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REVIEW

# Human taeniasis: current insights into prevention and management strategies in endemic countries



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**Abstract:** Human taeniasis is a zoonotic condition resulting from infection with the adult stages of *Taenia saginata* ("beef tapeworm"), *Taenia solium* ("pork tapeworm") or *Taenia asiatica* ("Asian tapeworm"). Although these parasites have a worldwide distribution, the overwhelming burden is felt by communities in low- and middle-income countries. This is particularly true for *T. solium*, whereby infection of the central nervous system with the larval stage of the parasite (neurocysticercosis) is a major cause of acquired epilepsy in low-resource settings. With a focus on endemic countries, this review provides an insight into the prevention and management of human taeniasis, concluding with some recent case studies describing their implementation. Discussion of the opportunities and challenges regarding current fecal and serological diagnostic assays for detecting *Taenia* spp. highlights the importance of accurate and accessible diagnostic options for the field situation. The lack of long-term impact on the parasites' lifecycle from human anthelmintic treatment, coupled with the propensity for adverse reactions, highlights the importance of a "two-pronged" approach that considers the relevant animal hosts, particularly in the case of *T. solium*. Aside from the therapeutic options, this review reiterates the importance of adequate assessment and consideration of the associated behavioral and policy aspects around sanitation, hygiene and meat inspection that have been shown to support parasite control, and potential elimination, in endemic regions.

**Keywords:** *Taenia solium*, *Taenia saginata*, cysticercosis, zoonotic disease, neglected tropical diseases

## Introduction

Human taeniasis is a parasitic infection caused by tapeworms of the family Taeniidae (subclass Eucestoda, order Cyclophyllidea). Despite the disease having a worldwide distribution, the highest burden is borne by communities in the developing world. There are three human-infective members of the family Taeniidae; 1) *Taenia saginata*, the "beef tapeworm", 2) *Taenia solium*, the "pork tapeworm", and 3) *Taenia asiatica*, the "Asian tapeworm". Humans are the definitive host for these three species, harboring the adult tapeworm in the small intestine. Cattle are the vertebrate intermediate host for *T. saginata*, while the larval stage develops in pigs for *T. asiatica* and *T. solium*. Human cysticercosis develops when humans consume *T. solium* eggs from the surrounding environment and become infected with the *T. solium* larval stage, thus acting as an aberrant intermediate host.

Human taeniasis is generally asymptomatic,[1] although abdominal discomfort and weight loss have been reported,[2,3] and carriers may suffer some distress from observing proglottids in their feces, especially those of *T. saginata* that are motile.[1] Rarely

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reported sequelae to intestinal taeniasis include gall bladder perforation,[4] appendicitis[5] and bowel obstruction.[6,7] The key human health burden imposed by *Taenia* spp. results from infection with the larval stage of the pork tapeworm, *T. solium*. Ingestion of viable *T. solium* eggs leads to an aberrant encystment of the larval stage in various areas of the human body, with cysts in the muscular, subcutaneous, ocular and central nervous systems being the common manifestations. Of these, neurocysticercosis (NCC), the presence of a cyst or cysts within the central nervous system – commonly the brain – has the highest associated morbidity.

The 2010 Global Burden of Disease (GBD) survey estimated that human cysticercosis caused by *T. solium* was responsible for 503,000 (95% confidence interval [95% CI] 379,000–663,000) disability-adjusted life years (DALYs) lost annually.[8] This is likely to be an underestimation of the true burden however, given ~30% of epilepsy cases in endemic areas may be attributable to NCC.[9–11] Extrapolating the DALYs attributable to epilepsy from the 2010 GDB survey suggests that the DALYs attributable to *T. solium* should in fact be in the region of 2.7 million (95% CI 2.16–3.61 million).[12] Annually, *T. solium* is also thought to be responsible for ~28,000 deaths worldwide (95% CI 21,000–37,000).[12] The prevention and management of human taeniasis is key to the control of human cysticercosis, which in turn will result in a reduction of the worldwide epilepsy burden. This review concentrates on the management and prevention of human taeniasis within endemic country settings.

