removed based on author names and titles. Screening questions based on the inclusion and exclusion criteria were developed and citation abstracts and full-text articles were uploaded.

Selection process. The selection process was conducted in two stages. Firstly, titles and abstracts were screened independently by two reviewers (GZ and CM) and then full-text reports were obtained by the same reviewers for a detailed assessment with respect to the inclusion criteria. For records that referred to the same study, only one was selected.

Data collection process. The data were collected using standardized data collection forms in Microsoft Excel (S2 File). Data extracted included demographic information, methodology, and all the relevant reported outcomes. GZ carried out the data extraction with verification by CM.

Data items. Predefined tables summarizing individual cases included the year of diagnosis, age, gender, the country where cases were detected, diagnostic method, and location of the lesion (for cysticercosis). Tables summarizing aggregated cases or prevalence data included country, level of data collection (e.g. national or regional), timeframe, number of cases (or prevalence proportion), number of people tested, and diagnostic method.

Eligibility criteria

Inclusion criteria. We included all studies describing human TSTC in ESA, which was defined as the area covered by the following countries/territories: Angola, Botswana, Burundi,

Comoros, Djibouti, Eritrea, Ethiopia, Kenya, Lesotho, Madagascar, Malawi, Mauritius, Mayotte, Mozambique, Namibia, Reunion, Rwanda, Seychelles, Socotra, Somalia, Somaliland, South Africa, Eswatini (former Kingdom of Swaziland), Tanzania, Uganda, Zambia and Zimbabwe. Included in this review were studies that describe the epidemiology, disease occurrence, burden, prevalence, incidence, prevention and control of TSTC in any of the twenty-seven countries of ESA. All observational studies including case series and case reports and systematic reviews of such studies were included. Only studies conducted between 1st January 2000 and 20th June 2022 were considered. No language limits were imposed on the search, although studies in languages other than English were only included if they could be adequately translated by using Google Translate.

Exclusion criteria. We excluded studies that did not concern *T. solium*, did not concern humans, did not report data from within ESA and studies conducted before 1st January 2000.

Risk of bias assessment

The risk of bias in the studies was assessed using items recommended by the Agency for Health Care Research and Quality (AHRQ) [13]. This assessment covered baseline characteristics, inclusion-exclusion criteria, confounding and modifying variables, performance bias, attrition bias, detection bias and reporting bias. Each of these factors was rated and categorized as low, or high risk of bias. If the information available was insufficient, the risk of bias was considered 'unsure'.

Statistical analyses

No statistical pooling of results was conducted and the findings of the review are presented in a narrative synthesis with tables and figures to aid data presentation. Prevalence data if not already provided were calculated using the numerator and denominator of the study sample. Data were analyzed separately for taeniosis, cysticercosis, and neurocysticercosis. For the latter two, data were also presented separately for the general population and people with epilepsy.

Ethical considerations

Ethical recommendation was not required for this review.

Results

Study selection

Our search yielded 2114 records of which 1198 were duplicates. Through screening of titles and abstracts, 776 (85%) records were excluded and for a further 8, no full text was found. Full-text assessment with respect to the inclusion criteria was performed on 132 records of which 19 (14%) were excluded (17 reported data described in other included studies, one did not concern *T. solium*, and one reported results outside the scope of the study). One hundred and thirteen (113) studies were finally included in the review. Of those, 49 were concerned with only (neuro) cysticercosis, 57 with taeniosis, and 7 with both cysticercosis and taeniosis. Of the 113 reports reviewed, 25 were case reports, 82 were cross-sectional, 3 cohort and 3 case-control studies. The flow diagram for the search is shown in (Fig 1). The reference for included studies is shown in (S2 Table).

Risk of bias

The risk of bias assessment revealed that most studies had a low risk of reporting, detection, attrition and performance bias. However, 7 studies had a high risk of performance bias, 20 had

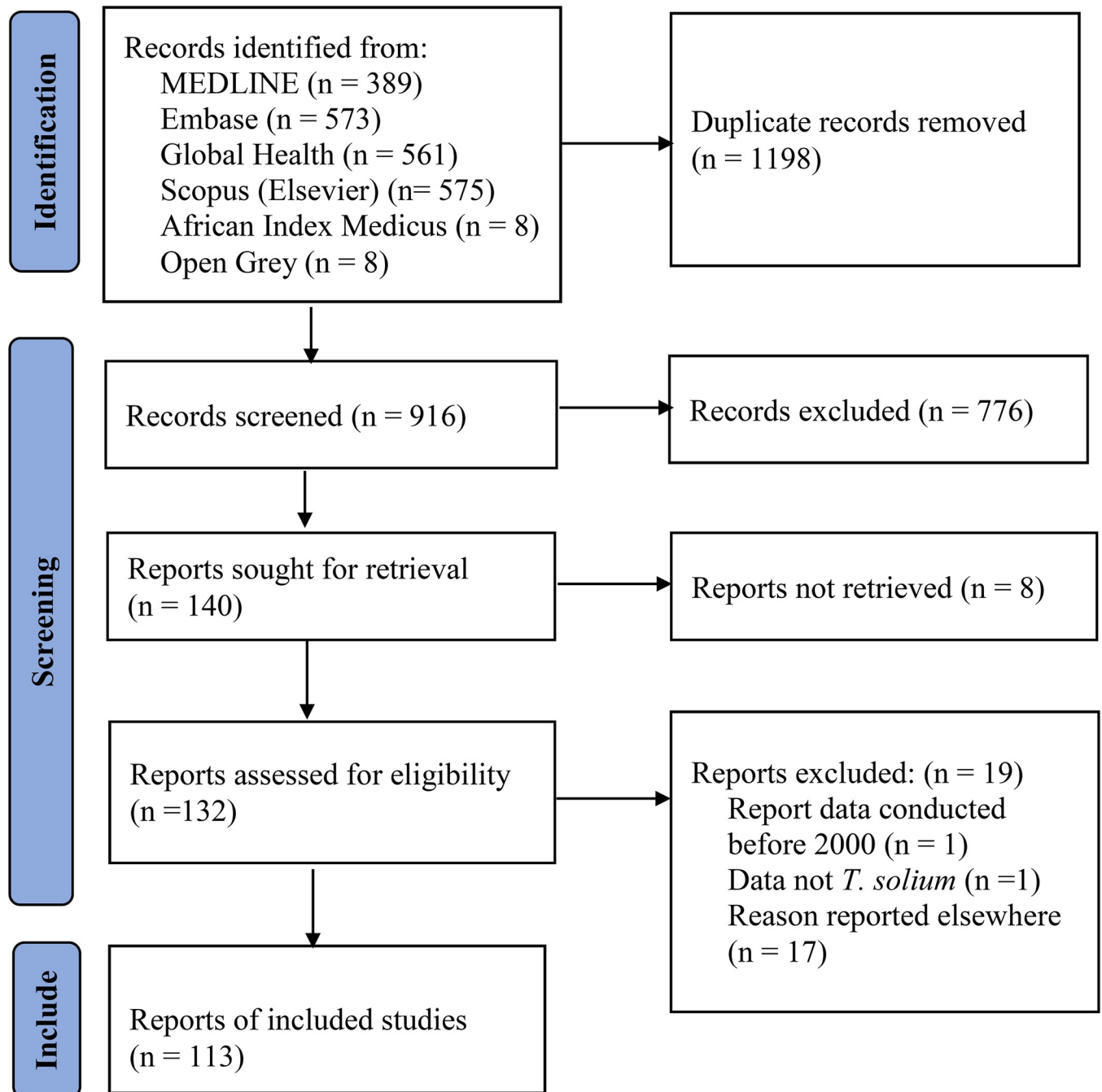


Fig 1. PRISMA flow diagram.

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a high risk of bias due to inadequate inclusion and exclusion criteria, and 45 articles had a high risk of bias due to confounding and modifying variables.

Results of individual studies

Human (neuro) cysticercosis. Information on human (neuro) cysticercosis was obtained from 62 sources. In total, 25 (40%) records provided individual information on NCC and CC.

Twelve (48%) of these records were on NCC only, seven (28%) on CC and six (24%) on both NCC and CC. Thirty-seven (60%) records reported aggregated information on NCC and CC. Ten (27%) of these records were on NCC only, twenty-one (57%) on CC only, and six (16%) on both NCC and CC. Information on human neuro(cysticercosis) was available for 14 of 27 ESA countries. No reports were available for Angola, Botswana, Comoros, Djibouti, Eritrea, Ethiopia, Lesotho, Mayotte, Reunion, Seychelles, Socotra, Somaliland and Somalia.

Human cysticercosis case reports. Individual human CC cases during the period 2000 to 2022 were reported in 13 hospital case records from six of the ESA countries with, South Africa reporting four cases; Madagascar, Malawi, Rwanda and Tanzania reporting two cases each and Mauritius reporting one case (Table 1). Individual NCC cases were reported in 18 hospital records from eight of the ESA countries with South Africa reporting eight cases while Madagascar, Malawi and Zambia reported two cases each. Mozambique, Eswatini, Tanzania and Zimbabwe reported one case each (Table 2). All reports were based on individual patients presenting with various signs/symptoms, and investigations leading to their diagnosis of either

Table 1. Individual human cysticercosis case reports as detected through histopathology of sample specimens from patients in Eastern and Southern Africa (2000–2022).