## Global distribution of human taeniasis

Valid epidemiological data are scarce for all *Taenia* species, with many studies failing to differentiate between species. Despite these knowledge gaps, it appears that zoonotic tapeworms of the family Taeniidae have a worldwide distribution, with the exception of *T. asiatica* that appears to be restricted to Asian countries.[13] *T. solium* has been effectively controlled in most of Europe, North America, Australia and New Zealand; however, autochthonous transmission – although rare – has been reported from the Iberian Peninsula and areas of Eastern Europe and North America.[14–16] The highest prevalence of *T. solium* is, however, found in the developing world, with the majority of Africa, Asia and Latin America being endemic for the parasite.[17,18] *T. saginata* has a more ubiquitous distribution, with reports from Europe,[14,19] New Zealand,[20] Australia[21] and throughout the developing world.[3] Prevalence of human taeniasis is incredibly variable across endemic areas, with a recent meta-analysis reporting prevalence ranges between 0% (95% CI 0–1.62) and 13.9% (95% CI 12.39–15.47) in Africa, 0.24% (95% CI 0.03–0.87) and 17.25% (95% CI 14.55–20.23) in Latin America and 0% (95% CI 0–1.74) and 3.02% (95% CI 1.90–4.53) in Asia.[17] These estimates have been made using a variety of diagnostic methods, including direct fecal examination, coprology, formal ether concentration, Kato–Katz and copro-antigen (copro-Ag) enzyme-linked immunosorbent assay (ELISA), all of which have different levels of specificity and sensitivity in taeniasis detection, as described later.

## Diagnosis of human taeniasis

Traditional diagnosis of adult *Taenia* carriers relies upon direct microscopy of expelled eggs in feces, with or without prior concentration, such as in formal ether. Despite the relative ease with which this diagnostic method can be undertaken in resource-limited settings, a major disadvantage of this is the sensitivity of microscopy, due to the intermittent nature of egg shedding; published sensitivity estimations range from ~3.9%[22] to 52.5%.[23] Furthermore, while the specificity of microscopy is high at the species level, speciation requires observation of expelled proglottids, given *Taenia* spp. eggs appear identical under a light microscope.[24,25] In order to improve the detection of taeniasis cases, a range of immunodiagnostic assays on fecal or sera samples have been developed, resulting in a great improvement in the sensitivity and specificity of diagnostic approches.[26]

Copro-Ag diagnostics, based upon the detection of parasite-specific secretory antigens, was first reported in the 1960s; however, it did not gain widespread scientific attention until the 1980s.[26] Copro-Ag detection relies on the presence of specific secretory antigens produced independently from reproductive material and, therefore unlike microscopy, does not depend on the active shedding of eggs or proglottids for infection detection. Copro-Ag ELISA has now been successfully demonstrated in a variety of situations to detect *Taenia* spp. carriers. A field trial in Mexico achieved a sensitivity/specificity (Se/Sp) of 98.0%/99.2% with copro-Ag ELISA, in comparison to a 38.0% sensitivity achieved with microscopy.[22] One limitation of the copro-Ag ELISAs currently available is that they are not species-specific; that is, they cannot differentiate between *T. solium* and *T. saginata*.[27] Furthermore, cross-reactions have been reported with a variety of other gastrointestinal parasites including *Ascaris lumbricoides*, *Trichuris trichiura*, *Hymenolepis nana* and parasitic protozoa.[23] To obtain species-specific diagnosis, work has been done on DNA-based diagnostics. A rapid nested polymerase chain

reaction (PCR) assay, using primers based on the published gene sequence of the *T. solium* oncospheral protein Tso31, achieved 100% specificity and 97%–100% sensitivity, including under field conditions.[28]

Given the inherent problems associated with diagnostic assays on fecal material, particularly regarding biohazards and cultural acceptability, there is undoubtedly a place for the serological diagnosis of adult *Taenia* spp. carriers. This has been achieved with an immunoblot assay for the detection of antibodies toward *T. solium* excretory secretory (TSES) antigens. The assay achieved Se/Sp of 95%/100% when used to analyze sera of known infection status, including sera from *T. saginata* carriers and echinococcosis infections.[25] The use of native proteins, however, was a limitation on the utility of this test in the field, and recombinant proteins have now been expressed in a baculovirus system for use in diagnostic assays.[29] These protein antigens (rES33 and rES38) are currently being used in an enzyme-linked immunoelectrotransfer blot (EITB) format in a recent Peruvian cysticercosis elimination program, both having shown high sensitivity (97%/98%) and specificity (100%/91%, respectively) in field trials.[30]

## Treatment of human taeniasis

Infections with the adult stage of *Taenia* spp. are responsive to the common anthelmintic drugs niclosamide (2 g/person as a single dose), praziquantel (5–10 mg/kg as a single dose),[31,32] tribendimidine (200 mg per <15 years or 400 mg per adult single oral dose)[33] and albendazole (3 × 400 mg/person for three consecutive days).[34] Triple-dose albendazole has been demonstrated to cure 100% of *Taenia* spp. cases,[34] whereas niclosamide and praziquantel have demonstrated efficacy of 85% and 95%, respectively.[35] Praziquantel and niclosamide have become the anthelmintic treatment of choice for taeniasis, with praziquantel appearing to be the most cost-effective treatment at $0.05–0.1/person,[36] compared to niclosamide at ~$5/person.[37] Reported minor side effects of praziquantel are abdominal pain, dizziness and diarrhea,[38] though there are also concerns that due to the ability of praziquantel to cross the blood–brain barrier (BBB), there may be neurological consequences due to activation of undiagnosed latent NCC.[39] Despite these concerns, no side effects were reported in a Tanzanian study in which school children were treated with 40 mg/kg praziquantel in an area jointly endemic for cysticercosis and schistosomiasis.[40] Neurological side effects are a potential danger in albendazole treatment that also crosses the BBB;[41] niclosamide, conversely, has little systemic absorption and therefore has no effect on NCC.[42]

## Control strategies for human taeniasis

### Preventative chemotherapy (PC) in humans

Treatment of taeniasis as a strategy to control the parasite burden in a target population is known as PC and can be implemented in three ways. Mass drug administration (MDA) occurs when the whole population of a predefined geographical area is treated at regular intervals, irrespective of clinical status. In contrast, targeted chemotherapy treats only specific risk groups at regular intervals, while selective chemotherapy screens patients and subsequently treats according to clinical status.[43]

Several studies have been undertaken to investigate the use of MDA as a control strategy for *T. solium*, either alone or in combination with other strategies[44–51] and are outlined in Table 1. Over the short-term – defined as within 2 years – a reduction in taeniasis prevalence has been demonstrated in most studies, although the effect on human and porcine cysticercosis (where measured) has been more variable.[52] Modeling data suggest that one-off MDA programs alone are unlikely to lead to sustained control of *T. solium*, with rapid reduction in prevalence being followed quickly by a rebound to previous levels.[53] When MDA has been used in combination with other strategies such as porcine vaccination and/or oxfendazole treatment, however, a sustained reduction in human taeniasis and porcine cysticercosis prevalence has been demonstrated, as will be discussed later in this review.[51,53–55]

Selective chemotherapy has been recommended as an integral part of *T. solium* control,[42,56–58] especially in areas with high (>70%) primary health care coverage,[59] with modeling data suggesting that this alone could lead to a sustained reduction in prevalence.[53] As yet, however, there are only two field trials involving selective chemotherapy, both of which occur as part of a combined strategy with targeted MDA in school children. In Honduras, the study demonstrated a significant reduction in NCC as an etiology of epilepsy over an 8-year period.[60] A shorter study in Tanzania reported >77% reduction in prevalence of taeniasis in the 22 months after either a single or a double round of MDA.[40]