Country	Age (yrs.)	Gender	Sample	Location of pathogen	Comment	Reference
Madagascar	20	Male	Bronchial specimen	Bronchus	A 20-year-old male who presented with hemoptysis following bronchial cysticercosis.	[16]
	15	Female	Breast lump	Breast	Breast cysticercosis in a 15-year-old girl.	[17]
Malawi	41	Female	Skin nodule	Subcutaneous all over the body*	A 41-year-old patient on ARVs with disseminated cysticercosis and more than 50 cysts in the brain.	[18]
	56	Female	Biopsy of neck mass	Left anterior and posterior triangles of the neck	A 56-year-old woman with a history of gradual but progressive growing left sided neck swelling for the past 25 years.	[19]
Mauritius	22	Female	Excision biopsy	Upper part of right breast	A 22-year-old woman with history of painless mobile swelling in the right side of the breast.	[20]
Rwanda	2 months—65 yrs.	-	Anatomical department files	Subcutaneous nodules	A case report of 10 cases of cutaneous cysticercosis confirmed by histopathology in the anatomical pathology department at a district hospital (Nyamasheke) in eastern Rwanda.	[14]
	46	Female	Subcutaneous nodule	Subcutaneous nodules on trunk and extremities	A 46-year-old woman who presented with a two-week history of bilateral lower limb weakness, causing difficulty walking.	[21]
South Africa	42	Male	Biopsy of subcutaneous nodule	Extensive calcifications in the muscle and subcutaneous tissue. Active cysts within myocardium [#]	A 42-year-old man with a rare case of myocardial cysticercosis with multiple calcifications in the muscle and subcutaneous tissues.	[22]
	86	Female	Excised cyst from pharynx Subcutaneous nodule biopsy	Left posterior oropharynx Subcutaneous nodules on the back	An 86-year-old woman with cysts in the left posterior oropharynx, brain and subcutaneous tissues on the neck and back.	[15]
	49	Male	Excisional nodule biopsy	Subcutaneous nodules on the trunk and upper extremities	A 49-year-old man with generalized cysticercosis.	[23]
	8	Nr	Cyst from pleural effusion	Right lung	An 8-year-old child with pulmonary cysticercosis who presented with a large right pleural effusion.	[24]
Tanzania	4	Male	Subcutaneous sample biopsy	Sub mandibular and cervical region and abdomen	A 4-year-old HIV positive child with disseminated cysticercosis.	[25]
	48	Male	Subcutaneous nodule	Neck	A 48-year-old male driver with disseminated cysticercosis treated as malaria.	[26]

ARV, Antiretroviral medication; HIV, Human immunodeficiency virus; Yrs., Years.

*detected through musculoskeletal ultrasound of nodules

#detected through chest and soft tissue x-rays

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Table 2. Individual human neurocysticercosis (NCC) case reports as detected by Brain CT in Eastern and Southern Africa (2000–2022).

Country	Age (yrs.)	Gender	Location of pathogen	Comment	Reference
Eswatini	40	Male	Multiple intra-parenchymal cysts, mural scoleces, calcified granulomas, right sided and parafalcine septate subdural collections, pathognomonic of racemose, stage I and stage IV NCC	A 40-year-old male with a history of chronic headache, unsteady gait and progressive deterioration in vision.	[27]
Madagascar	71	Male	Not described*	A 71-year-old man with dysarthria and memory problems.	[28]
	31	Male	Two ring enhancing lesions in the left capsulo-lenticular area [‡]	A 31-year-old man presenting with dysarthria, blurred vision and monoparesis of the right upper limb 7 weeks after starting anti-tuberculosis medication.	[29]
Malawi	58	Female	Multicystic lesion in the left temporal lobe ^{‡#}	A 58-year-old woman with coincidental racemose NCC who was being treated for HIV associated cryptococcal meningitis, clinically and microbiologically responding to antifungal therapy.	[30]
	41	Female	Multiple intra-parenchymal cysts in the brain	A 41-year-old patient on ARVs with disseminated cysticercosis and more than 50 cysts in brain.	[18]
Mozambique	18	Female	Multiple lesions with different stages ranging from cerebral ring-enhancing cysts with scoleces to transitional or degenerative colloidal cysts to multiple parenchymal calcifications	An 18-year-old female admitted to Hospital Central de Quelimane, Zambezia province in Mozambique, 8 days after delivery with a misdiagnosis of eclampsia that turned out to be NCC.	[31]
South Africa	52	Female	Granuloma within bilateral frontal and temporal lobes; Multicystic racemose lesion in the right cerebellar hemisphere; active cyst within the left cerebellar hemisphere; hydrocephalus with blocked ventriculo-peritoneal shunt; Intraventricular cyst	A 52-year-old woman with multiple types of NCC pathology.	[32]
	42	Male	Multiple active and calcified lesions in the brain.	A 42-year-old man with NCC and disseminated cysticercosis with myocardial involvement and with multiple calcifications in the muscle and subcutaneous regions.	[22]
	86	Female	Active brain cysts (not specific)	An 86-year-old woman with NCC and cysts in the left posterior oropharynx and subcutaneous tissues on the neck and back.	[15]
	49	Male	Bilateral multiple parenchymal non-enhancing cerebral cystic lesions	A 49-year-old man with generalized cysticercosis.	[23]
	46	Female	Spinal and vertebra region. A spinal lesion at T12, causing vertebral collapse ^{‡§†}	A 46-year-old HIV+ patient with NCC affecting the spine with severe pain with spasms and weakness in lower limbs.	[33]
	30	Female	Cyst in the occipital horn of the right lateral ventricle	A 30-year-old woman with acute unilateral hydrocephalus.	[34]
	8	-	A non-specific solitary sub centimeter calcified granuloma abutting the tentorium cerebellum	Letter to the editor of a case report on an 8-year-old child with pulmonary cysticercosis who presented to Red Cross children's hospital, Cape Town, with a large right pleural effusion.	[24]
	32	Male	Brain with isolated cystic lesions with scolex and ring enhancing lesion in colloidal stage	A 32-year-old known PWE admitted with COVID-19 and developed recurrent epileptic seizures due to dying cysts after beginning of NCC treatment.	[35]
	42	Female	Not described	A 42-year-old known PWE admitted with COVID-19 and NCC with poor response to treatment and in status epilepticus for a long time.	
Tanzania	48	Male	Multiple cystic lesions with dot sign diffusely distributed in the brain, neck, chest, including the heart, abdomen, and pelvis [‡]	A 48-year-old driver with disseminated cysticercosis treated as malaria.	[26]
Zambia	48	Female	Numerous round points with T1 hypo intense, T2 hyper intense dot-form cores seen in all cerebral slices. [#]	A 48-year-old woman who presented with subcutaneous nodules on the face, recurrent headache and epileptic seizures in Chambishi Zambia.	[36]
	60	Male	Thoracic intramedullary cystic lesions. Also, cystic lesions in subcutaneous tissue ^{‡†}	A 60-year-old man with progressive lower extremity weakness and numbness at University Teaching Hospital in Zambia.	[37]

(Continued)

Table 2. (Continued)

Country	Age (yrs.)	Gender	Location of pathogen	Comment	Reference
Zimbabwe	35	Male	A Suprasellar cystic lesion compressing the optic nerve ^{#§}	A 35-year-old man presenting with pain accompanied by mild vision loss in the right eye due to a cystic mass compressing the optic nerve.	[38]

ARVs, Antiretroviral medication; HIV, Human immunodeficiency virus; NCC, Neurocysticercosis; Yrs., Years.

* Serology with Ag-ELISA and EITB also used for diagnosis

‡ CSF Ag-ELISA also used for diagnosis

MRI employed as detection method

‡ CT of head, neck chest, abdomen, pelvis employed as detection method

§ Histopathology employed as detection method

† NCC affecting the spine with no brain involvement

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CC or NCC. Twelve (48%) of the 25 case reports described only NCC diagnosed through the use of brain computed tomography (CT) scan [7] and magnetic resonance imaging (MRI) [5], while seven (28%) presented with CC affecting other organs i.e. bronchus, breast, abdomen, neck and subcutaneous tissue diagnosed through histopathology and other investigations. Six (24%) case reports were on patients who presented with both NCC and CC affecting other organs (disseminated CC). At a district hospital in Rwanda ten cases of cutaneous CC were reported with the youngest being only 2 months old [14]. The oldest reported case of NCC was from South Africa in an 86-year-old female with a pharyngeal cyst, cutaneous cysts and active brain cysts [15]. The median age in years was 41 (17–48 years). Twenty-three (92%) of the case reports had information on the affected gender with 54% of the reported cases being female and 46% being male.

Aggregated human cysticercosis. The number of aggregated human CC reports (community-based, cross-sectional studies) for the period 2000 to 2022 in ESA was 27 (Table 3). These were reports from nine countries, the majority of which were conducted in Tanzania (n = 7) followed by Madagascar (n = 6) and Zambia (n = 4). South Africa, Mozambique, Rwanda and Kenya had two reports each. For Burundi and Uganda one report each was available. There was great variation in the aggregated number of human CC cases across countries with over 2307 cases reported from Madagascar alone. The number of human CC cases identified in other ESA countries in documents published between 2000 and 2022 is shown in (Fig 2) below.

To ascertain cases of aggregated human CC, various diagnostic methods were utilized in the included reports with nine (33%) studies employing a combination of antibody and antigen based serologic tests. Seven (26%) studies employed only the Ag-ELISA, while eight (30%) utilized only the immunoblot methods. One report (4%) utilized only the electroimmuno-transfer blot assay (EITB) and one report (4%) was based on postmortem findings of CC through full-body dissection [65]. One report did not specify the type of serologic test used. The methods used for CC diagnosis are shown in (Fig 3).

The prevalence of human CC in ESA in different study populations showed wide variation within and between countries (Fig 4 and Table 3). The CC seroprevalence ranged between 0.7–40.8% on Ag-ELISA and between 13.1–45.3% on Ab-ELISA tests. Based on Ab-tests using the immunoblot the CC seroprevalence ranged between 1.7–39.3%. The highest point prevalence based on serum Ab-ELISA was reported in Tanzania (45.3%) from a study conducted in the Mbozi area of Mbeya District [55].