### Vaccination and anthelmintic treatment of the porcine or bovine host

Vaccines have been developed against the larval infection of *T. solium* in the porcine host, with two of these (SP3VAC and TSOL18) demonstrating high efficacy in protecting pigs from

**Table 1** Summary of available studies investigating human PC as a control strategy for human taeniasis/cysticercosis

| Year, country, reference | Human PC | Ancillary strategy | Reduction in prevalence/incidence | | | Coverage achieved | Follow–up period |
|---|---|---|---|---|---|---|---|
| | | | Taeniasis | Human cysticercosis | Porcine/bovine cysticercosis | | |
| 1978–1983, China[46]* | Yearly MDA with agimorphol | N/A | 90.8% reduction in incidence | 96.8% reduction in incidence | Not reported | Not reported | 6 years |
| 1978–1988, China[35]* | Bi-annual targeted treatment of *Taenia* spp. carriers praziquantel | Confinement of pigs and health education | 98.7% reduction in prevalence | Not reported | 96.5% reduction in porcine prevalence | Not reported | 10 years |
| 1986–1987, Ecquador[124] | One round of praziquantel 5 mg/kg | N/A | 100% reduction in prevalence | Not reported | 77.2% reduction in porcine prevalence | 75.8% | 1 year |
| Mexico[50]** | MDA praziquantel 5 mg/kg | Health education | Not reported | Not reported | 66% increase in porcine prevalence (from 6.6% to 11%) | 60% | 2 years |
| 1988–1989, Mexico[47] | One round of MDA praziquantel 10 mg/kg | N/A | None found (non-significant) | 74.1% reduction in prevalence in 30–39 years age group | None found (non-significant) | 71% | 1 year |
| 1991–1996, Mexico[125] | One round of MDA praziquantel 5 mg/kg | N/A | 56% reduction in prevalence | 75% reduction in prevalence | 55% reduction in prevalence*** | 87% | 42 months |
| 1994–1996, Guatemala[48] | One round of MDA niclosamide (2 g >6 years, 1 g <6 years) | N/A | 71.4% reduction in prevalence | Not reported | 87.3% reduction in porcine prevalence | 74.9% | 10 months |
| Years not reported, Mexico[126] | One round of MDA praziquantel 5 mg/kg | Health education | 68% reduction in prevalence | Not reported | 50–100% reduction in porcine prevalence | Not reported | 3 years |
| | | N/A | 68% reduction in prevalence | | No change | | |
| 1996, Peru[51] | One round of MDA praziquantel 5 mg/kg | Two rounds of porcine MDA oxfendazole 30 mg/kg | Not reported | Not reported | Protective intervention compared to control village (OR 0.51, $p<0.001$) | 75% human, 90% porcine | 20 months |
| 1997–2005, Honduras[60] | MDA of school children albendazole (three daily doses 400 mg) followed by single dose q.6 months | Selective treatment of *Taenia* spp. carriers with niclosamide 2 g, health education and latrine construction | 89.3% reduction in prevalence | 63.2% reduction in NCC as the etiology of epilepsy | Not reported | Not reported | 8 years |
| 2004–2009, Peru[123] | Three rounds of MDA nicolamide 2 g | Six rounds of porcine MDA oxfendazole 30 mg/kg plus 3× TSOL18 vaccination | Not reported | Not reported | Porcine cysticercosis eliminated in 105 villages | 84.7% (human) | 1 year post-intervention |
| 2012–2013, Tanzania[40] | One round of MDA school children praziquantel 40 mg/kg<br>Two rounds of MDA school children praziquantel 40 mg/kg | Selective chemotherapy of *Taenia* spp. carriers | 80% reduction in prevalence 10 months after MDA; 77% reduction (from baseline) after 22 months<br>73.3% reduction in prevalence | Not reported | Not reported | | 22 months |
| 2013–2014, Lao PDR[54] | Two rounds of MDA albendazole 3 × 400 mg | Three rounds of porcine vaccination (TSOL18) and MDA oxfendazole 30 mg/kg | 78.7% reduction in prevalence | Not reported | Not reported | 85% (human), 75% (porcine) | 27 months |

**Notes:** Adapted from *Landscape Analysis: Control of Taenia solium*, Thomas LF, Copyright (2015)..[52] *Review, **abstract only available, ***significant reduction at 6 months, no significant change between 6 and 42 months.
**Abbreviations:** PC, preventative chemotherapy; MDA, mass drug administration; N/A, not available; OR, odds ratio; NCC, neurocysticercosis.

both experimental and natural challenges.[61–71] One limitation of current vaccine options is that neither destroys existing cysts; in order to impact porcine cysticercosis infections acquired prior to the first round of vaccination, it is therefore suggested to combine porcine vaccination with oxfendazole treatment at a cysticidal dose of 30 mg/kg. This combination of TSOL18 vaccination and a high-dose oral oxfendazole administration demonstrated complete protection from infection when used in a field trial in Cameroon.[55] TSOL18 vaccine has recently been commercialized (Cysvax$^{\grave{O}}$) with support from GALVmed, Indian Immunologicals Limited and the University of Melbourne, and production at commercial levels has been initiated. Approval for its use in India is now underway and approval across Africa is expected by 2020.[52]

Vaccination of cattle against *T. saginata* has been attempted with some success, with the TSA9/TSA18 vaccine demonstrating high efficacy in protecting cattle from infection.[72–75] Commercialization of this vaccine is, however, not currently being pursued, as the available evidence does not indicate it to be commercially viable.[71,76]

Treatment of the larval stage of *T. solium* can be achieved through the use of anthelmintic treatment, with oxfendazole (30 mg/kg) demonstrating the best efficacy.[77–81] Oxfendazole has no reported side effects,[77] has now been approved in many countries and is now being formulated specifically as Panthic 10% for this indication in pigs.[52] Bovine cysticercosis also responds to anthelmintic treatment with praziquantel,[82–84] and protection against re-infection appears to last at least 12 weeks.[85] Despite the efficacy of this anthelmintic treatment in cattle, praziquantel has not yet been formulated for cattle and is therefore not commercially available as a control measure for *T. saginata*.

## Meat hygiene

Meat hygiene, achieved through stringent inspection and correct processing or cooking, is fundamental to the prevention of human infection with *Taenia* spp. from both pork and beef. Regulations exist in many countries guiding the inspection of meat prior to sale, including visual inspection for cysticerci.[86] In the European Union (EU), regulation 854/2004 lays out the requirements for ante- and postmortem inspection of animals for human consumption, including cattle and pigs. In pigs, no incisions into the musculature are required for this testing, with a visual-only inspection allowed if the food chain information indicates that the pigs were raised in controlled housing conditions, reflecting the low risk of porcine cysticercosis within this region.[87] Currently, the legislation for cattle requires both visual inspection of carcass surfaces (external and internal, including the diaphragm) and incision and examination of various cysticerci predilection sites including the mandible, masseters and heart, as well as palpation of the tongue.[87] Changes in legislation are currently in progress that would allow for the visual-only inspection of cattle carcasses, a move which the European Food Safety Authority (EFSA) panel on biological hazards (BIOHAZ) concluded would likely only further decrease the already low sensitivity of meat inspection for the detection of bovine cysticercosis,[88] with the likely consequence of reporting an increased prevalence of *T. saginata* across the EU.