For the studies conducted within Tanzania, this was an outlier value. High prevalence variation was also observed within countries as seen in Madagascar, Rwanda and Zambia (Fig 5).

Table 3. Aggregated human cysticercosis cases identified in Eastern and Southern Africa (2000–2022).

Country	No. Tested	Prevalence	Method	Comment	Reference
		No. (%)			
Burundi	972	397 (40.8)	Ag-ELISA	A prevalence matched case-control design used in the Kiremba area, Burundi to evaluate the role of cysticercosis in PWE.	[39]
Kenya	2113	122 (5.8)	Ag-ELISA	A cross-sectional survey around the Lake Victoria region to evaluate human and animal zoonotic and non-zoonotic disease in a rural farming community.	[40]
	17 12	0 (0) [‡] 1 (8.3) [‡]	Ag-ELISA	A cross-sectional study to determine the prevalence of cysticercosis and NCC among PWE (17) and PWOE (12) in a pig keeping community in Western Kenya.	[41]
Madagascar	73	6 (8.2) [‡]	EITB	Screening of peace corps volunteers for cysticercosis and NCC before their return from Madagascar.	[42]
	1751	485 (27.7)	Ag-ELISA	A cross-sectional study to investigate the prevalence of active cysticercosis and associated risk factors in school children (3-16years) in seven cities in Madagascar.	[43]
	2094	527 (25.2)	Ag-ELISA	An epidemiology study to evaluate cysticercosis seroprevalence in Madagascar in two groups. Group 1: All age groups (2–24) in Antananarivo, capital of Madagascar (n = 2094).	[44]
	2048	269 (13.1)	Ab-ELISA*		
	1760	489 (27.8)	Ag-ELISA	Group 2: Children aged between 3 to 16 years old from seven different cities (n = 1799).	
	1799	242 (13.4)	Ab-ELISA*		
		3619	76 (2.1)	Serology (not specified)	A retrospective study on 76 patients hospitalized for NCC in the pediatrics department of the Tamatave University Hospital Center to evaluate the epidemiological aspect of NCC.
237		35 (14.8)	Immunoblot	A cross-sectional descriptive study at the Regional Referral Hospital in Antsirabe to determine the seroprevalence of cysticercosis as well as its associated risk factors in patients from the region of Vakinankaratra with clinical suspicion.	[46]
543		166 (30.6) 12 (2.2)	Ag-ELISA EITB	A review of cysticercosis in Madagascar. Data for 2017 national survey in Infanadiana district.	[47]
Mozambique Mozambique	1723	267 (15.5) [‡]	Ag-ELISA	A cross-sectional study to estimate the prevalence of NCC in Angónia district, Tete province, Mozambique based on prevalence of human <i>T. solium</i> cysticercosis.	[48]
	601	61 (10.2)	Immunoblot	A cross-sectional serological study among HIV infected people in Beira (Ponta Gea Health Centre (PGHC)), located in the central part of the Mozambique.	[49]
Rwanda	211	46 (21.8) [‡]	Immunoblot	A health-facility based study in the southern province of Rwanda to determine the prevalence of NCC among PWE.	[50]
	572	76 (13.3)	EITB	A cross-sectional study conducted in 680 children from a rural primary school in Gakenke district, Northern province to assess the prevalence of <i>T. solium</i> taeniosis cysticercosis.	[51]
	71	27 (38)	Ag-ELISA		
South Africa	113	42 (37.2) [‡]	Immunoblot	A descriptive prospective study to survey the prevalence of NCC in PWE in Lusikisiki, Eastern Cape province.	[52]
	281	89 (32.6) [‡]	Ab-ELISA [‡]	A cross-sectional study of NCC prevalence among PWE at St Elizabeth hospital Eastern Cape province.	[53]
		15 (7.9)	Ag-ELISA		
Tanzania	20	6 (30) [‡]	Ag-ELISA	A cross-sectional study to assess the prevalence of NCC among PWE in northern Tanzania.	[54]
	830	139 (16.7) [‡]	Ag-ELISA	A cross-sectional study to determine prevalence and risk factors of human <i>T. solium</i> infections in Mbeya Region of Tanzania.	[55]
		376 (45.3)	Ab-ELISA*		
	218	6 (2.8) [‡]	Immunoblot	A cross-sectional study among PWE in a door-to-door study in an established demographic surveillance site in Hai district North East Tanzania.	[56]
	404	10 (2.5)	EITB	A cross-sectional study to estimate the prevalence of and factors associated with <i>T. solium</i> infections among HIV+ and HIV—individuals in Mbulu district, northern Tanzania.	[57]
		3 (0.7)	Ag-ELISA		
	302	3 (0.99)	Ag-ELISA	A cross-sectional study to investigate the presence and prevalence of TSTC in PWE in Dar es Salaam.	[58]
		8 (2.65)	EITB		
	528	9 (1.7)	Immunoblot	Tanzania results from a multi-center case-control study using prevalent cases of ACE identified from HDSS in Tanzania, Kenya, Uganda and South Africa.	[59]
1051	171 (16.3) [‡]	Immunoblot	A cross-sectional study conducted to determine the status and health burden of NCC in Mbulu district.	[60]	

(Continued)

Table 3. (Continued)

Country	No. Tested	Prevalence	Method	Comment	Reference
		No. (%)			
Uganda	84	2 (2.4)	Immunoblot	Uganda results from a multi centre case-control study using prevalent cases of ACE identified from HDSS in Tanzania, Kenya, Uganda and South Africa.	[61]
Zambia	708	41 (5.8)	Ag-ELISA	A community-based cross-sectional survey to determine the prevalence of human taeniosis and cysticercosis in Petauke district in Eastern province.	[62]
	867	(12.2–14.5)	Ag-ELISA	A prospective study conducted to ascertain the incidence of human cysticercosis in Katete district in Eastern province.	[63]
		(33.5–38.5)	EITB		
	56	22 (39.3) [‡]	EITB	A cross-sectional study to assess NCC prevalence among PWE in Katete district in Eastern province.	[64]
		13 (23.2)	Ag-ELISA		
9	9 (-)	Histopathology Full body dissection postmortem	A descriptive study looking at postmortem examinations of the past 12 months for cardiac cysticercosis and NCC in sudden and unexpected community deaths in Lusaka.	[65]	

ACE, Active convulsive epilepsy; Ab-ELISA, Antibody based ELISA; Ag-ELISA, Antigen based ELISA; EITB, Enzyme linked electroimmunotransfer blot; ELISA, Enzyme linked immunosorbent Assay; HDSS, Health demographic surveillance systems; HIV, Human immunodeficiency virus; NCC, Neurocysticercosis; No., Number; PWE, People with epilepsy; PWOE, People without epilepsy; TSTC, *T. solium* taeniosis cysticercosis.

*Antibodies detected using the rT24-ELISA

[‡]Antibodies detected using the IgG-ELISA

[§] Employed imaging in addition to serology.

<https://doi.org/10.1371/journal.pntd.0011042.t003>

The lowest point prevalence (0.7%) was also reported from Tanzania. For details on sources refer to Table 3.

Aggregated human neurocysticercosis. For reports presenting aggregated NCC cases (Table 4), 16 records were available. Four (25%) employed imaging (brain CT or MRI) only, whereas 11 (69%) incorporated both imaging and serological tests, and one (6%) was based on postmortem full-body dissection. The NCC-suggestive lesions on brain CT scans showed a

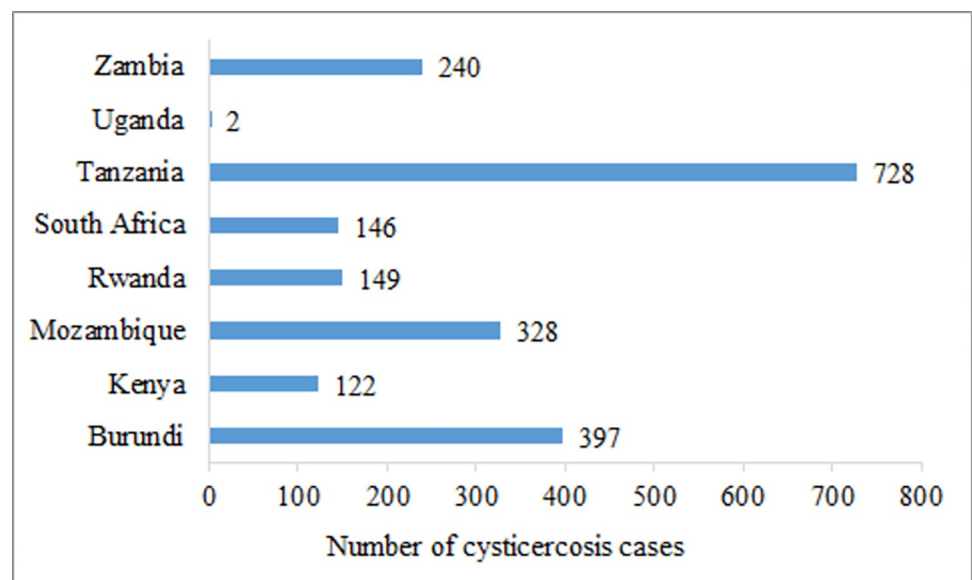


Fig 2. Aggregated human cysticercosis cases reported in community-based cross-sectional studies in Eastern and Southern Africa between the years 2000 and 2022.

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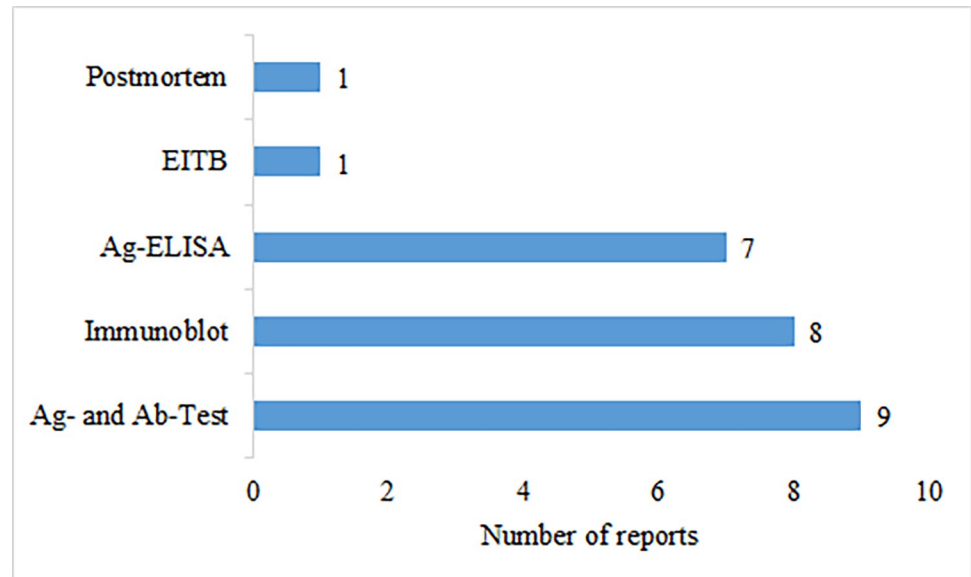


Fig 3. Diagnostic methods used for aggregated human cysticercosis cases in the included studies for Eastern and Southern Africa.

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proportion ranging between 1.0–76% in different study populations in ESA (Fig 6 and Table 4).

One report utilized MRI to identify lesions suggestive of NCC in HIV+ children. In this report, four children (8.5% of the total) were found to have NCC, with imaging suggesting the vesicular (active) stage of NCC in all of them [66].

Neurocysticercosis and epilepsy. Among the 16 records reporting aggregated NCC, eight (50%) reported data linking NCC and epilepsy (Table 5). Three of these records were reported from South Africa whereas one record each was reported from Kenya, Mozambique, Rwanda, Tanzania and Zambia. Three (33%) of these NCC epilepsy studies were community-based studies and six (67%) were conducted in hospital/health facility settings. The prevalence of NCC among people with epilepsy ranged between 0–61%. One study in Kenya in a *T. solium* endemic area found none of the participants with epilepsy had serological evidence of cysticercosis and none had radiographic findings consistent with NCC [41]. Whereas at St Elizabeth's Hospital, Lusikisiki, Eastern Cape, 61% of the patients presenting with epilepsy had NCC associated epilepsy, the prevalence being highest in the 10–19-year-old age group [52]. For details on sources refer to Table 5.

Human taeniosis. A total of 64 records were identified providing information on taeniosis cases in ESA for the period 2000 to 2022 (Table 6). These records were reported in 11 out of 27 ESA countries (Fig 7) with Ethiopia reporting the most records ($n = 38$) followed by Tanzania ($n = 6$) and Zambia ($n = 5$). Kenya and Uganda had three records each while Angola, Mozambique, and South Africa had two records each. Malawi, Madagascar and Rwanda had one record each. There were no cases reported from Botswana, Burundi, Comoros, Djibouti, Eritrea, Lesotho, Mauritius, Mayotte, Namibia, Reunion, Seychelles, Socotra, Somalia, Somaliland, Swaziland, and Zimbabwe.

Several groups of people were studied for human taeniosis with 25 records reporting taeniosis cases in school children, 18 records on patients presenting at health facilities, 15 on consenting community volunteers, and six on food handlers. There was great variation in aggregated numbers of human taeniosis cases across countries with 595 cases reported from

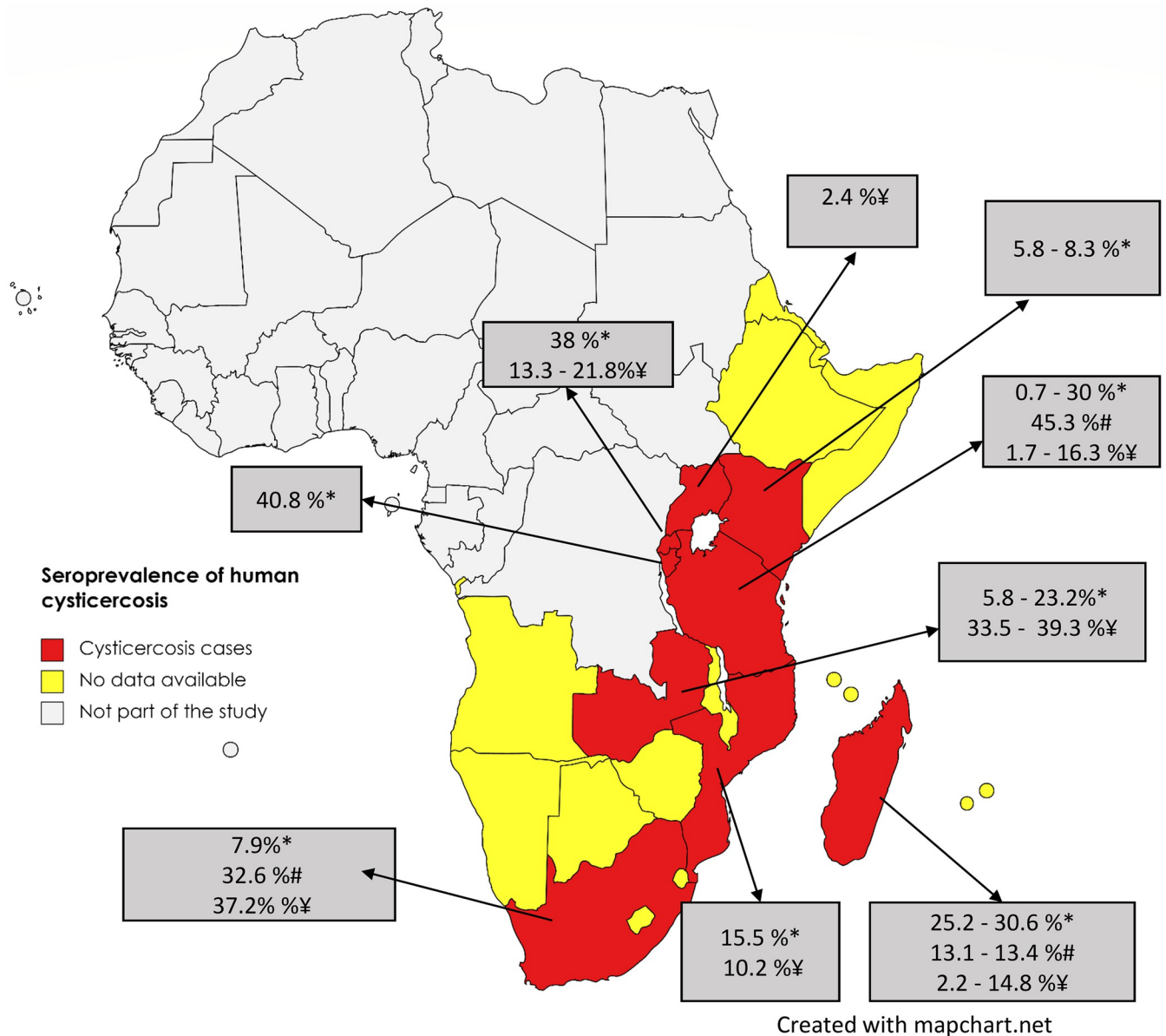


Fig 4. The distribution of human cysticercosis seroprevalence in the included studies for Eastern and Southern Africa (*Ag-ELISA, #Ab-ELISA, ¥Immunoblot). The maps were obtained from an openly available source, [Mapchart.net](https://www.mapchart.net/terms.html#licensing-maps) for free. Link: <https://www.mapchart.net/terms.html#licensing-maps>. Permission has been obtained from the owner).

<https://doi.org/10.1371/journal.pntd.0011042.g004>

Ethiopia alone and even more (4834) reported from Mozambique. The number of human taeniosis cases identified for the other nine countries in ESA is shown in (Fig 8).

The largest number of cases were reported as *Taenia* spp. (Table 6) without specifying the type of species. One record from Madagascar and another from Zambia, reported confirmed *T. solium* using PCR; [62,70]. Microscopy alone was employed for 53 studies, and copro Ag-ELISA alone in three studies. Five studies used both copro Ag-ELISA and microscopy for taeniosis diagnosis. Three studies used the rES33 EITB for the presence of a tapeworm antibodies in the body. Immunological data (copro Ag-ELISA or rES33 EITB) on taeniosis was only available from Kenya, Rwanda, Tanzania, and Zambia.