If porcine cysticercosis is detected at meat inspection, legislation in both high- and low- to middle-income countries generally requires that the carcass is condemned as unfit for human consumption.[87,89,90] The Food and Agriculture Organization of the United Nations (FAO) manual for meat inspection in developing countries gives provision for cold treatment (see later) of localized cases of porcine cysticercosis; however, the lack of appropriate facilities for such treatment means that a judgment of total condemnation is generally the case.[91] Cases of bovine cysticercosis are differentiated into generalized and localized, with generalized cases requiring condemnation and localized cases requiring condemnation of the affected part with the conditional release of the carcass after the requisite cold treatment according to the local legislature.[87,89–91]

Cold treatment has been proven to kill the cysticerci of *T. solium* and *T. bovis*, with 6–10 days at temperatures <−10°C reliably killing all cysticerci[92,93] and temperatures of −24°C killing cysticerci in just 24 hours.[94] Other meat-processing techniques have also proven successful, including irradiation[95] and 12–24 hours of salt pickling,[96] although these techniques do not appear to be feasible at a large scale in rural endemic countries.[97] The most important form of meat processing, and one that should be made clear to all people preparing and consuming beef and pork, is correct and thorough cooking to kill any viable cysticerci. Meat should be brought to a temperature of between 60 and 65°C, or until it loses its pink color, to ensure that cysts are killed.[96,98,99]

Models have demonstrated that strategies concentrating on improving human sanitation and pig management, including meat inspection, are likely to be the most effective long-term strategies for the control of human taeniasis and cysticercosis,[53] with concurrent assistance in the control of other food- and water-borne diseases. In this way, the case for improved sanitation and husbandry should be encouraged as part of any long-term strategy. Exemplifying this, reviewing and strengthening the meat inspectorate in Southern and

Eastern Africa is part of the regional action plan for *T. solium* formulated by the Cysticercosis Working Group of East and Southern Africa (CWGESA)[100] and has been recommended in Nepal.[101]

## Sanitation

Key to the propagation of the *Taenia* lifecycle is the contact between the intermediate hosts (cattle, pigs) and human fecal material containing infective eggs. Hygiene measures such as the use of well-constructed latrines, correct management of sewerage sludge and wastewater and best practices in animal husbandry all contribute to preventing the intermediate host becoming infected. As discussed in the "Meat hygiene" section, effective meat inspection and correct cooking techniques can also contribute to the prevention of human taeniasis infection. Poor hand hygiene, such as not using soap to wash hands after defecation, has been associated with greater risk of exposure to porcine cysticercosis.[102] Education and awareness around personal hygiene practices are important in the control of *T. solium*,[37] as human cysticercosis infections can be prevented through stringent hand hygiene to prevent fecal–oral contamination with the infective eggs.

Free-ranging pigs are often more at risk from infection with *Taenia* spp. than those that are kept under confined conditions.[103–105] An increase in the popularity of free-ranging pork in Europe has been identified as having the potential to increase the prevalence of porcine cysticercosis found in that region.[15] Housed cattle and pigs can also be exposed through fodder contaminated by slurry containing *T. saginata* eggs or due to family or farm workers defecating in the housing unit.[105–108]

The absence of access to – or usage of – a latrine in the homestead has been identified as a risk factor for porcine cysticercosis.[108–113] Out of necessity, members of the homestead will engage in open defecation, therefore allowing free-ranging pigs to easily access potentially infective human fecal material. It has been hypothesized that the practice of open defecation may be associated with outbreaks of bovine cysticercosis in New Zealand.[114] Improvements in sanitation have been suggested to be responsible for the reduction in NCC cases in Ecuador between 1990 and 2009,[115] but there is no evidence yet for the successful control of *T. solium* through use of specific latrine provision.[52,116] Focus group discussions with a community in Zambia where a program of "community-led total sanitation" (CLTS)[117] was undertaken identified several barriers to the use of latrines, including taboos surrounding the use of latrines by men if in-laws or grown-up children of the opposite sex use the same latrine.[118] Another anthropological study undertaken as part of a *T. solium* intervention in Lao PDR highlighted the practical issues regarding latrine usage in agriculture-based societies where people often work for long periods away from their homesteads.[119] Studies such as these illustrate the importance of considering cultural norms when designing and implementing interventions aimed at improving community-level hygiene and sanitation as part of broader human taeniasis control programs.

If sanitation infrastructure is available, correct sewerage management is vitally important for the control of *Taenia* spp. as illustrated by the association of cattle access to surface water, and the close proximity of wastewater effluent, with cases of bovine cysticercosis in Belgium.[120] *Taenia* spp. eggs are one of the most resilient parasites found in sewerage sludge,[121] with bovine cysticercosis risk associated with the presence of sewerage effluent/sludge in drinking water or flooded pasture.[120,121] These examples indicate that despite the stringent controls on sewerage processing under various clean water acts passed in the 1970s, difficulties in the complete inactivation of eggs remain even in high-income nations.

# Multi-host interventions via a one health approach to control

As a zoonotic disease, there are great opportunities to tackle both *T. solium* and *T. saginata* through strategies that target both the human and animal hosts.[122] Modeling of a single round of MDA in humans, combined with annual vaccination of pigs, indicates that the prevalence of both human taeniasis and porcine cysticercosis would rapidly and sustainably reduce >120 months, with 24% and 15% of replications of the model resulting in 0% prevalence in humans and pigs, respectively.[53] In comparison to the rapid return to baseline prevalence after human MDA alone,[53] the benefit of a "two-pronged" strategy targeting both human and animal hosts is demonstrated.

A Peruvian case–control study carried out between 1996 and 1997 involved a single round of MDA in humans with two rounds of porcine treatment.[49] Individuals within treatment villages received 5 mg/kg praziquantel and pigs received 30 mg/kg oxfendazole, in combination with hog cholera vaccine. The control village residents were offered pyrantel pamoate (11 mg/kg), with pigs being vaccinated against hog cholera without anthelmintic treatment. The intervention achieved 75% coverage of the human population and ~90% coverage of the porcine population. Pigs were monitored over an 18-month period using EITB strip diagnostic tests

(US Centers for Disease Control, Atlanta, GA, USA). The results demonstrated that being in a treatment village after the intervention was shown to be a protective factor against porcine cysticercosis, compared to being in a control village (odds ratio [OR] 0.51, $p<0.001$).[51] More recently, The Bill & Melinda Gates Foundation has sponsored a large-scale trial of strategies aimed at eliminating *T. solium* from a large area of rural Peru. The recently reported results indicated that human MDA (2 g nicolsamide, three rounds per annum) administered in combination with porcine vaccination (TSOL18) and anthelmintic treatment (oxfendazole 30 mg/kg) successfully eliminated *T. solium* from the porcine intermediate host in 105 of 107 intervention villages, with elimination sustained for at least 1 year post-intervention.[123] Recently in southeast Asia, porcine vaccination (TSOL18) and anthelmintic treatment (oxfendazole 30 mg/kg) have been combined with a human MDA program (two rounds triple-dose albendazole 400 mg) in Lao PDR, where an initial rapid reduction in human taeniasis prevalence was sustained over the 2 years of the study.[49,54]

## Conclusion

This review highlights a number of important aspects around the prevention and management of human taeniasis, examining key opportunities and challenges of current diagnostic and therapeutic tools for control. Despite promising recent examples from endemic settings where parasite control and elimination – particularly for *T. solium* – has been maintained for extended periods of time post-intervention, this review highlights the need for further scale-out of these successful pilot control programs to better assess their long-term impact and cost-effectiveness, particularly in the Asia and African contexts. Increasing the current global evidence base is expected to help drive translation of research outputs into national policy and community-level action in order to better address the impact of taeniasis on affected communities worldwide.

## Disclosure

The authors report no conflicts of interest in this work.

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