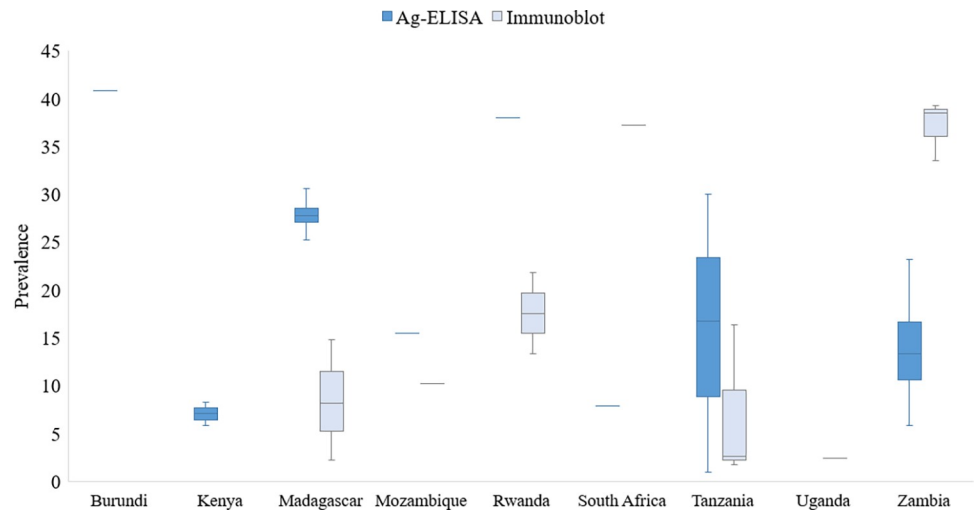


Fig 5. Prevalence of human cysticercosis in Eastern and Southern Africa based on serology data in reviewed studies with high variation observed in Madagascar, Rwanda, Tanzania and Zambia.

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Within the ESA region, the prevalence of human taeniosis based on microscopy ranged between 0.1–14.7% with the highest prevalence reported in a study conducted among food handlers at Wolkite University in Ethiopia [71] (Figs 7 and 9). Among studies based on copro Ag-ELISA conducted in Kenya, Rwanda, Tanzania, and Zambia, the highest prevalence was reported in Kenya at 19.7% [40]. Rwanda had a taeniosis prevalence of 1.4% [51], Tanzania ranged between 0.5 to 5.2% [55,72] [16], [22] and Zambia ranged between 0.3 to 13.8% [62,73] (Fig 10). For details on sources refer to Table 6.

Discussion

This study aimed at collecting epidemiological data on *T. solium* infections in humans in the ESA region for the period 2000 to 2022. For both cysticercosis and taeniosis, there was no data from Comoros, Djibouti, Eritrea, Mayotte, Reunion, Seychelles, Socotra, Somalia and Somaliland that could be retrieved. Seventy per cent of the Somali human population subsists in pastoralism with sheep and goats being the dominant animals. Camels are primarily raised for milk production and small ruminants are for generating cash income for the family [126]. Somalia has for some time now experienced internal conflicts and this may have a bearing on the diagnosis and reporting of human cysticercosis and taeniosis cases. In addition, Somaliland and Somalia are predominantly Muslim communities where pig rearing and pork consumption is prohibited [127]. For the other six island states and territories, a lack of *T. solium* research in reporting cases has been cited [128]. The same can be said about Botswana and Lesotho from which data on cysticercosis and taeniosis was also lacking. Cysticercosis data was lacking in even more countries.

According to the World Bank IBRD-IDA report of 2022 [129] the population using safely managed sanitation services for both Comoros and Djibouti only stood at 37% with no data for other island states. People practicing open defecation were higher in Eritrea (67%) with Somalia reporting (23%) and Djibouti (16%). On the Réunion island, pork is said to be the most popular meat with a total annual pork consumption of about 20 000 tones. Half of this is produced on the island and the rest is imported frozen from Europe [130]. Comoros on the other hand has a small livestock sector with most of its meat including pork imported from Tanzania, Madagascar and France [131]. For Mayotte, Eritrea and Djibouti, information on

Table 4. Aggregated human neurocysticercosis cases as detected by Brain CT scan in eastern and southern Africa (2000–2022).

Country	No. Tested	Proportion	Comment	Reference
		No. (%)		
Kenya	17	0 (0) [‡]	A cross-sectional study to determine the prevalence of cysticercosis and NCC among PWE (17) and PWOE (12) in a pig keeping community in Western Kenya.	[41]
	12	1 (8.3) [‡]		
Madagascar	73	1 (1.4) [‡]	Screening of peace corps volunteers for cysticercosis and NCC before their return from Madagascar.	[42]
Malawi	98	1 (1)	Hospital study on patients presenting with a stroke in Blantyre hospital.	[67]
Mozambique	151	77 (51) [‡]	A cross-sectional study to estimate the prevalence of NCC in Angónia district, Tete province, Mozambique.	[48]
Namibia	117	96 (51.4)	An analytical cross-sectional study conducted among patients with a first seizure presenting to the casualty and medical in-patient wards of Oshakati hospital in northern Namibia.	[68]
Rwanda	211	46 (21.8) [‡]	A health-facility based study in the southern province of Rwanda to determine the prevalence of NCC among PWE.	[50]
South Africa	113	69 (61.1) [‡]	A descriptive prospective study to survey the prevalence of NCC in PWE in Lusikisiki, Eastern Cape province.	[52]
	92	34 (37) [‡]	A cross-sectional study of NCC prevalence among PWE at St Elizabeth hospital Eastern Cape province.	[53]
	75	14 (18.7)	A retrospective review of the brain CT findings in adults presenting with new-onset seizures in a tertiary hospital in Gauteng province.	[69]
Tanzania	212	68 (32.1) [‡]	A cross-sectional study to assess the prevalence of NCC among PWE in northern Tanzania.	[54]
	55	30 (54.6) [‡]	A cross-sectional study to determine prevalence and risk factors of human <i>T. solium</i> infections in Mbeya Region of Tanzania.	[55]
	200	8 (4) [‡]	A cross-sectional study among PWE in a door-to-door study in an established demographic surveillance site in Hai district North East Tanzania.	[56]
	25	19 (76) [‡]	A cross-sectional study conducted to determine the status and health burden of NCC in Mbulu district.	[60]
Zambia	49	20 (41) [‡]	A cross-sectional study to assess NCC prevalence among PWE in Katete district in Eastern province.	[64]
	34	3 (8.8) *	Observational study of cognition and HIV in children's hospital Lusaka. Three of 34 HIV+ participants and one of 13 controls were found to have neurocysticercosis.	[66]
	13	1 (7.7) *		
	9	9 (-) #	A descriptive study looking at postmortem examinations for the past 12 months for cardiac cysticercosis and NCC in sudden and unexpected community deaths in Lusaka.	[65]

CT, Computed tomography; HIV, Human immunodeficiency virus; NCC, Neurocysticercosis; No., Number; PWE, People with epilepsy; PWOE, People without epilepsy.

* NCC detected through use of MRI

NCC detected through full body dissection postmortem histopathology

[‡] Serology employed in addition to imaging

<https://doi.org/10.1371/journal.pntd.0011042.t004>

pig rearing could not be found as these countries focus mostly on cattle, sheep, goats, and camels [132]. However, for Eritrea, pig breeding has recently begun to be promoted [133] and so is the case for Seychelles whose 2011 census of agriculture showed that 2% (483/24770) of the households were raising pigs in small holdings [134]. While it is not possible to ascertain the presence or absence of human *T. solium* infections in these countries, there is a possibility that these infections do exist as pork consumption seems to be practiced and risk factors are present. Therefore, the numbers collected for this review represent an underestimation of the *T. solium* epidemiology for human disease in ESA.

Regarding human cysticercosis cases, *T. solium* tapeworm carriers being the source of *T. solium* eggs are the sole cause of infection in both rural and urban areas of the ESA region [10,135]. *T. solium* tapeworm carriers, if not treated, pose a risk to themselves if they ingest infective eggs leading to cysticercosis but can also pose a risk to other people in contact [70,136]. A study in Madagascar found that the overall prevalence of cysticercosis at a household level was 46% and 34% detected by Ab-ELISA and EITB respectively, in the same household where a tapeworm carrier was found [70]. Individual human cysticercosis cases were identified from a third of the 27 ESA countries. South Africa reported the highest number of

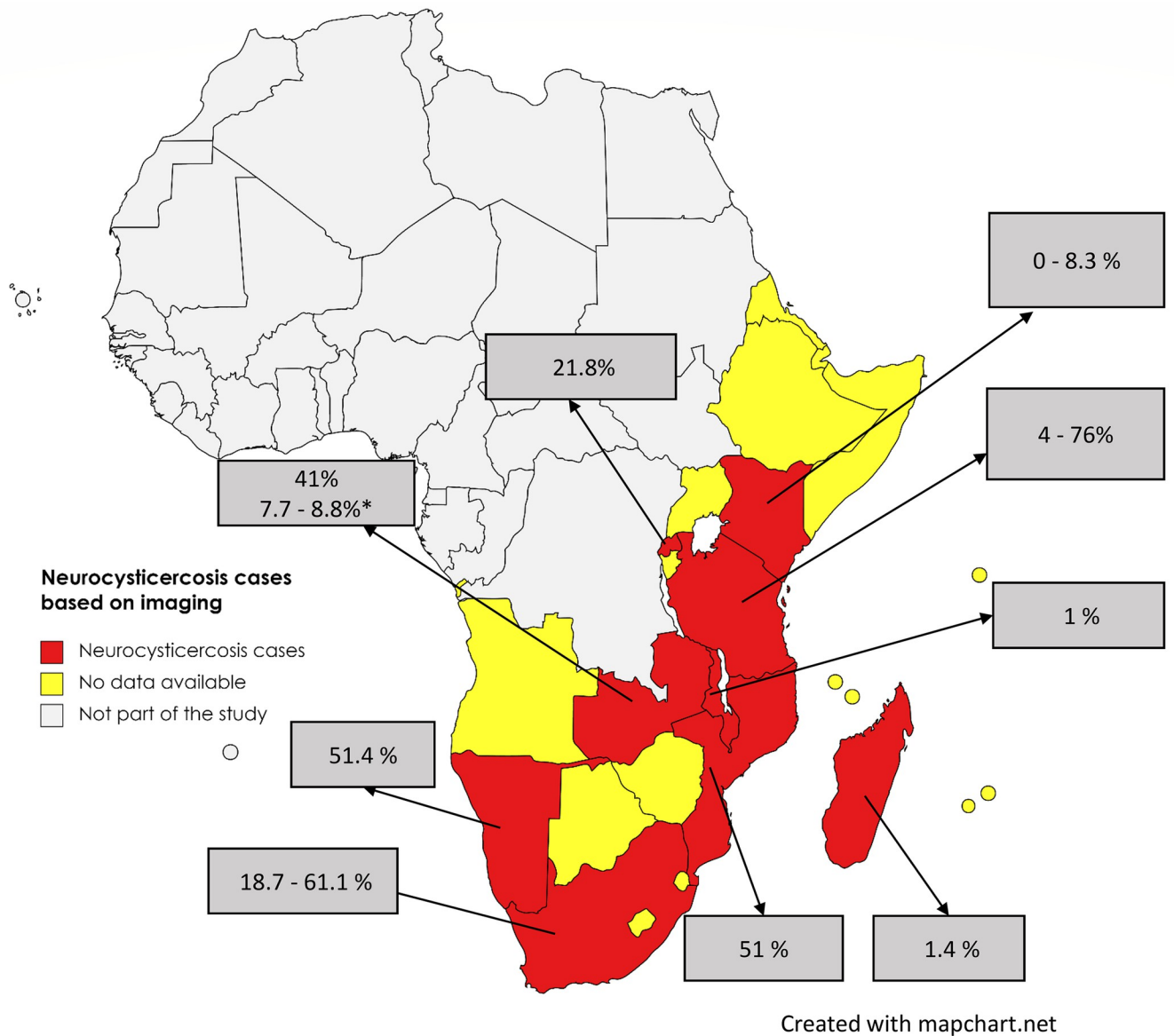


Fig 6. The distribution of human neurocysticercosis based on imaging data in reviewed studies in Eastern and Southern Africa. *Proportion based on MRI. (The maps were obtained from an openly available source, Mapchart.net for free. Link: <https://www.mapchart.net/terms.html#licensing-maps>. Permission has been obtained from the owner).

<https://doi.org/10.1371/journal.pntd.0011042.g006>

individual human cysticercosis cases followed by Madagascar. This could be due to increased awareness of cysticercosis as a possible diagnosis in, for example, people with epilepsy in these countries compared to other countries within the region. South Africa also has more resources to carry out testing compared to the other countries within the region. For example, as early as 2003 South Africa already had 214 CT scanners and 111 neurologists. This is an advantage in terms of diagnosis and management of particularly NCC that is not present in other countries within the region [137]. With poor pig management, poor meat inspection, and poor sanitation those who do not eat pork are equally at risk of infection with cysticercosis as those eating pork [138–140]. Additionally, certain cultural practices within the region have also been cited as contributing factors to cysticercosis. For example, in South Africa, it has been reported that

Table 5. Human neurocysticercosis with epilepsy as detected by Brain CT scan in eastern and southern Africa (2000–2022).

Country	No Tested	Proportion	Comment	Reference
		No (%)		
Kenya	17	0 (0) [‡]	A cross-sectional study to determine the prevalence of cysticercosis and NCC among PWE in a pig keeping community in Western Kenya	[41]
Mozambique	151	77 (51) [‡]	A cross-sectional study to estimate the prevalence of NCC in Angónia district, Tete province, Mozambique based on prevalence of human <i>T. solium</i> cysticercosis.	[48]
Rwanda	211	46 (21.8) [‡]	A health-facility based study in the southern province of Rwanda to determine the prevalence of NCC among PWE.	[50]
South Africa	113	69 (61.1) [‡]	A descriptive prospective study to survey the prevalence of NCC in PWE in Lusikisiki, Eastern Cape province.	[52]
	92	34 (37) [‡]	A cross-sectional study of NCC prevalence among PWE at St Elizabeth hospital Eastern Cape province.	[53]
	75	14 (18.7)	A retrospective review of the brain CT findings in adults presenting with new-onset seizures in a tertiary hospital in Gauteng province.	[69]
Tanzania	212	68 (32.1) [‡]	A cross-sectional study to assess the prevalence of NCC among PWE in northern Tanzania.	[54]
Zambia	49	20 (41) [‡]	A cross-sectional study to assess NCC prevalence among PWE in Katete district in Eastern province.	[64]

CT, Computed tomography; NCC, Neurocysticercosis; PWE, People with epilepsy.

[‡] Serology employed in addition to imaging

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some unqualified traditional healers "baloi" used *Taenia* segments and added them to medicinal mixtures as strengthening ingredients. There are also reports of *T. solium* segments being added to the beer of unfaithful husbands or lovers as punishment [137].

NCC has been associated with up to 57% of epilepsy cases in sub-Saharan Africa to which the region under consideration belongs [7,64]. This is higher than the global average of 30% of NCC among PWE [6]. For most countries within ESA, the diagnosis of NCC is problematic due to the scarcity of neuroimaging, serology and trained neurologists [141,142]. This diagnostic challenge is not only present in ESA but also in Europe where a lack of awareness of NCC leads to underdiagnoses [143]. Only a quarter of the countries within the ESA reported data on NCC and epilepsy. Epilepsy is one of the most common neurological disorders in many parts of sub-Saharan Africa and NCC seems to be a major cause of it in *T. solium* cysticercosis endemic areas. Diagnosing NCC among people with epilepsy is vital to prevent further morbidity and mortality from the disease as well as to reduce the social stigma associated with epilepsy in the region [141,144–146].

Regarding human *T. solium* taeniosis in ESA, only Kenya, Madagascar, Rwanda, Tanzania, and Zambia conducted community-based studies and employed serological tests that specifically aimed at determining the burden of infection. The other countries reported data on taeniosis as incidental findings following microscopic examinations of stool samples conducted for soil-transmitted helminths. The reported human taeniosis cases were also reported on an aggregated level without evidence of species determination. Thus, cases reported as either taeniosis or *Taenia* spp. could not for instance be differentiated from cases due to *Taenia saginata* which is also widely distributed in ESA [128]. Only two studies, one from Madagascar and another from Zambia were able to confirm the *T. solium* species after collecting tapeworm proglottids [62,70].

This lack of species differentiation creates uncertainty regarding the epidemiology of *T. solium* infections in ESA. Therefore, the prevalence of *T. solium* taeniosis in the region may be overestimated as most *Taenia* spp. diagnoses could be *T. saginata* as beef is consumed in most countries, while in some regions, the consumption of pork is prohibited for religious reasons. This is worsened by the fact that *T. solium* taeniosis is not even a notifiable disease in most of these countries. Application of molecular methods to differentiate *T. solium* species on stool

Table 6. Aggregated human taeniosis cases detected by stool microscopy and reported as *Taenia* spp. in eastern and southern Africa (2000–2022).

Country	No. Tested	Prevalence No (%)	Comment	Reference
Angola	1237	1 (0.1)	A cross-sectional study of 1,237 preschool children (0–5 year olds), 1,142 school-aged children (6–15 year olds) and 960 women (15 year olds) conducted to understand the distribution of malnutrition, anemia, malaria, schistosomiasis (intestinal and urinary) and geohelminths in north-western province.	[74]
	1142	2 (0.2)		
	960	1 (0.1)		
	328	2 (0.6)	A cross-sectional study conducted among 328 children attending a primary school in Lubango.	[75]
Ethiopia	93	4 (4.3)	A cross-sectional study among food handlers in Awassa town.	[76]
	372	2 (0.5)	A cross-sectional study among HIV infected and non-infected patients in Jimma zone.	[77]
	1021	14 (1.4)	A cross-sectional community based parasitological survey conducted among population living around the Gilgel Gibe dam catchment areas.	[78]
	248	2 (0.8)	A cross-sectional study among HIV negative subjects in Bahir Dar city.	[79]
	459	13 (2.8)	A cross-sectional study to assess the magnitude and pattern of intestinal parasitism in lowland (2.8%) and highland (1.2%) dwellers in Gamo area, south Ethiopia.	[80]
	399	5 (1.2)	A cross-sectional study to assess prevalence of intestinal parasites infection and associated risk factors among school children in Dagi primary school.	[81]
	399	28 (7)		
	343	14 (4.1)	A cross-sectional study to determine the prevalence of intestinal parasitic infections in patients living with HIV/AIDS at Hawassa University referral hospital.	[82]
	778	10 (1.3)	A cross-sectional study among 12 primary schools in Bahir Dar region.	[83]
	121	5 (4.1)	A cross-sectional study among prison inmates (4.1%) and tobacco farm workers (0.9%) in Northcentral Ethiopia.	[84]
	115	1 (0.9)		
	385	6 (1.6)	A cross-sectional study among elementary school children in Sanja, northwest Ethiopia.	[85]
	415	1 (0.2)	A cross-sectional study among TB patients in Gondar hospital.	[86]
	272	1 (0.4)	A cross-sectional study among food handlers in food establishments at Hassawa University.	[87]
	260	1 (0.4)	A cross-sectional study among diarrhea children at Jimma health centre.	[88]
Ethiopia	400	3 (0.8)	A cross-sectional study among children of selected primary schools in Chencha town south Ethiopia.	[89]
	307	4 (1.3)	A cross-sectional study among university students at Mekelle University.	[90]
	32,191	322 (1.0)	A retrospective observational study of all stool samples examined for parasites from patients presenting with diarrhea in the period 2007–2012 at Gambo Rural hospital.	[91]
	464	4 (0.9)	A cross-sectional study among patients attending at Anbesame health center, South Gondar.	[92]
	374	20 (5.3)	A cross-sectional study among school children in Dawro Zone, Southern Ethiopia.	[93]
	95	4 (4.2)	A cross-sectional study to determine the prevalence of intestinal parasite among HIV/AIDS patients attending ART clinic at Arba Minch hospital southern Ethiopia.	[94]
	345	14 (4.1)	A cross-sectional study among food handlers at Arba Minch University student's cafeteria, South Ethiopia.	[95]
	401	2 (0.5)	A cross-sectional study among preschool-aged children in Chuahit, Dembia district, Northwest Ethiopia	[96]
	173	4 (2.3)	A cross-sectional study among HIV infected individuals in Wolaita Sodo hospital.	[97]
	503	13 (2.6)	A cross-sectional parasitological and malacological survey among school children in Wolaita zone south Ethiopia.	[98]
	94	2 (2.1)	A cross-sectional study among food handlers at cafeteria of Jimma University specialized hospital.	[99]
	427	2 (0.5)	A cross-sectional study among patients seen at Adwa health centre North Ethiopia.	[100]
	279	2 (2.4)	A cross-sectional study among primary school children of Haike primary school Northeast Ethiopia.	[101]
	256	3 (1.2)	A cross-sectional study conducted at University of Gondar hospital to assess the prevalence of intestinal parasites among pulmonary tuberculosis suspected patients.	[102]
	213	5 (2.3)	A cross-sectional study among TB patients in Arba Minch facility.	[103]
	108	5 (4.6)	A cross-sectional study to compare prevalence of intestinal parasites and associated factors among adult pre-ART (4.6%) and on ART (2.0%) patients in Goncha Siso Enesie Woreda, East Gojjam, Northwest Ethiopia.	[104]
	204	4 (2.0)		
	Ethiopia	280	8 (2.9)	A cross-sectional study to determine the prevalence of schistosomiasis and other intestinal helminthiasis among school children and free ranging vervet monkeys in Bochessa area, Ziway. Results for school children.
247		1 (0.4)	A cross-sectional study to assess intestinal parasitic infections among under-five children attending in Debre Birhan referral hospital, Northeast Ethiopia.	[106]
391		4 (1.0)	A cross-sectional study conducted among primary school children in Arbaminch Zuria district.	[107]
273		6 (2.2)	A cross-sectional study among rural school children in Northwest Ethiopia.	[108]
170		25 (14.7)	A cross-sectional study among food handlers at Wolkite University.	[71]
406		12 (3)	A cross-sectional study among primary school children in Jawi town, northwest Ethiopia.	[109]
200		3 (1.5)	A cross-sectional study among food handlers at Wollo University Northeastern Ethiopia.	[110]
383		5 (1.3)	A cross-sectional study conducted among Gara Riketa primary school children at Hawassa Tula Sub-City, Southern Ethiopia.	[111]
525		11 (2.1)	A cross-sectional study in three primary schools in Sululta after deworming.	[112]

(Continued)

Table 6. (Continued)

Country	No. Tested	Prevalence	Comment	Reference
		No (%)		
Kenya	797	1 (0.13)	A cross-sectional study to determine a baseline prevalence of IPIs among children of five years and below at Webuye HDSS area in western Kenya.	[113]
	2113	416 (19.7) * 6 (0.3)	A cross-sectional survey around the Lake Victoria region to evaluate human and animal zoonotic and non-zoonotic disease in a rural farming community.	[40]
	310	17 (5.5)	A cross-sectional study among school children in lodwa municipality Turkana county.	[114]
Madagascar	459	10 (2.2) #	A cross-sectional study aimed at assessing the prevalence of <i>T. Solium</i> infections and associated risk factors in twelve remote villages surrounding Ranomafana national park, Ifanadiana district.	[70]
Malawi	190	4 (2.1)	A cross-sectional survey among preschool children in Mangochi district.	[115]
Mozambique	269	1 (0.4)	A cross-sectional study among children living in urban environs of Maputo and attending the health clinic at xipamanine.	[116]
	83,331	4833 (5.8)	A cross-sectional study among school children across the country.	[117]
Rwanda	144	2 (1.4) *	A cross-sectional study conducted in 680 children from a rural primary school in Gakenke district, Northern province to assess the prevalence of <i>T. solium</i> taeniosis cysticercosis.	[51]
South Africa	510	- (0–1.4)	A cross-sectional study conducted to estimate the prevalence of fecal helminths in a series of rural and urban African school pupils residing at a relatively high altitude above sea level.	[118]
	998	55 (5.6)	A cross-sectional study to determine the prevalence and risk factors of schistosomiasis and STH infection among preschool aged children aged 15 years in Ngwavuma area of Mkhanyakude district.	[119]
Tanzania	820	43 (5.2) * 34 (4.1) & 9 (1.1)	A cross-sectional study conducted in Mbozi area of Mbeya district. Of the stool samples testing positive for taeniosis by copro-Ag-ELISA, 34 (4.1%) were Ab positive against adult <i>T. solium</i> . <i>Taenia</i> eggs were detected in 9 (1.1%) stool samples by routine coprology.	[55]
	404	5 (1.2) &	A cross-sectional study to estimate the prevalence of and factors associated with <i>T. solium</i> infections among HIV+ and HIV— individuals in Mbulu district, northern Tanzania	[57]
	1517 1501	9 (0.6) * 7 (0.5)	Taeniosis estimates after 3 rounds of MDA for schistosomiasis in the two regions Mbozi (0.6%) and Mbeya (0.5%).	[120]
	1514 1500	12 (0.8) * 8 (0.5)	Repeated MDA to school aged children in Mbozi (0.8%) and school aged children in Mbeya (0.5%), Tanzania.	[72]
	302	5 (1.7) &	A cross-sectional study to investigate the presence and prevalence of TSTC in PWE in Dar es Salaam.	[58]
Uganda	162	1 (0.6)	A cross-sectional study among children attending Mwanamugimu nutrition unit of Mulago hospital, Kampala, Uganda.	[121]
	331	2 (0.6)	A cross-sectional study among slum dwellers without risk of flooding at least 2 km away from the Nakivubo wetland in Kampala.	[122]
	476	14 (2.9)	A cross-sectional study aimed at determining the prevalence and the outcomes (including anaemia) of intestinal parasitic infections and co-infections among children in Kiryandongo refugee camp.	[123]
Zambia	297	1 (0.3)	Prospective study conducted among HIV infected patients in Lusaka.	[124]
	403	4 (0.9)	A cross-sectional study to determine the prevalence and intensity of STH infections, intestinal protozoa and the presence of multiple infections in children attending preschool centres in Kafue district Zambia.	[125]
	718 712	2 (0.3) # 45 (6.3) *	A community-based cross-sectional survey to determine the prevalence of human taeniosis and cysticercosis in Petauke district in Eastern province.	[62]
	226	27 (11.9) *	A prospective study conducted to ascertain the incidence of human cysticercosis in Katete district in Eastern province.	[63]
	54	8 (14.8) *	A cross-sectional study to assess NCC prevalence among PWE in Katete district in Eastern province.	[64]

HDSS, Health and demographic surveillance system; HIV, Human immune deficiency virus; IPIs, Intestinal parasite infections; MDA, Mass drug administration; NCC, Neurocysticercosis; No., Number; PWE, People with epilepsy; STH, Soil transmitted helminths; TSTC, *T. solium* taeniosis cysticercosis.

*Detection by copro Ag-ELISA.

#*T. solium* species confirmed.

& Detection based on serology using EITB (rES33 immunoblot).

<https://doi.org/10.1371/journal.pntd.0011042.t006>

examination is not widely practiced and it is not possible to differentiate *Taenia* eggs based on microscopy [135,147]. More sensitive and specific diagnostic tools need to be used to identify the true prevalence and outline the epidemiology of *T. solium*.

Human taeniosis in the region is due to the high prevalence of porcine cysticercosis in ESA countries which is ranked amongst the highest in the world [10]. The pooled prevalence for porcine cysticercosis within the region was recently estimated to be as high as 27% by carcass dissection which is a gold standard technique for porcine cysticercosis diagnosis [11]. Over the last decade, pig production as a risk factor for human taeniosis in the rural communities of

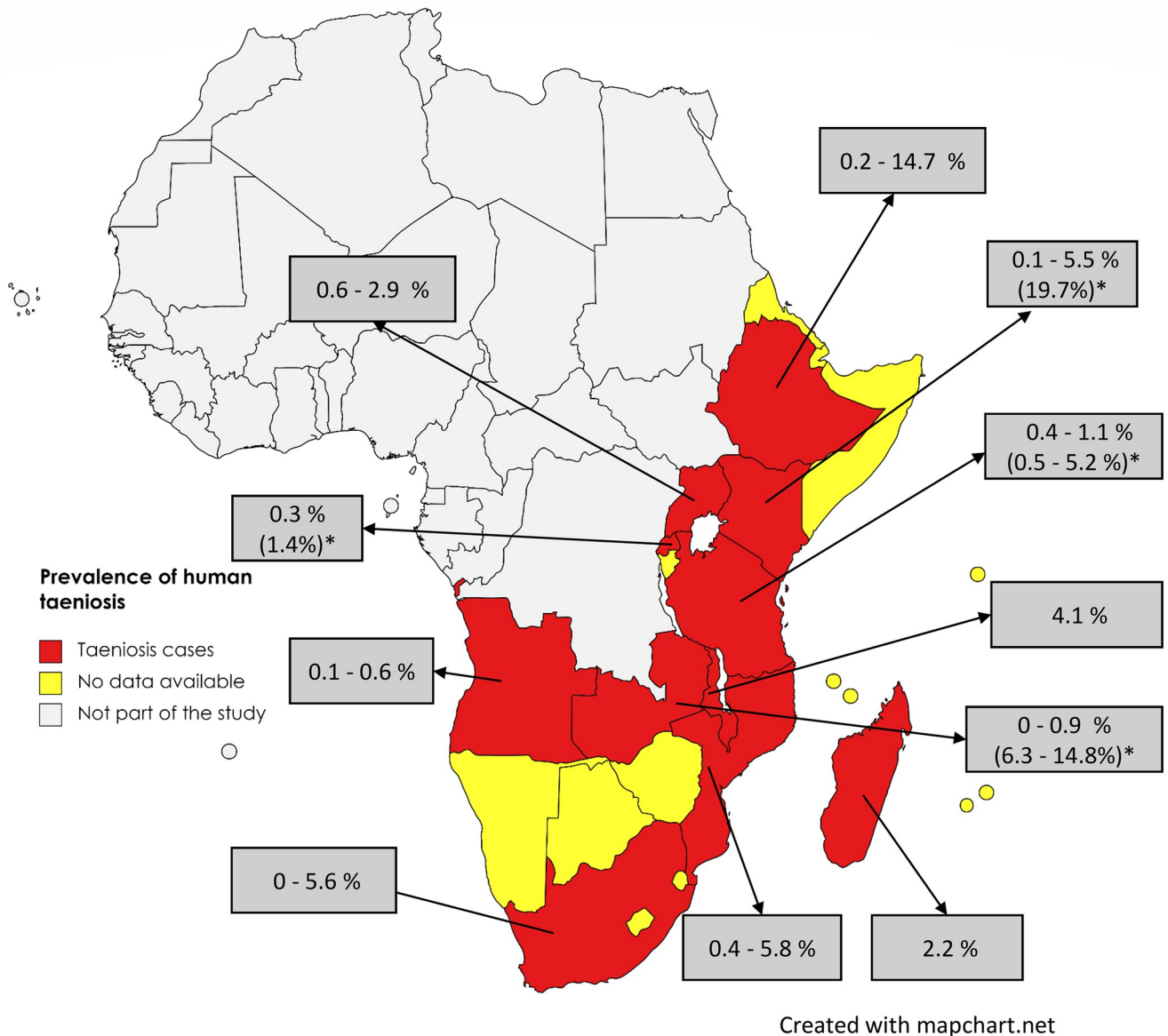


Fig 7. The distribution of human taeniosis in Eastern and Southern Africa showing prevalence data based on microscopy and *prevalence based on serology (rES33-immunoblot), and copro-Ag ELISA. (The maps were obtained from an openly available source, [Mapchart.net](https://www.mapchart.net/terms.html#licensing-maps) for free. Link: <https://www.mapchart.net/terms.html#licensing-maps>. Permission has been obtained from the owner).

<https://doi.org/10.1371/journal.pntd.0011042.g007>

ESA countries has increased mainly because pig raising is an attractive alternative to other animals as it does not require grazing land compared to ruminants. Free-range pig keeping is popular, especially in rural areas of the region as it is easy and cheap. This coupled with the general lack of slaughterhouses and inspection of pork with a lack of sanitation facilities has contributed to the risk for people to acquire taeniosis and cysticercosis [3,10,148].

Study limitation

Our study is limited by the fact that search platforms were used only for online publications. Thus, unpublished data which could have contributed significantly to a more nuanced picture

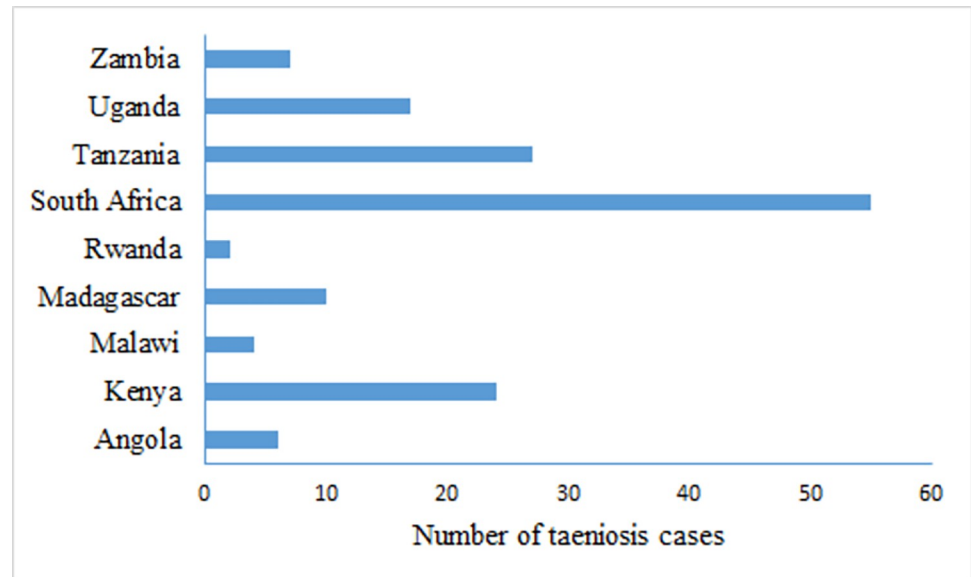


Fig 8. Taeniosis cases reported in Eastern and Southern Africa between 2000–2020.

<https://doi.org/10.1371/journal.pntd.0011042.g008>

of the epidemiology of human *T. solium* infections in ESA could have been missed. Another limitation of our study is the difficulty in comparing epidemiological data from different study populations using different diagnostic tests used and the different diagnostic approaches.

Conclusion

In this review on human *T. solium* taeniosis and (neuro) cysticercosis within ESA, we found wide variations in the prevailing prevalence estimates depending on the quality of the study and the diagnostic methods used. There remain large gaps with regards to *T. solium* infections within the ESA region with 11 countries without any information on human taeniosis and cysticercosis, and even more countries [18] without any information for cysticercosis.

Considering the public health and economic impact that *T. solium* infections have, it is important to understand its epidemiology in humans. Human taeniosis, cysticercosis and

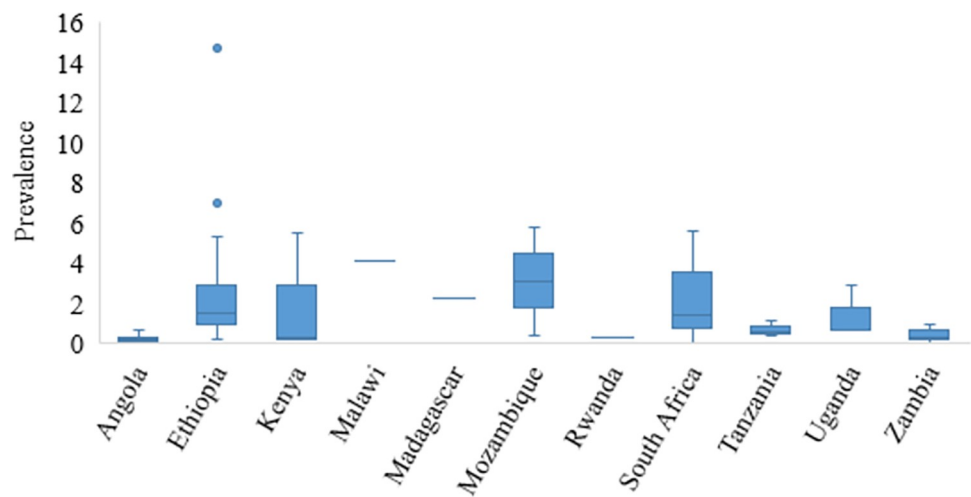


Fig 9. Prevalence of taeniosis in Eastern and Southern Africa based on microscopy data in reviewed studies.

<https://doi.org/10.1371/journal.pntd.0011042.g009>

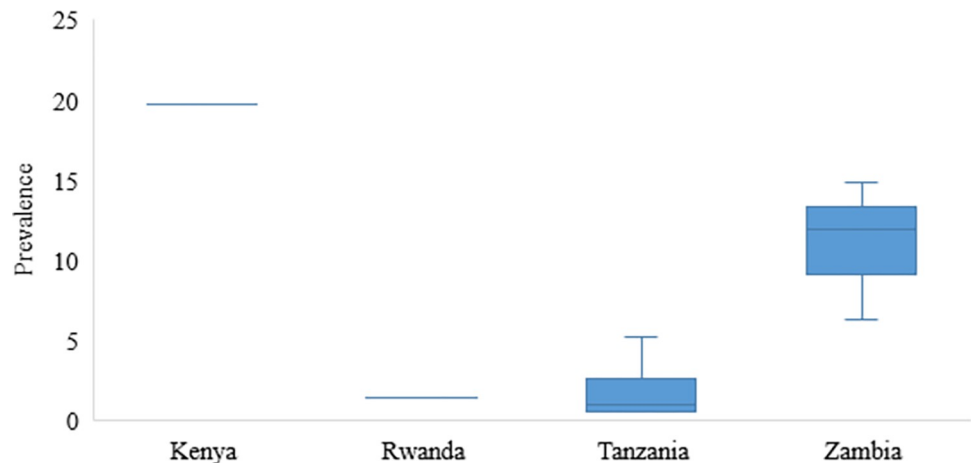


Fig 10. Prevalence of taeniosis based on copro-Ag ELISA in reviewed studies in Eastern and Southern Africa.

<https://doi.org/10.1371/journal.pntd.0011042.g010>

NCC cases need to be reported and notified to public health authorities. More community-based surveys as well as ante-mortem and postmortem porcine surveys must be conducted for control and surveillance purposes. Lack of awareness about the presence of *T. solium* among medical, community and government authorities including inadequate technology for diagnosis of taeniosis, cysticercosis and NCC, in both humans and pigs (cysticercosis) remains a challenge that needs to be addressed for proper surveillance, prevention and control.

Supporting information

S1 File. Documentation of literature search.

(DOCX)

S2 File. Data collection forms.

(DOCX)

S1 Table. PRISMA 2020 checklist.

(DOCX)

S2 Table. References retrieved through online international databases.

(XLS)

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